

ELECTRICAL AND ELECTRONICS ENGINEERING

EE464 STATIC POWER CONVERSION 2



Team Power

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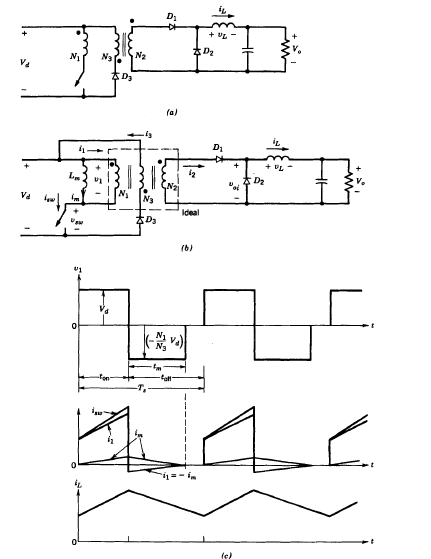
**1. Introduction**

In this project, we designed a forward converter which has 48V input and 24V output. It has total output power of 100 W. In addition to this forward converter, we implemented a controller which should keep output voltage same even if the output load is halved or the input voltage changed.After theoretical calculations and simulation results, we construct this forward converter on PCB.

**2. Forward Converter Topology**

**2.1 Theoretical Results**

Schematic of the forward converter is on the following figure 1.



**Figure 1.** Forward converter and it’s corresponding waveforms [1]

First of all, when switch is on D1 becomes forward biased D2 becomes reverse biased. Voltage on the inductor, therefore, is

When the switch is off,

Average inductor voltage should be zero, therefore

For the forward converter, magnetizing current of the transformer should be taken into account in order to obtain proper operation. One should prevent the magnetic saturation of the core in the transformer. One way to transfer the stored energy back to the supply voltage is to use practical forward converter topology which can be seen on the figure 1.

