POWER LOSS OPTIMIZATION OF BOOST CONVERTOR USING GENETIC ALGORITHM

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Abstract -Traditional DC-DC Boost converters are used in high voltage applications, but they are not economical due to limited output voltage, large voltage ripples, current ripples and power losses. A closed loop control scheme for a simple DC-DC Boost converter in designed and the performance characteristics are studied using MATLAB simulink. The performance of the controller is also studied for various load and line disturbances. The designed converter gives satisfactory results. Usually it is very difficult to design the source inductance (L) and the filter capacitance (C) of the converter for desired performance. i.e optimal switching losses, voltage ripples, and current ripples. Normally the L & C values of the converter are designed using trial and error method. In this paper, genetic algorithm is used to design the DC-DC boost converter for optimal switching losses, voltage ripples and current ripples. The results obtained using genetic algorithm are validated using the simulation results.

Keywords: Boost converter, PI controller, Genetic Algorithm, MATLAB.

1. INTRODUCTION

Controlling switched power converters is a challenging area of research in control engineering. Although a typical DC-DC converter circuit requires few components and, from a theoretical point of view, is simplistic to operate, all DC-DC converters require control circuitry in order to account for load variations, component tolerances, system aging and input source voltage variations.

The controllers used in practical implementations are frequently of analogue nature and have a PID compensator structure, with suboptimal design for specifications such as fast system response and stability. Hence, there is a need in designing advanced controllers, which can now be implemented in practice thanks to the latest advances in digital signal processors (DSP).

From a control-engineering point of view, DC-DC converters are a traditional benchmark for testing (advanced) nonlinear controllers. However, apart from their nonlinear characteristics, DC-DC converters pose another interesting feature: they have unstable zero dynamics -"non minimum phase" systems. Control of non minimum phase systems is significantly more difficult than control of systems with stable zero dynamics, due to the fact that unstable zero-dynamics restricts the closed-loop performance.

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However, in spite of these difficulties, a number of nonlinear controllers have been reported in literature, such as: sliding mode control strategies, nonlinear PI controllers based on the method of extended linearization and a predictive controller using the in-house EPSAC algorithm. The results of an experimental comparison of five control algorithms on a boost converter are presented in: linear averaged controller, feedback linearizing controller, passivity-based controller, sliding mode controller, sliding mode plus passivity-based controller.

The control laws derived for such a system can be classified in two groups, depending on whether they generate directly the switching signal q(t) - a hybrid system approach - or whether they require an auxiliary pulse width modulation (PWM) circuit to determine the switch position.

This paper deals with designing a classical PI control scheme for a boost converter, and the controller performance is tested for various line and load disturbances. While designing a controller, the design of source inductance (L) and Filter Capacitance (C) is very crucial . Because these parameters very much affect the performance of the converter such as optimal switching losses, voltage ripples and current ripples. Normally these parameters are designed bytrail and error method to suit any one of the performance only, not possible to satisfy all the above mentioned. Thus in this paper genetic algorithm is used to design the L & C values of the converter to satisfy all the desired specifications such as constant voltage, optimal losses, minimal ripples, etc. The fly back converter is used as an example in this paper but this can be extended to any converter.

2.CRICUIT DESCRIPTION

The (switched) boost converter[3] considered in this paper is represented in Fig. 1 and the differential equations describing [7]the circuit are given by:

$$\dot{i}(t) = -(1-q(t))\frac{1}{L}v(t) + \frac{1}{L}v_s(t)$$

$$\dot{v}(t) = (1-q(t))\frac{1}{C}i(t) - \frac{1}{RC}v(t) \qquad (1)$$

with i(t) and v(t) the inductor current, respectively the output capacitor voltage; vs(t) the value of the external voltage source – subject to changes; R the resistance of the load; q(t) denotes the switch position function and acts as the control input, taking values in the discrete set {0,1}.

