Design and Implementation of Closed Loop Soft Switching Boost Converter using PI Controller

P. Usha
Professor, Dept. of EEE
Dayanada sagar college of Engineering, Banglore
pu1968@yahoo.co.in

Priyanka. K
Student, Dept. of EEE
Dayanada sagar college of Engineering, Banglore
Priyanka.priya127@gmail.com

Abstract**—**The design and implementation of closed loop soft switching boost converter have been proposed. The steady state analysis of open loop converter with operational modes are evaluated. Equations for the design of all the circuit parameters are attainted and discussed in details for simulation and experimental purpose. The main aim of this paper to maintain constant output at the converter end with variable voltage source. This is achieved by designing the PI controller as the feedback to the main circuit. The stability analysis of the proposed converter is done and improving the stability by designing the controller circuit and making the converter to operate in closed loop mode. The main advantage of this proposed converter is reduction in the swathing losses, current and voltage stress on the circuit parameter decreases, switching frequency increases. The simulation studies are done using a MATLAB software**.** And the hardware model is developed with the designed values.

Keywords— *Positive output voltage, Voltage gain, PI controller, Closed loop control, stability, voltage stress*

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1. INTRODUCTION

A boost converter is generally a DC-DC converter that produces output voltage based on the supplied input voltage. Lower voltage gain is a drawback for stepping converters in several applications. Various converter technologies are established to meet the limitations. DC/DC converters are widely used in many applications.

In special applications, such as military affairs, aerospace, winches, sensitive control instrumentation, renewable energy interface devices, and motor speed control, dc/dc converters are efficiently being utilized [1–4]

Reducing or eliminating the switching losses will be possible if the product of the voltage and current of the switch is zero right before the transition. In order to realize the soft-switching feature, many techniques have been presented in the literature, which all are based on three main categories: zero-voltage switching (ZVS), zero-current switching (ZCS), and zero-voltage zero-current switching. By ZVS, high-frequency switching is possible for the MOSFETs. Thus, the size of the converter is decreased, without any increase in switching losses. In addition, insulated gate bipolar transistors (IGBTs) are the most appropriate switches for providing ZCS conditions [5]

By adding a clamp diode, voltage oscillations on the diode will be removed, but the ZVS range for both switches decreases. The clamp diode increases the freewheeling current, which results in higher conduction losses. The main switch in series with auxiliary one leads to high conduction losses. In the structure presented in, the clamping circuit is complicated, and there are many elements. Moreover, because of high-voltage stress on the clamping diode, costs and conduction losses are accordingly high. By adding a resonant circuit, ZVS conditions are provided, but the auxiliary circuits are complicated and have very high-voltage stresses.[5-9]

In , a soft-switching bidirectional dc/dc converter has been presented, which utilises an auxiliary active lossless snubber circuit, in order to provide soft switching conditions. In this converter, the switches are turned on with ZVS, but due to not having ZCS conditions, the turning off transitions are lossy. In this structure, the large number of the semiconductors and energy storage devices lead to more complexity, high losses, and high costs. In this paper, according to the usage of auxiliary elements and resonant circuit, ZVS conditions have been provided for the switches. Theoretical analysis of the operating modes shows that high current and voltage stresses can significantly be reduced, during the transitions. The design considerations have been proposed in detail. [10]

The PI controller is proposed is to improve the performance of the soft switched boost converters. The duty cycle of the boost converter is controlled by PI controller. The conventional PI controllers for such converters are designed under the worst-case condition of maximum load and minimum line condition. As power electronic converters are nonlinear, and also are prone to variations in its operating states over a wide range, the conventional PI controllers are to be designed to provide optimal performance as the operating point changes. To provide optimal performance at all operating conditions of the system PI controller is developed to control the duty cycle of the boost converter. PI

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controller is designed based on an average state space model of the classical boost DC-DC converter. Simulation of boost converter subjected to load changes is performed to demonstrate the effectiveness of the proposed controller.[11]

2.Soft Switch DC-DC Boost converter

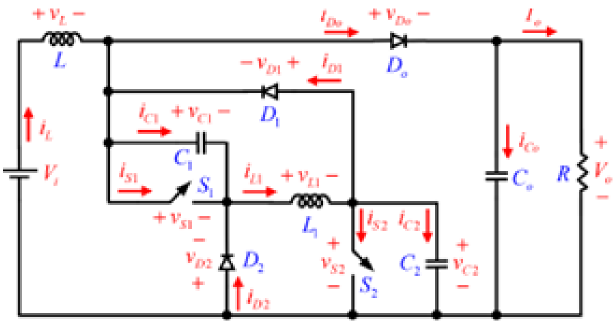


Fig1: Soft switch DC-DC converter

In Fig. 1, V_i is the input dc voltage, S_1 is the auxiliary

switch, C_1 parallel capacitor of S_1, D_1 and D_2 are auxiliary elements for resonant circuit, L_1 is the resonant inductor, S_2 is the main switch, C_2 is the parallel capacitor of S_2, D_o is the output diode, L is the filter inductor, C_o is the filter capacitor, and R is the load resistance.