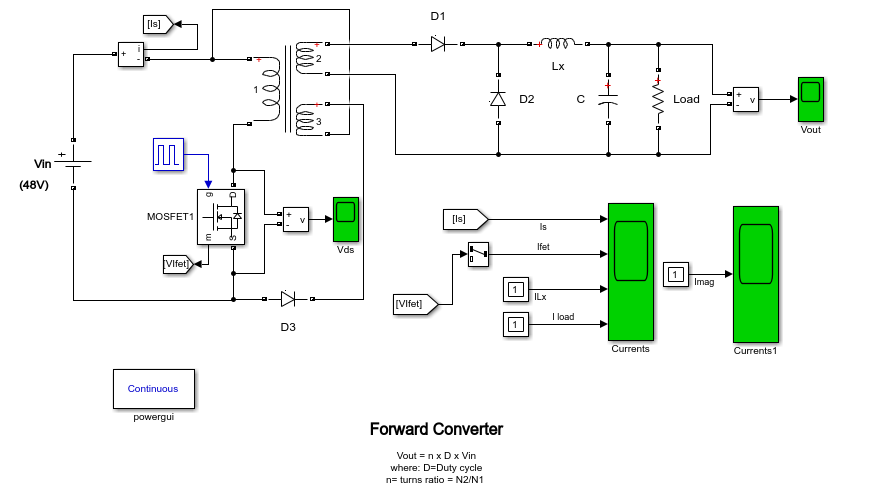
When the switch is on

When the switch is turned off

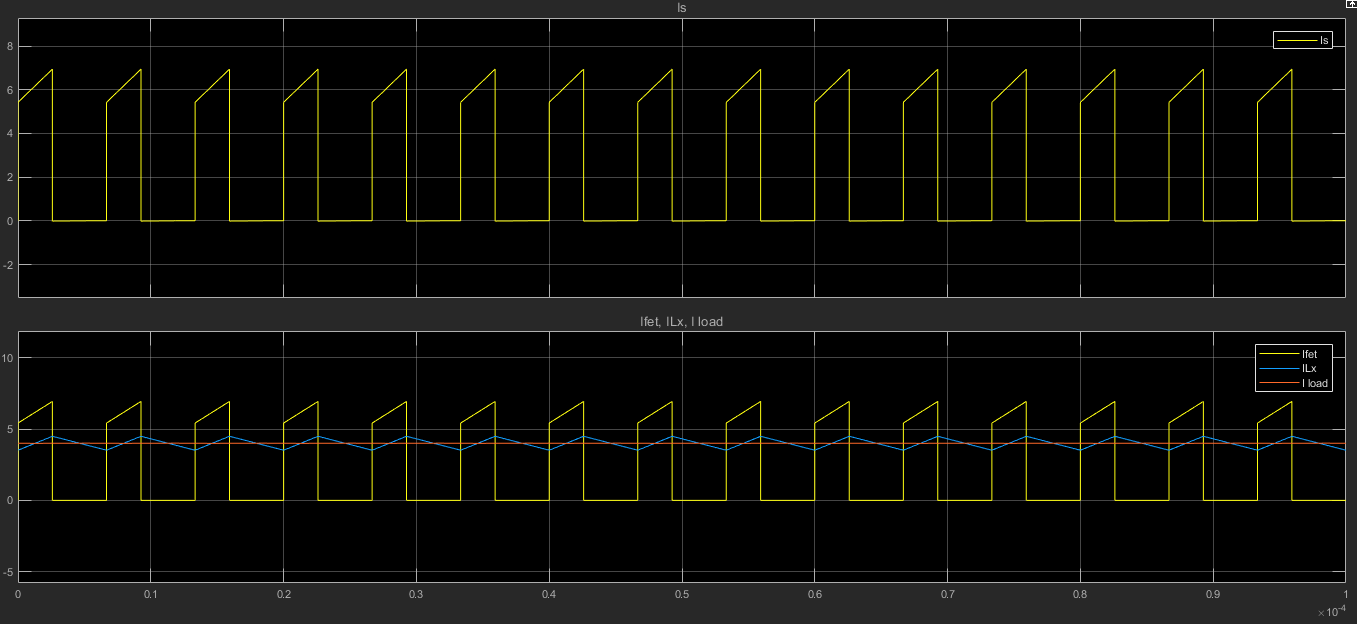
One needs to completely demagnetize the core which means , minimum required of time is; [1]

**2.2 Simulation Results & Equipment Selection**

Simulations are created via using Matlab Simulink. Figure 2 represents forward converter.