When the switch is closed (q(t)=1) the inductor current increases and the capacitor C discharges over the resistor R according to the relations:

$$L\frac{di(t)}{dt} = v_s(t); \quad C\frac{dv(t)}{dt} = -\frac{v(t)}{R} \qquad (2)$$

Alternatively, when the switch is open (q(t)=0), the variations of the inductor current and of the output capacitor voltage are described respectively by:

$$L\frac{di(t)}{dt}=v_s(t)-v(t); \quad C\frac{dv(t)}{dt}=i(t)-\frac{v(t)}{R} \quad (3)$$

Notice that in this last situation, the current is decreasing continuously; because for a boost converter - in nominal operation - the output voltage v(t) is higher than the input voltage vs(t). If the current possibly becomes zero, it will remain there until the switch q(t)=1 again, because the presence of the diode in the circuit prevents that the cur rent flows in the opposite direction.

The output to be controlled [7]isv(t) and the objective is to bring it at a desired voltage v* (t), which is higher than vs(t) .

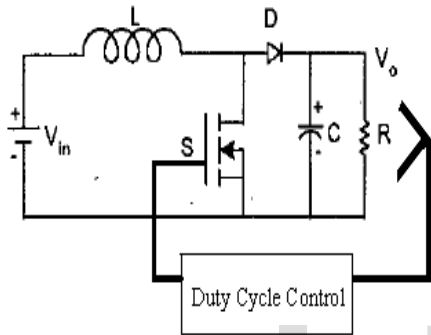**Figure. 1 Boost converter**

Where the duty ratio dR(t) is the control signal and vs(t) is the input voltage deviation (considered here as a disturbance to the system). In the linearized model all variables are now deviation values with respect to the operating point[3]. The operating point for the system is calculated from superimposing equilibrium conditions and a nominal duty ratio value DR.

3.CLOSED LOOP CONTROLLER FOR BOOST CONVERTER

Closed Loop control scheme for the proposed DC-DC boost converter is given in this section. The control scheme essentially consists of only one voltage sensor with simple control structure when compared with classical DC-DC boost converter which requires both voltage and current sensors. DC voltage of the load is fed back and compared with Vdc reference voltage and the error is given to the PI controller[5] to stabilize the error and the signal obtained from the controller is the modulating signal for the PWM[4] scheme. Signal from the PI controller is compared with high frequency ramp signal to produce required pulse for the N-channel MOSFET switch to obtain the reference DC voltage at the load. In this paper for the above model of the converter using the Ziegler-Nichols method II is (S-shaped curve technique) applied to design the PI controller. Step input is applied to the plant model and the response is the S shaped curve. By drawing the tangent to the S shaped curve at its inflection point with reference to X axis, the time delay L and time constant T is calculated. Using Ziegler-Nichols algorithm, the value of the Kp and Ti are calculated.

The PI controller designed by the above method is tested under different disturbance conditions and results are obtained are feasible. Closed control scheme for the both topology are the same and tuning parameter Kp and Ki are different.

$$G_c=K_p\left[1+\frac{1}{T_i s}\right] \quad (4)$$

A number of tests are performed over the whole range of the variables L1, C1, and corresponding switching loss, voltage ripples and current ripples are calculated manually. In order to get detailed information on the problem, simulations over the feasible component range were performed. Equally spaced points, 12 in total, were chosen from each of the component ranges L1(Lmin…Lmax)□and C1(Cmin…Cmax). Component pairs were picked-up one by one from the [L1, C1] □set. The steady-state search was performed and the objective functions calculated. Finally, the boundary condition, i.e. output voltage , voltage ripples, current ripples are calculated. If the boundary condition was not fulfilled, the LC-pair was excluded from the feasible design set.