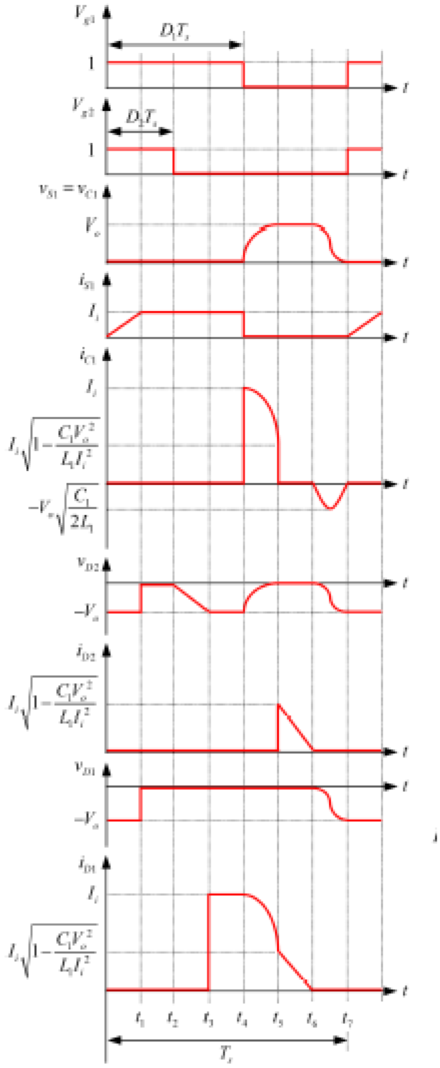
(b)

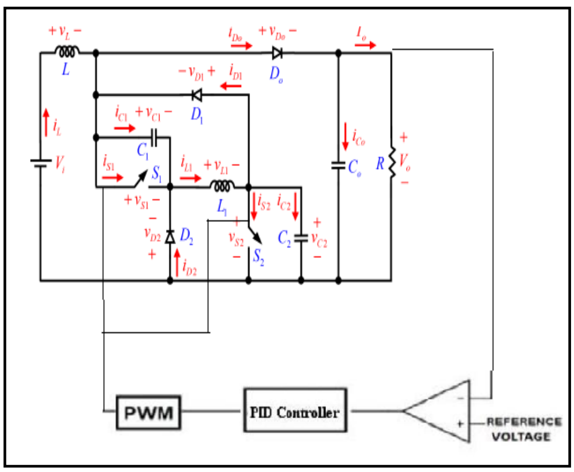
Fig 3:closed loop control of soft switch DC-DC Boost converter

Fig. 2 Ideal waveforms of the voltages of DC-DC converter

2.2 Closed-Loop Control System

A PI controller is generally used in control system by using its feedback mechanism and also used for industrial requirements. This controller can be used to regulate certain parameters like temperature, pressure, flow, speed and other variables. In this proposed converter, PI controller is equipped for controlling output voltage by varying duty cycle.





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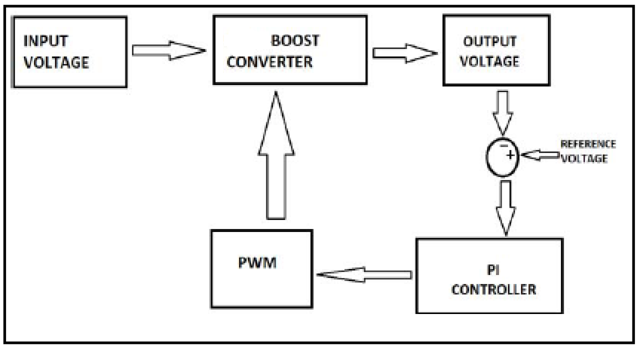


A PI controller repeatedly determines an error value by comparing the obtained output voltage(Vo) and reference voltage and applies closed loop control based on three main terms i) proportional,and ii) integral. The major advantage of PI controller is its feasibility and it can be easily implemented. The PI controller ensures satisfactory closed loop operations of the buck-boost converter system.

In the proposed system, it always produces a positive output voltage and its voltage gain is high. Wider range of positive output voltage is obtained by this proposed system. Hence this proposed buck-boost converter with PI controller used to overcome the drawbacks of the conventional ones for satisfying the industrial oriented requirements is very valuable and important.

A **control system** is a procedure or system, which regulates the characteristics of other systems to obtain desire results. The most important type of control system is a closed loop system, whose main feature is feedback mechanism (i.e) the output obtained from the control system is used to adjust the input signal. PI controller is a feedback mechanism which is used in the closed loop control system. It delivers its output based on the measured error and the three controller gains namely proportional gain Kp,and integral gain Ki, So, the well-designed feedback system has an ability to produce output with increased accuracy.

The operation of the closed loop control of proposed soft switch DC-DC boost converter begins from the point, where output voltage is obtained. The obtained output voltage (V_o) is compared with the reference voltage in the comparator, which produces an error signal which is send as input to PI controller. The PI controller tries to decrease the error over time by adjusting the control variable and in end of this process a new value is determined. The output signal from the PI controller is used as reference signal in PWM control.

The fundamental principle involved in working of this converter is creating a square pulse to control the switching of the MOSFET. This square pulse is called the duty cycle and this duty cycle (D) controls the output voltage. The switching is controlled by the duty cycle. Here, the constant reference signal is compared with carrier signal (in this paper a triangular wave is taken as carrier signal), which produces the square pulses. Then again the square pulses are compared with the signal from the PI controller The obtained signal by comparing both PWM generator and PI controller is used to control the switching of switches.