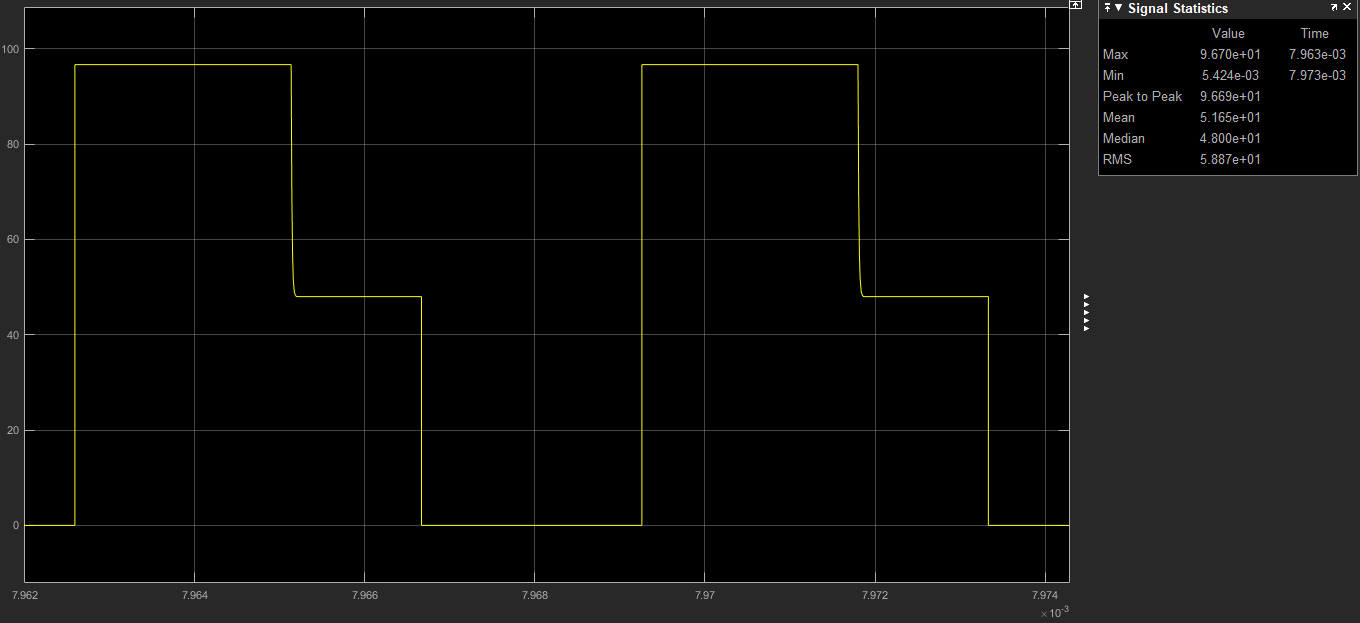


**Figure 2.** Forward Converter



**Figure 3** : Input,Output, Output inductor and switch currents.

Duty cycle is 0.38



**Figure 4.** Mosfet drain source voltage.

Figure 4 represents mosfet drain source voltage. This waveform has 3 steps in one period which means core is fully demagnetizing before next operation.

**Transformer design:**

The transformer turns ratio N1/N2 is calculated 0.67. The turns ratio selected 0.6.

A ferrite core N87 with ETD39 coil former from TDK company is selected. Primary turns ratio is selected to be 6 secondary turns ratio is 10.

The core is un-gapped and its parameters given in figure 5.

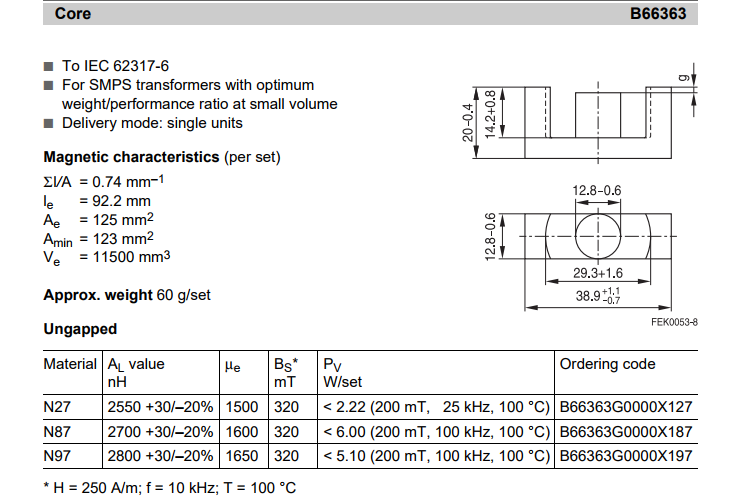
Primary magnetizing inductance :

Minimum primary turns ratio in order to guarantee saturation:

, (our selection is 6)

For

(max allowed core flux density for ferrites to guarantee non-saturation)



**Figure 5.** EDT39 N87 core parameters

The turn ratio is wounded with litz wire which has small resistance compared with copper.