4.SIMULATION RESULTS

The Boost converter is designed for a frequency of 100 kHz is used to step-up 120-V dc supply to 480-V dc and for a load current of 2.08-A.   The various design parameters are given below. The transfer function of the PI controller is obtained.
Input Voltage V_s= 120 volts
Desired output Voltage V_o = 480 volts
Inductance L_{min}= 270 μH
Inductance L_{max}= 330 μH
Capacitance C_{min}= 13 μF
Capacitance C_{max}= 19μF
Load Resistance R = 230Ω
Switching Frequency f = 100 KHz
MOSFET On state Resistance R_{on} = 0.001 Ω

PI Controller Transfer Function:

$$G(s)=\frac{0.1205(s+6235.4)}{s} \quad (5)$$

4.1 SIMULATION DIAGRAM OF BOOST CONVERTER
In this paper, the Boost converter with PWM control technique is designed using MATLAB and is used to control the output voltage at a desired value with minimum ripples. This Boost converter designed works satisfactorily for line and load disturbances also.
The Boost converter designed for a frequency of 100 kHz is used to step-up 120-V dc supply to 480-V dc and for a load current of 2.08-A. The Output voltage is controlled by the duty cycle of the converter. It depends on the "on and off" state of the switch. The gate pulses are given by the PWM block. This PWM pulse of MOSFET is shown in figure 2.
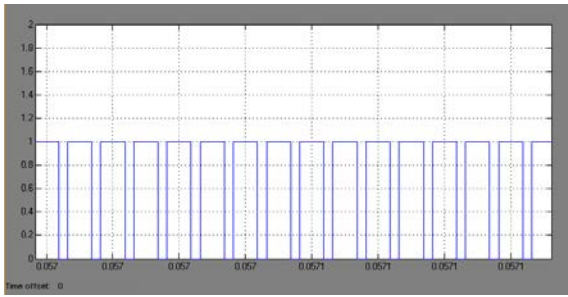
Figure .2: PWM pulses given to MOSFET Converter

4.2 LINE DISTURBANCE

Initially the input of the converter is 120 volts, after 0.01msec the input of the converter is changed to 130 volts. The Timer is used for setting the disturbance time. Here ideal switches are used for disconnecting the supply. The changes in input do not affect the output of the converter. When the input is changed the output will change for a fraction of ms, then it comes to steady state. The output waveform is shown in figure 3.

4.3 LOAD DISTURBANCE

Initially the load resistance of the converter is 230 ohms, after 0.03msec the load resistance of the converter is set to 235 ohms. The Timer is used to set the disturbance time. The load changes do not affect the output. When the load is changed the output changes for fraction of ms, then it comes to steady state.The current waveforms of the converter for line and load disturbances are given in figure 4. The maximum and minimum Currents through the inductor are 15.15-A and 1.514-A. This Current through the inductance is shown in figure 5. The output voltage and current waveforms of boost converter designed is shown in figure 6 & figure 7

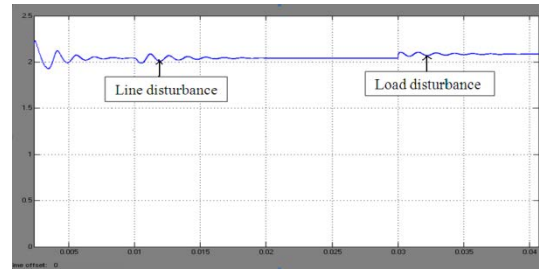**Figure 3 Output voltage waveform for Line & Load disturbance**