The main characteristics of this closed loop control are to reduce errors, to improve stability of the system, to increase the systems sensitivity and to produce a performance which is more reliable. The main advantage of this closed loop control system is that it has the ability to adjust its output voltage automatically by feeding its output signal to the switches to control duty cycle. Thus, the closed loop control is employed for efficient operation of converter which gives high voltage gain.

3. DESIGN CONSIDERATION

$$R = \frac{Vo^2}{P0} = \frac{18^2}{30} = 12\Omega$$

$$Ii = \frac{Vo^2}{RVi} = \frac{P0}{Vi} = 2.25A$$

$$C1 = \frac{1}{(2\pi fsk)^2 L1} = \frac{4.06e-15}{L1}$$

$$L1 = \sqrt{\frac{4.06e-15}{1.5e-4}} = 0.1mH$$

$$C1 = \frac{4.06e-15}{5e-6} = 0.4\mu F$$

4.Stability analysis of the converter in open loop and closed loop operation.

When a system is unstable, the output of the system may be infinite even though the input to the system was finite. This causes a number of practical problems. For instance, a robot arm controller that is unstable may cause the robot to move dangerously. Also, systems that are unstable often incur a certain amount of physical damage, which can become costly. Nonetheless, many systems are inherently unstable - a fighter jet, for instance, or a rocket at liftoff, are examples of naturally unstable systems. Although we can design controllers that stabilize the system.

The controller is an element ehich accepts the error in some form and decides the proper corrective action. The output of the controller is then applied to the process or final control element. This brings the outpur back to its desired set point value. The controller is the heart of the control system. The accuracy of the entire system depends on how sensitive is the controller has its own logic to handle the error.

The actual output is sensed by a sensor and converted to a proper feedback signal b(t) using a feedback element. The set point value is the reference input r(t).and the feedback signal is b(t). The feedback signal is compared with the refererence input.

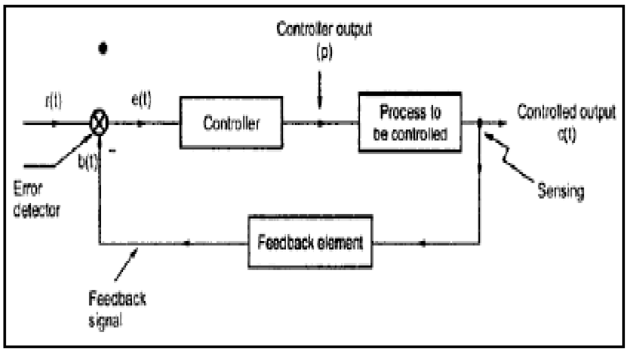


Figure 4:Block diagram of the controller

In order to design the controller firsf we need to obtain the transfer function of the open loop soft switching DC-DC Boost converter. It is obtained by the small signal analysis and circuit averaging method.The small signal transfer function of a boost converter is as follows

$$\frac{V0(s)}{D(s)} = \frac{V}{(1-D)^2}\frac{1-S\frac{L}{R(1-D)^2}}{1+S\frac{L}{R(1-D)^2}+S^2\frac{LC}{(1-D)^2}} \quad (9)$$

On substituting the L,C,R and D values we obtain the open loop transfer function of the proposed Boost DC-DC converter

$$\frac{\mathbf{V0(s)}}{\mathbf{d(s)}} = \frac{-0.075s+51.84}{6e-6s^2+1e-3s+0.6912} \quad (10)$$

$$U(t) = Kp\ e(t) + Ki \int_0^t e(t)dt \quad (11)$$

With the Zigler Nicolous method the Kp and Ki values of the PI controller is determined that is Kp=5.08e-3 and Ki=0.556.The controller transfer function is given by

$$H(s) = \frac{Ki}{s}+Kp(s)$$

$$H(s) = 5.08e\text{-}3s+\frac{0.556}{s} \quad (12)$$

The closed loop transfer function of the converter and controller is give by

$$Gc(s)=\frac{G(s)*H(s)}{1+G(S)*H(s)} \quad (13)$$

$$Gc(s)=\frac{-0.03s+20.99}{6e-6s^3+1e-3s^2+0.622s+20.99} \quad (14)$$

Theload current of the proposed converter is given to the PI controller. The time constant of thecontroller is designed according to the small signal transfer function of the boost converter whichis given below. Then the output of the PI controller changes the pulse width of the square wavewhich changes the firing angle of the MOSFET switch, so the output of the converter is controlled for different load disturbances.

However, for the output powers between 26 and 33W the switching loss of the main switch is lower than the conduction loss of the auxiliary elements, which recommends that the usage of the auxiliary elements for achieving soft-switching feature is useful, and will lead to loss reduction for the proposed converter. Similarly, for output powers >33 W the conduction loss is higher than the switching loss, which means using auxiliary elements does not make any sense for having ZVS.