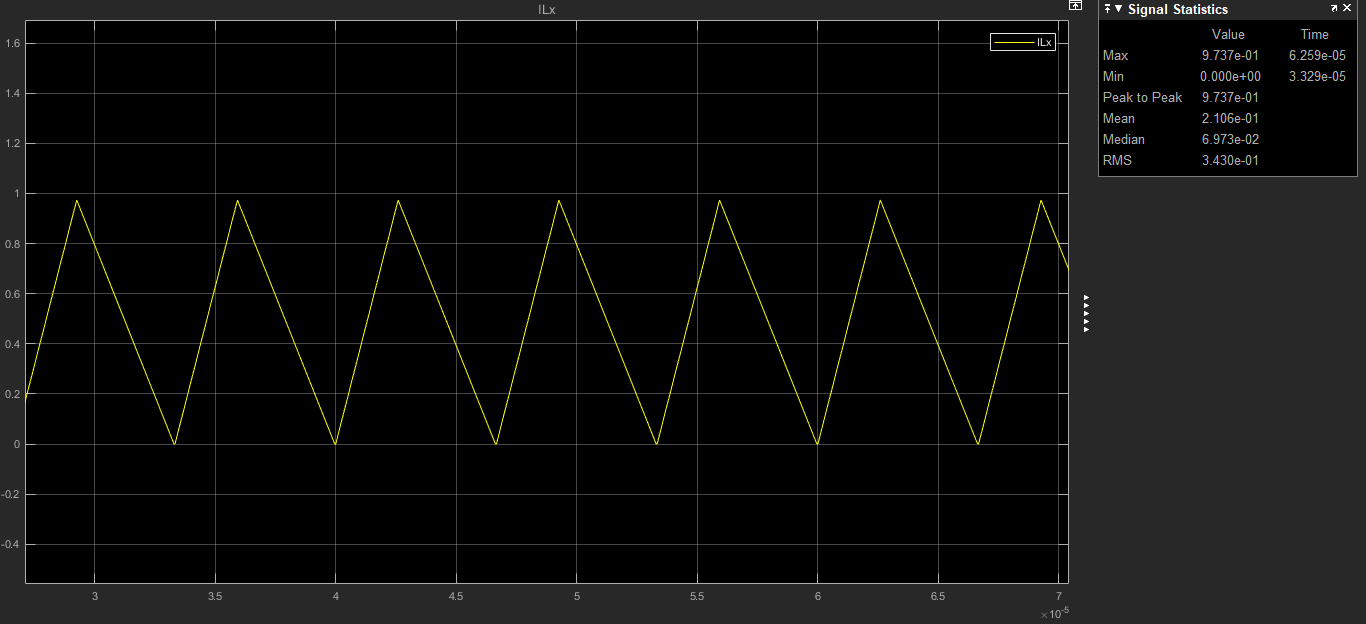
The wire is compound of 270x0.05 wire. It has 32.9 ohm/km resistance.

The mean length of one turn for our coil former is 69mm.

At primary:

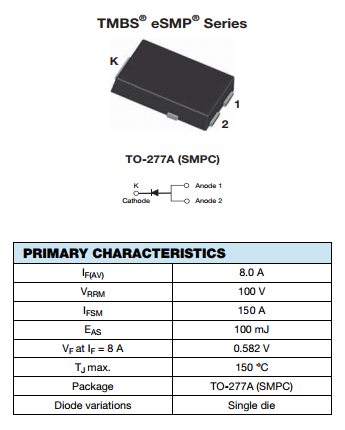
At secondary:

At primary:



**Figure 6.** Output inductor current at boundary

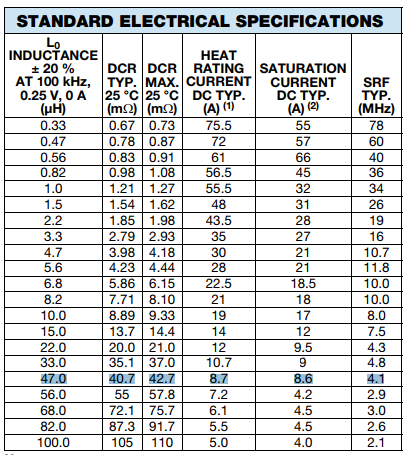
**Main switch:** As a main switch STL18N65M5 is selected. It has low on resistance. It is features are given below:



,

**Figure 7.** Main switch properties

Finally, as an **output inductor**, 47uH inductor with 8.6A saturation current from Vishay company.



**Figure 8.** Output inductor characteristic

**3. Controller Design**

**3.1 Theoretical Calculations**

Small signal analysis of the forward converter is as follows.