Figure 4 Output current waveform for Line & Load disturbance

It has been found that the converter output voltage and current remains constant irrespective of line and load disturbances. From this results it is evident that the converter designed is stable.
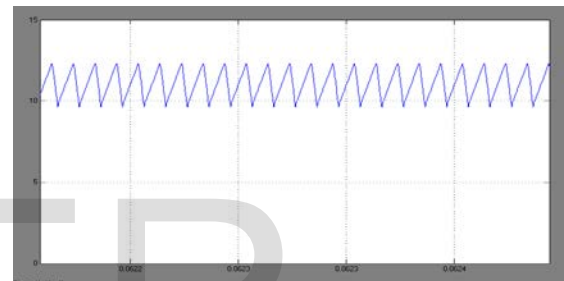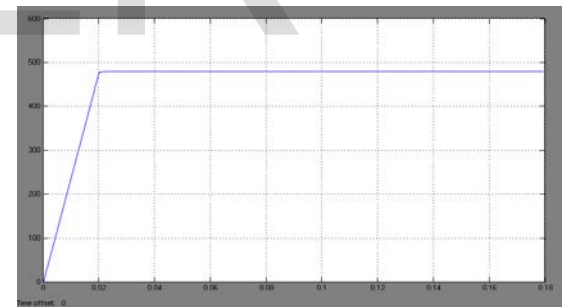

Figure 5 Current through Inductance
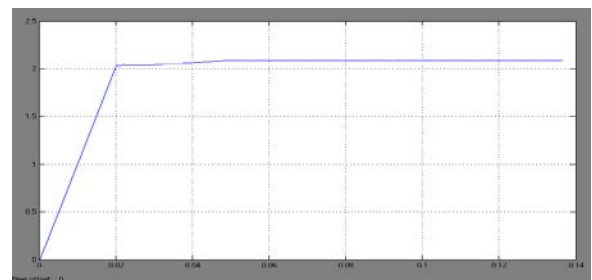

Figure 6 Output voltage of Boost converter

Figure 7 Output Currrent waveform for Boost converter

4.4 SIMULATION RESULTS FOR VARIOUS

COMBINATION OF L & C

The Boost converter is simulated for various combinations of L & C values. The best possible combinations of L & C values that give the desired output voltage for the voltage ripple less than 1% and minimum switching losses are given in table.1, whereas the other combinations which are not satisfying the requirerments are discarded.

L(mH)	C(μF)	V0(volts)	Psw(w)	ΔI(amps)	ΔV(volts)
270	14	480	742.85	0.000001	0.00000
270	16	480	744.82	0.000001	0.00000
275	16	480	742.42	0.000001	0.00000
280	13.5	480	741.43	0.000001	0.00000
280	14	480	741.38	0.000001	0.00000
280	17.5	480	741.12	0.000001	0.00000
280	19	480	741.03	0.000001	0.00000
285	15.5	480	739.45	0.000001	0.00000
290	13.5	480	732.80	0.000001	0.00000
290	16.5	480	738.11	0.000001	0.00000
305	19	480	733.22	0.000001	0.00000
310	14	480	731.74	0.000001	0.00000
310	16	480	732.19	0.000001	0.00000
310	17	480	732.09	0.000001	0.00000
310	19	480	732.01	0.000001	0.00000
315	14	480	730.544	0.000001	0.00000
315	17	480	730.91	0.000001	0.00000
320	16.5	480	729.14	0.000001	0.00000
320	18.5	480	729.03	0.000001	0.00000
325	13.5	480	728.16	0.000001	0.00000
330	18	480	726.58	0.000001	0.00000
330	14.5	480	726.90	0.000001	0.00000