	Rise time(sec)	Settling time (sec)	Steady state error	Stability unstable	Gain margin	Phase margin
Open loop	0.0032	0.0429	0.5	unstable	-37.5	-88.1
closedloop	0.06	0.113	0	stable	0.358	116

Table 1: stability analysis of open loop and closed loop

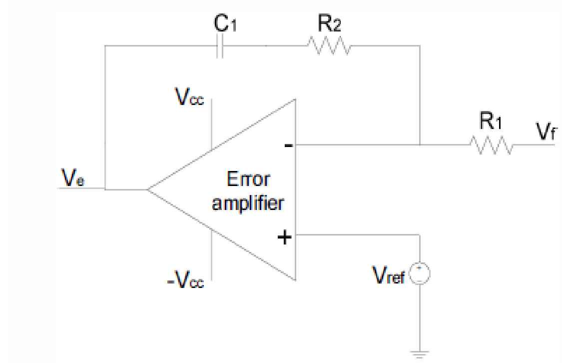


Figure 5: realization of the PI controller using op-amps

The transfer function in terms of passive circuit elements can be written as

$$\frac{V_e}{V_f} = -\frac{Z_2(s)}{Z_1(s)}$$

$$Z_2(s) = R_2 + \frac{1}{sC_1} \text{ and } Z_1(s) = R_1$$

$$G_c = \frac{R_2}{R_1}\left(\frac{s+1/R_2C_1}{s}\right)$$

The gain term and zero location is given by

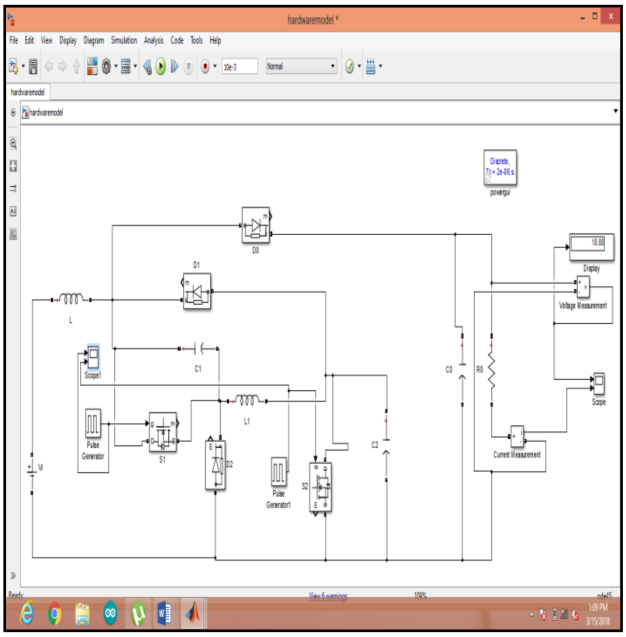
$$K = \frac{R_2}{R_1}, \quad W_z = \frac{1}{R_2 C_1}$$

The hardware model is developed using the designed values. As shown in the design procedure.the gate pulses aree generated using the 555 timer for both the switches of duty cycle 76% and 54% with 10khz as the frequency.

A AC-DC boost converter is also developed and simulated using the MATLAB simulation. The AC voltage of 230 volts is step down to 12volts AC using step down transformer then it is rectified to 12 volts DC with the bridge rectifier.the main advantage of this circuit is we can operate the boost converter with AC voltage.

The harware model are developed with the following specifications as shown in the table below.

Mosfet, S1 and S2	Irf540, Irfz44n
Diode,D1,D2,D0,D3	1n5819
Input voltage, Vin	12v
Output voltage, Vout	18v
Switching frequency	10KHz
Capacitor C1 ,C2 and C0	0.4µf, 500µf
Inductor L and L1	1mH, 0.1MH



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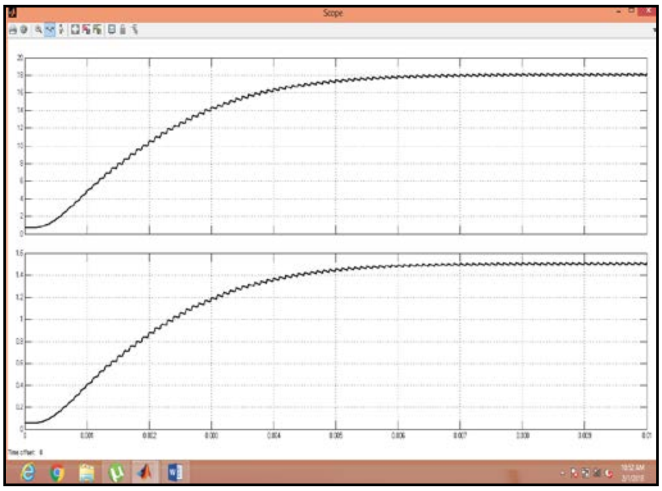