State equations are as follows:

On state Off state

ẋ = A1 + B1u ẋ = A2x + B2u

y= C1x y= C2x

where u is input.

Averaging them:

ẋ = [A1d +A2(1-d)] x + [B1d+B2(1-d)] u

y=C1d+C2(1-d)] x

Introducing small perturbations as follows (assuming perturbations in input is equal to zero):

x=X+x y=Y+y d=D+d

in steady state ẋ=0 and neglecting products of x and d;

ẋ=AX+Bu+Ax+[ (A1 – A2 ) X+(B1 -B2 )u]d (10-50) in text book Mohan

A = A1D + A2(1-D)

B= B1D + B2(1-D)

In steady state

AX+Bu= 0

Equation 10-50 becomes

ẋ= Ax+[ (A1 – A2 ) X+(B1 -B2 )u]d and

Y+y=CX+Cx+[(C1-C2)X]d (10-58) in text book Mohan

Where

C=C1D+C2(1-D)

Y=CX

y=Cx+[(C1-C2)X]d

Y/U=-CA-1B

Taking lap lace transform of small signal eqn. (10-58)

Y(s)/d(s)=C[sI-A]-1 [(A1-A2)X + (B1-B2)U] + (C1-C2)X

Let’s apply the formula to the forward converter state variables are defined as inductor current and capacitor voltage.

A1= [ -(R\*rc + R\*rl + rc\*rl)/(L\*(R + rc)), -R/(L\*(R + rc))]

[ R/(C\*(R + rc)) , -1/(C\*(R + rc))]

A1=A2=A;

B1= [ 1/L ]

[ 0 ]

B2=0;

B=B1\*D

For the sake of simplicity assuming R is much greater than (rc+rl);

A=A1=A2= [ -(rc + rl)/L, -1/L ]

[ 1/C , -1/(C\*R)]

C=C1=C2=[rc 1];

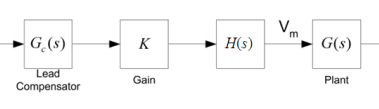
B remains same.

A-1=1/det(A)\* [-1/(C\*R ) , 1/L ]

[ -1/C , -(rc + rl)/L]

Small signal transfer function is as follows

Gain crossover frequency is 70 000 (rad/s). Corresponding phase margin is relatively low. We need to design lead compensator here.



**Figure 9.** Lead Compensator design

H(s) is standing for elimination of steady state error and will be 1/s. K is gain.G(s) is lead compensator which has unity gain. It has a form of

We obtained characteristic of via using type 2 controller circuit. Overall open loop characteristic is

**3.2 Simulation Results & Equipment Selection**

Let’s choose;

Vd=48V

Vo=23.6V

rl=0.02ohm

L=47uH

rc=0.013ohm

C=60uF

R=5ohm

Fs=150kHz

Bode diagram is in following figure 10. Gain crossover frequency



**Figure 10.** Bode plot characteristic of open loop system.

We designed lead compensator unit here. Let’s start with integrator term in order to eliminate steady state error. Bode plot with H(s)=1/s is following figure 11.



**Figure 11.** Bode diagram of

Choose K=250; bode plot of K\*H(s)\*G(s) is in figure 12.



**Figure 12.** bode plot of K\*H(s)\*G(s)

Let’s design unity gain lead compensator at gain crossover frequency. Bode plot of single compensator is in following figure 13.

rad/s

a=11;

which means we add 80 degrees phase at gain crossover frequency.