Table .1 Best L & C Combinations

4.5 CHARACTERISTICS OF BOOST CONVERTER

The boost converter performance are evaluated for various combinations of L and C values using MATLAB. The Characteristics curves given in figure 8 and 9 show the variation of switching loss and output voltage for various possible combinations of Inductance and capacitance values. From the figure 8, it is found that losses are less for 280mH and 330mH, but the output voltage for 280mH inductance is very low whereas for 330mH inductance it is of desired value. From figure 9, it is found that losses are less for 15 μF and 18 μF, but output voltage is constant for 18 μF only. The desired output voltage (480 V) and minimum switching loss (726.78 W) is obtained. The best combination of the L & C values is 330 μH and 18 μF.
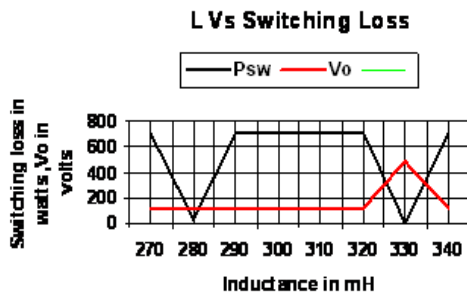
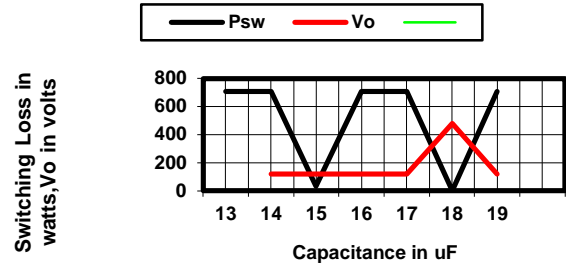**Figure 8 Characteristics of Boost converter**

Figure 9 Characteristics of Boost converter

5. GENETIC ALGORITHM (GA) APPROACH

Genetic algorithms are one of the best ways to solve a complex optimization problem. GAs are very general algorithm and can work well in any search space. Genetic algorithm will be able to produce a high quality solution. Genetic algorithms use the principles of selection and evolution to produce several solutions to a given problem. Genetic algorithms tend to thrive in an environment in which there is a very large set of candidate solutions and in which, the search space is uneven and has many hills and valleys. True, genetic algorithms[1] will do well in any environment, but they will be greatly outclassed by more situation specific algorithms in the simpler search spaces. They are, however, one of the most powerful methods with which to (relatively) quickly create high quality solutions to a problem.

The most common type of genetic algorithm works like this: a population is created with a group of individuals created randomly. The individuals in the population are then evaluated. The evaluation function is provided by the user and gives the individuals a score based on how well they perform at the given task. Two individuals are then selected based on their fitness, the higher the fitness, higher the chance of being selected. These individuals then "reproduce" to create one or more offspring, after which the offspring are mutated randomly. This continues until a suitable solution has been found or a certain number of generations have passed, depending on the needs of the user.

After creation of look up table as given in table1 for the search variables L1 & C1, the genetic algorithm picks up the values closest to the point k in the database

$$k = \text{index}\left[\min_{i=1..N} \sqrt{\left(\frac{Ll_i - Ll^*}{Ll_{max}}\right)^2 + \left(\frac{Cl_i - Cl^*}{Cl_{max}}\right)^2} \right]$$

5.1 POWER LOSS OPTIMIZATION

A typical design of Boost converter is to minimize the size of the converter. This means that the losses in the converter's transistor should be minimal to reduce the area of the heat sinks. The design parameters i.e values of inductor *L* and filter capacitor *C* should be less. They are varied within a certain range in order to obtain the desirable loss. The models of the

inductor and capacitor include equivalent series resistance, which is a function of the capacitances and inductances with quality factor Q. The input and output voltages are specified and at the same time, the converter should maintain an acceptable level of the output ripple.

In this paper loss minimization problem is taken as an objective with L & C values, output voltage and voltage and current ripples as constraints, i.e the output voltage and output ripple should be maintained within the given specification.

A database has been created for loss optimization problem. Simulated results are stored in the database, because at each and every step, it is not required to simulate the circuit. The information stored in data base will be used for the Genetic Algorithm approach. The various information obtained are output voltage, Drain to source voltage of MOSFET, duty ratio and input current.

5.2 PROBLEM FORMULATION

To Minimize = Transistor conduction loss,
Subjected to Lmin < L1 < Lmax
            Cmin < C1 < Cmax
            Vo= Constant, $\Delta Vo \leq \Delta Vspe$
Where,
    L1,C1 = Adjusted components,
     Lmin, Cmin, Lmax, Cmax = Boundary values of the components.