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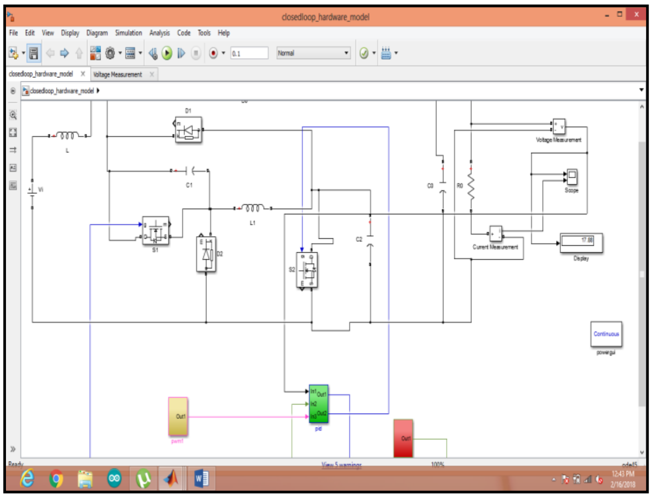

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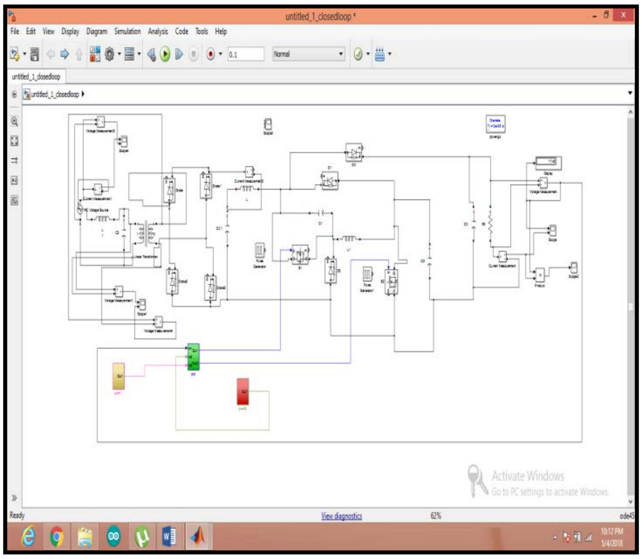

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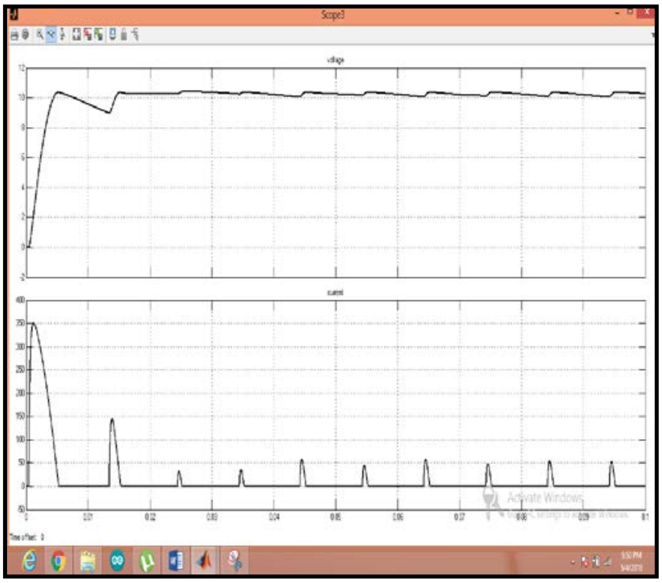

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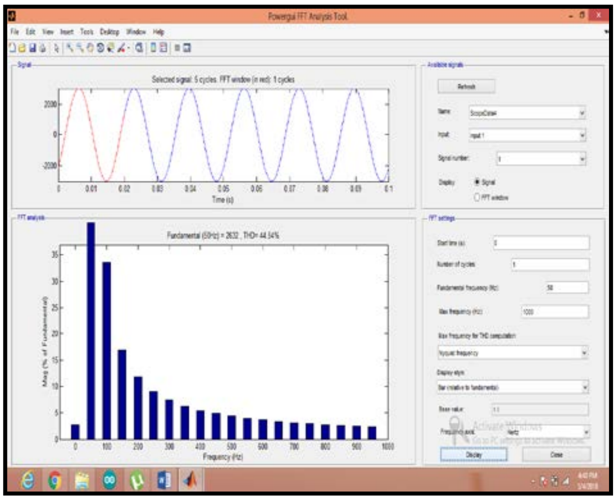

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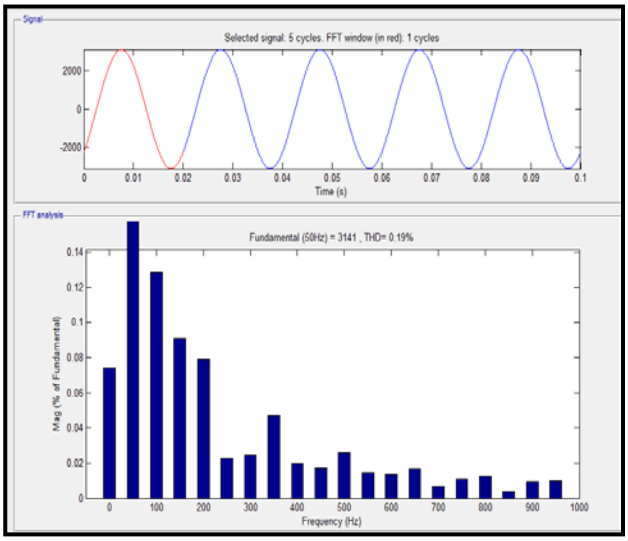