**Figure 13.** Characteristic of lead compensator

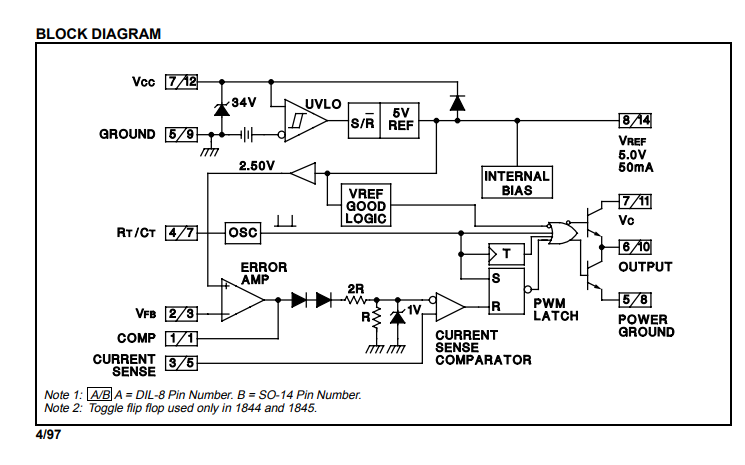
Overall open loop system characteristic is in following figure 14.



**Figure 14.** Overall open loop characteristic

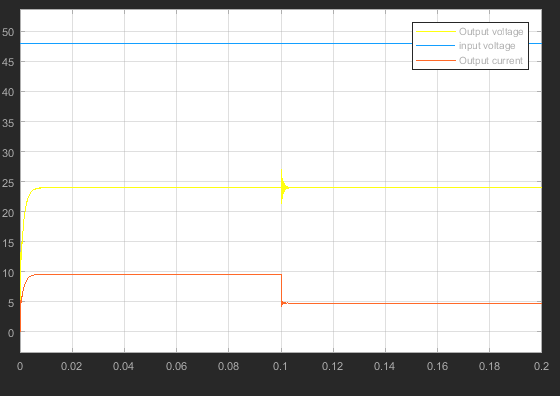
Figure 14 shows our closed loop system will be stable.

In order to control our DC/DC converter we are decided to use UC1845 Current mode PWM controller it has also current limiter. Block diagram of controller is in following figure 15.