5.3 PROCEDURE FOR LOSS OPTIMIZATION

The detailed procedure for optimization of power loss of boost converter using Genetic Algorithm is given below
1.   Creation of new values for search variables L1*, C1* by Genetic Algorithm.
2.   The created values are compared with database values for finding out the K values. From this process the minimum K value and its corresponding L and C values are found out.

$$k = \text{index}\left[\min_{i=1..N} \sqrt{\left(\frac{L1_i - L1^*}{L1_{max}}\right)^2 + \left(\frac{C1_i - C1^*}{C1_{max}}\right)^2} \right]$$

(6)

Where   L1,C1 – values stored in the database,
L1*,C1* - values of the variables, created by the genetic algorithm, for which the search is performed,
$L1_{max}$, $C1_{max}$ – feasible maximum values,
N – size of the database.
3.   After finding out the L and C values, the corresponding V_o, I_{in}, V_{ds} are taken from the database.
4.   If the output voltage is desired value, then it calculates the P_{sw}, ΔI_L, and ΔV_o.
5.   If the condition is satisfied among the population considered, the algorithm terminates.
6.   If the condition is not satisfied, it goes to next step.
7.   Then fitness function is calculated. Then crossover and mutation operation are performed.

8.   Then it produces the new population for L and C values.
9.   Then it goes to Step-2
The parameters used for Genetic Algorithm is given in Table .2

Table .2 The Parameter values used in GA

Parameter	Values
Number of individuals in the initial population	150
Crossover Probability	1.0
Mutation probability	0.01

5.4 GA RESULTS

Table 3 shows the optimal result obtained using genetic algorithm. The results obtained using GA are used for simulation. It has been found that GA results are best when compared to simulation results.

Table 3 Optimization results after 40 Iteration

Inductance in μH	299.88
Capacitance in μF	13.63
Switching loss in watts	732.01
Output Voltage in volts	480
Fitness value	0.000825

The program is run 40 times and the obtained fitness values are plotted as shown in figure 10. This shows that the convergence characteristic of GA.
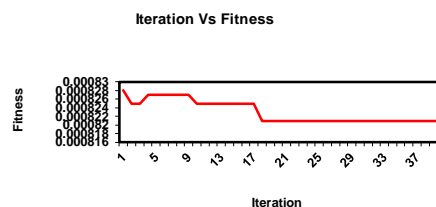

Iteration Vs Fitness

Figure 10 FitnessVs Iteration

5.5 COMPARISON OF GA AND SIMULATION RESULTS

The same problem is solved by both the approaches. The values of L and C values obtained from GA is used to simulate the converter using MATLAB. Almost simulation results are same as results obtained using GA. The simulation process consumes more time to design L & C values using trial and error method to get the optimal performance. The book keeping

technique reduces the convergence time of GA. To design the Boost converter with minimum loss, this approach is very useful. The results obtained by GA and simulation are given in table 4.

Inductance in µH	299.88	Inductance in µH	310
Capacitance in µF	13.63	Capacitance in µF	14
Switching loss in watts	732.01	Switching loss in watts	731.75
Output Voltage in volts	480	Output Voltage in volts	480

Table 4 Comparisons of GA and Simulation Results

6. CONCLUSIONS

Boost converter along with the control scheme is designed and performance of the converter is analyzed using MATLAB software. Designing the values of source inductance (L) and filter capacitance (C) is a critical issue in the converter design, because the L & C values affects the performances like output voltage, voltage ripple and current ripples. Also larger L and C values increase the size and cost of the converter. In this paper, Genetic Algorithm is used to design the source inductance (L) and filter capacitance (C) values. It has been found that the GA gives better results. The convergence time in GA is very less, when compared to simulation results. Since GA is used to design the converter at OFF line, in this paper certain parameters like line current, drain to source voltage and duty ratio are obtained from simulation results and is stored as database. This database is used by GA to optimize the power losses of the converter . Also a closed loop PWM controller is designed. The boost converter designed is tested for line and load disturbances. The controller designed is very stable.

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