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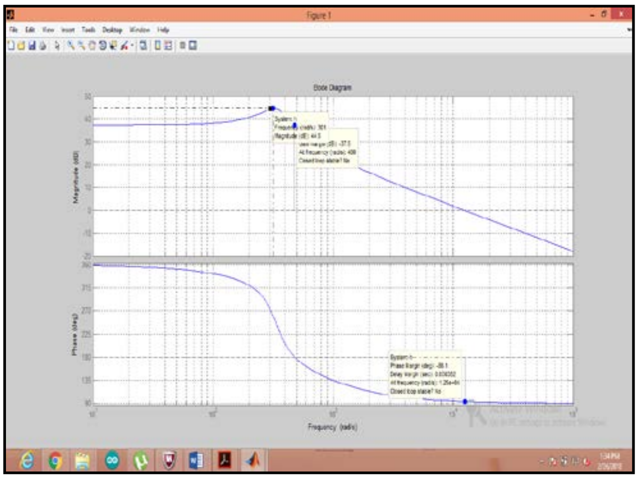

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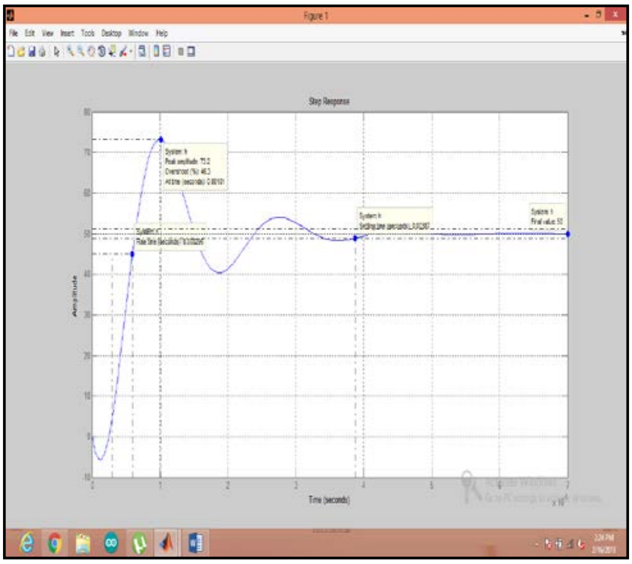

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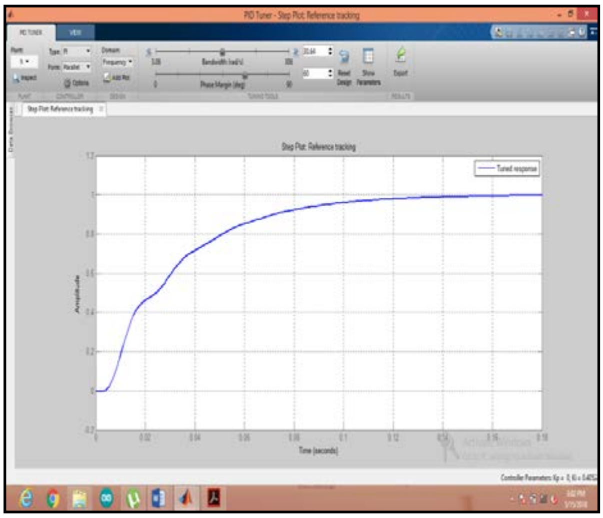

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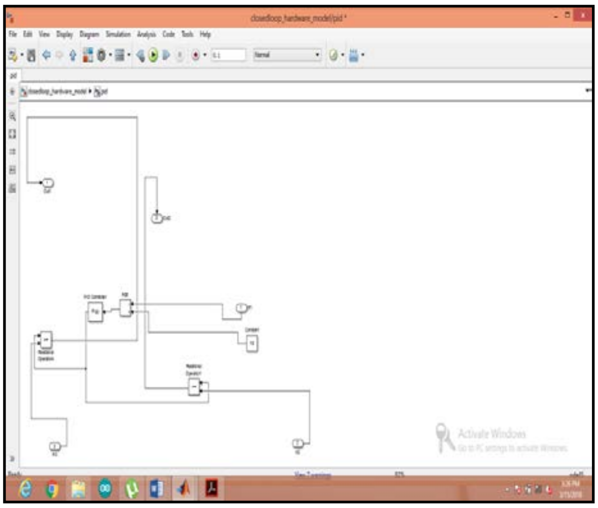

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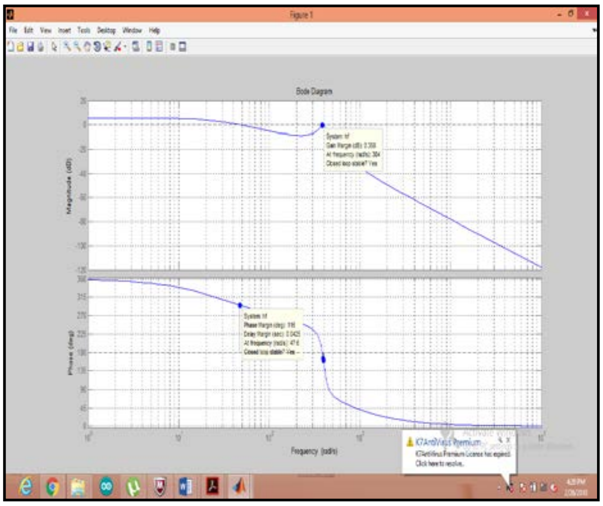