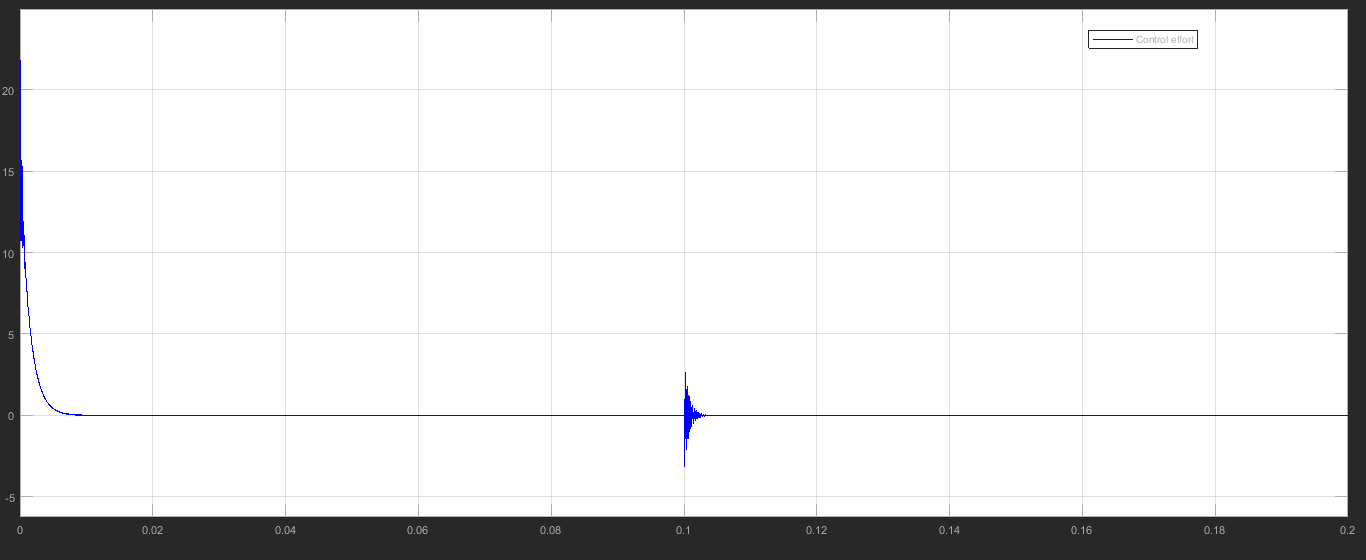


**Figure 15.** UC1845 Current mode PWM controller

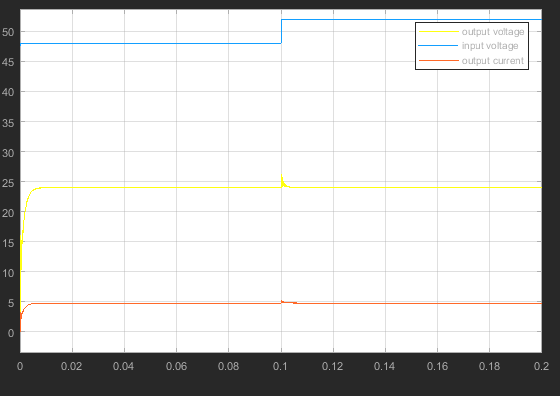
Simulation results of closed loop system are in following figure 16, 17, 18 19.



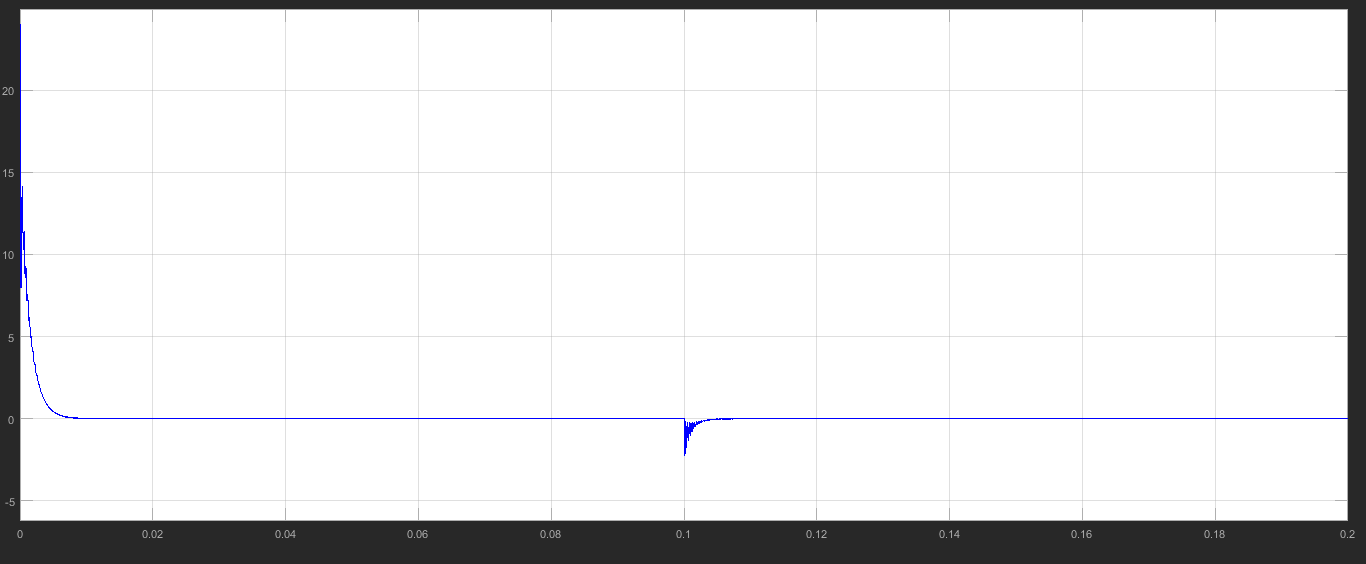
**Figure 16.** Response of the system when load is increased two times

Control effort is in following figure 17.

**Figure 17.** Control effort



**Figure 18.** İnput voltage is increased %10



**Figure 19.** Corresponding control effort

**4. Demonstration Results**

**5.References**

**[1] Mohan**