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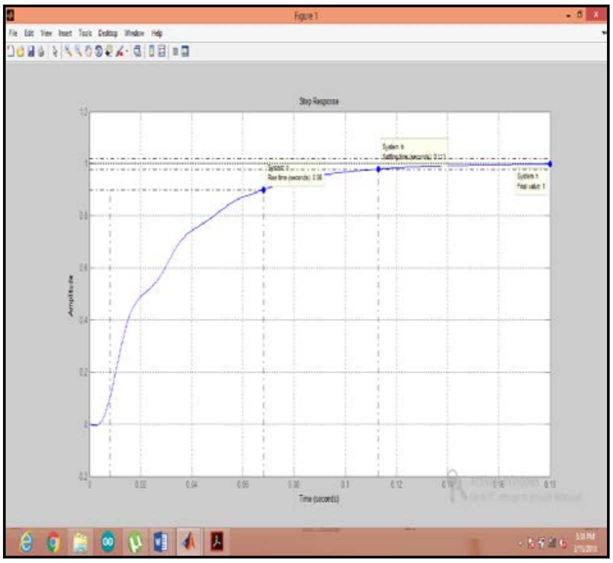

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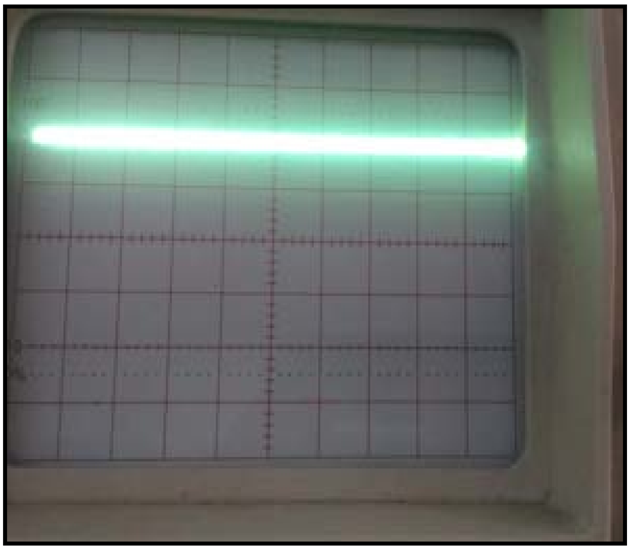

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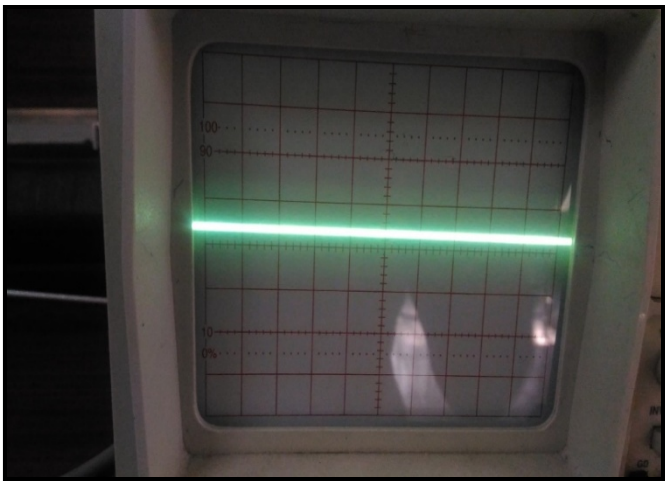

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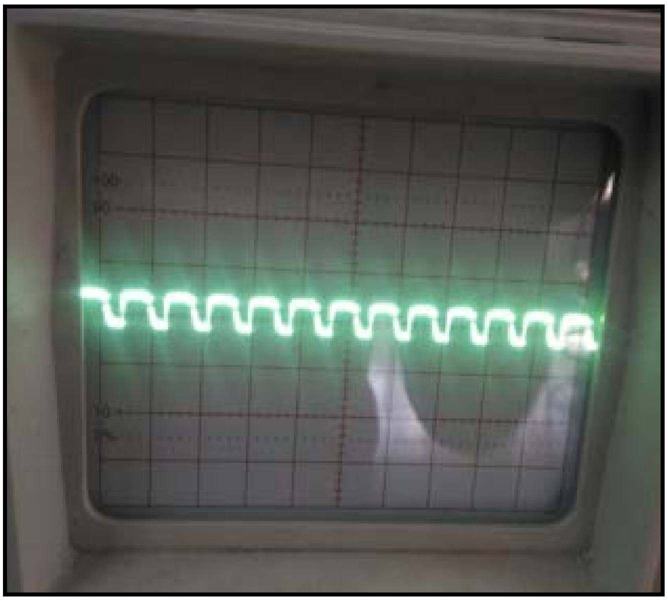

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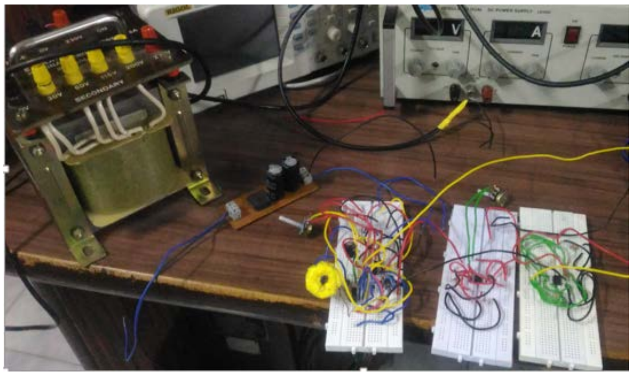

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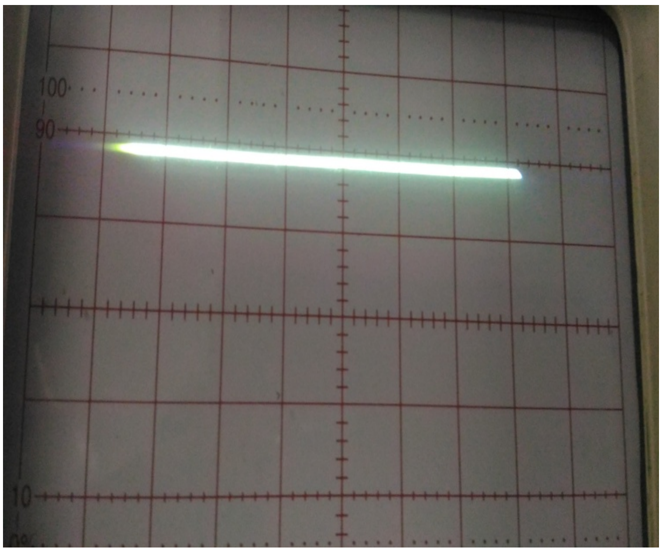

(s)

Figure 5: simulation results in MATLAB: (a) soft switching DC-DC boost converter, (b) output voltage and current, (c) simulink model of closed loop circuit of soft switch dc-dc boost converter,(d) simulink model of closed loopAc-Dc boost converter (e)rectified voltage from the bridge,(f) total harmonic distortion without input filter,(g) THD of the input AC current with input filter,(h) bode plot of the converter in open loop,(i) step response of the converter in open loop,(j) step response of the PI controller (k) circuit of the PI controller,(l) bode plot of the cconverter in closed loop,(m) step response of the converter in closed loop,(n)output voltage fromt the boost converetr,(o) feedback from the converter to the PI controller ,(p) error signal genrated from the PI controller,(q)hardware model of the closed loop soft switching DC-DC boost converter,(r) hardware model of the AC-DC soft switching boost converter,(s) 12volts dc input from the rectifier bridge

From fig 5b the output voltage of 18volts and the output current of 1.5 amps is observed in the simulink results.which is veified with the theoretical calculation.

From fig 5e the rectified voltage from the bridge rectifier of 12 volts is obtained.this is given as the input to the converter circuit.the 230 volts ac is stepdown using a step down transformer to 12 volts Ac.

From fig 5f it is found that the input AC current has toatal harmonic distortion of 44.7%

From fig 5g it is found that the total harmonic distortion of the input current is reduced to 0.19% using the fiter circuit at the input side.

According to Fig 5h, the bode plot of the soft switching dc-dc boost converter is obtained. It is found that the converter in open loop operation is unstable.

According to Fig 5i, the step reponse of the converter in open loop is obatined.it is found that the converter has high stady state error

In order to increase the stability of the soft switching DC-DC boost converter a PI controller is deigned and the feedback from the contverter out put end is give to controller in order to compensate the error that is obtained by comparing the output with the refernce value.

According to Fig 5(l) the bode plot of the converter in closed loop operation is obtained. From this figure we can found the the stability of the system changes from unsatble to stable system. Thus the stability of the sysytem increases with the addition of controller to the circuit.

According to Fig 5(m) the step response of the converter in the closed loop is obtained. From this figure is evident that steady state error decrases and the rise of the response also increases.

From fig 5n, the output voltage of the boost converter is obtained.it is found that the output voltage is about 18volts.which is verified with the matlab simulation and the theoretical calculation.

From fig 5(o), it is found that the output from the converter cicuit is scaled down using a voltahe divider circuit to feed the voltage as the input to the PI controller.

From fig 5(p), the feed back signal from the converter is comapred with the reference voltage which is made fixed to generate the error signal.that signal is comapred with the gate pulse which is generated from the 555 timer to produce new pulses with the slight change in the duty cycle. That signal is given as the gate pulse to switches.to obtain the closed loop operation.

From the fig 5(s), the rectified voltage of the 12 volts is obtained which is shown in the CRO. This is provided as the input to the boost converter circuit.

5. Conclusion

In this paper, analysis, design, experimental, and simulation results of soft-switching boost dc/dc converter have been presented. PI controller is designed and with the addition of the controller the system stability increase.from the simulation reults is evident that the stabity of the system inreases to stsbe from unstable. The output is maintained constant with the help of controller.The stady state error of the system is decreased.with the design of the AC-DC boost converter circuit one can operate the converter when there is no dc supply. With inclusion of the input LC filter circuit reduces the total harmonic distortion to be fron 44.9% to 0.19%.

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