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# • Unidirectional Battery Charger using DC-DC SEPIC converter

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# PROBLEM STATEMENT:

Simulate a unidirectional battery charger circuit feeding power from the grid. The DC-DC SEPIC converter needs to be used for charging current control.

The required details are as follows:

Input AC supply = 230 V AC

Battery details: 48 V, 28 Ah.

Switching frequency, Fs = 30 KHz

# THEORY:

A SEPIC is in continuous-conduction mode if the current through the $L_1$ and $L_2$ inductors never goes down to zero. The average voltage across the capacitor $C_1$ and $C_2$ is equal to the input voltage (Vin) during a steady-state operation of a SEPIC. Due to the fact that capacitors $C_1$ and $C_2$ block direct current, the average current through it is zero, rendering inductors $L_1$ and $L_2$ the only source of current. Therefore, the average current flow through inductor $L_2$ is the same as the average current of the load and therefore independent of the voltage input. The following can be written when looking at average voltages:

$$V_{in} = V_{L1}+V_{CS}+V_{L2}$$

Because the average voltage of $V_{CS}$ is equal to $V_{in}$

$$V_{L1} = -V_{L2}$$

The two inductors could therefore be wound on the same core. Since the voltages are the same in magnitude they will have zero mutual inductance effect. Here the polarity of the coil is presumed to be correct. The ripple currents of the two inductors will be equal in magnitude as the voltages are equal in magnitude. One can sum up the average currents as follows:

$$i_{D1}= i_{L1} + i_{L2}$$

**ON STATE:-** The current $i_{L1}$ rises when switch Q is switched on and the current $i_{L2}$ rises in the reverse direction. The energy from the input source raises the current $i_{L2}$. Because Q is closed for a short time and the instantaneous voltage $V_{C1}$ is approximately $V_{in}$, the voltage $V_{L2}$ is also around $V_{in}$. The capacitor $C_1$ therefore provides the energy to increase the current magnitude in $i_{L2}$ and hence increases the energy in $L_2$.

**OFF STATE:-** The current $I_{C1}$ becomes the same as the current $i_{L1}$ when switch $Q_1$ is turned off, as the inductors will not permit instantaneous current changes. The current $i_{L2}$ proceeds in the negative path, in fact it never changes direction. The negative $i_{L2}$ will be added to the current iL1 in order to raise the load current. So while Q is off, both $L_2$ and $L_1$ supply energy to the load. During this off process, the coupling capacitor ($C_1$) is charged by $L_1$ and will charge $L_2$ during the on process. Due to capacitor $C_1$ and inductor $L_2$, the SEPIC's boost / buck capabilities are feasible.

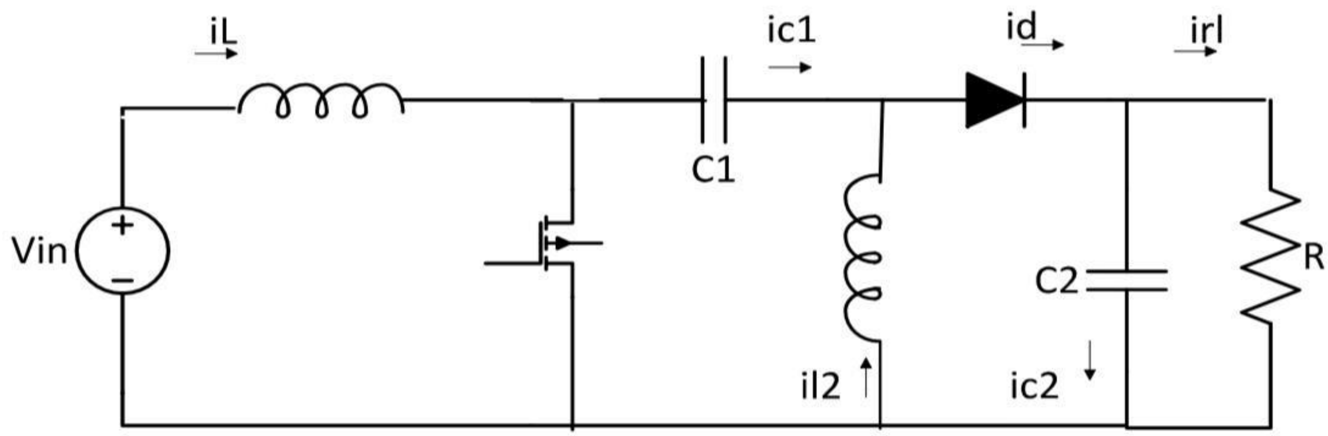


Figure-1: SEPIC Converter

## Closed-Loop Control System:

The below figure shows the general structure of a closed-loop feedback control system. We used the PI controller for close loop control in the project.

The regulation is based on the current error value and on the integral of these errors

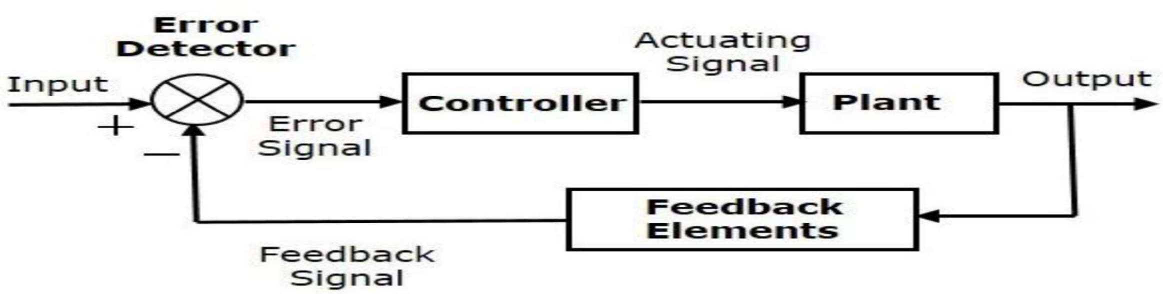


Figure-2: Close Loop Feedback Control

simultaneously. The error represents the difference between the setpoint value which the user wants and the real output. Hence, PI controller should be applied in a feedback loop:

The proportional component provides an output that depends on the instantaneous value of the error. So, it allows fast correction of every error. The integrative component provides an output that is proportional to the accumulated error. The integrative component is a “slow mode” because the error needs enough time to be accumulated to provide a significant effect. However, for an infinite time for the steady-state, the integrative component allows canceling the error out.

The measured current and the reference current are compared to generate the control current. The duty ratio is changed by the DC-DC PWM generator, which gets the input from the PI controller and hence is used to control the current. Here, since the output voltage is constant, the change in duty ratio forces the current to be changed, and hence we attain current control.

# CONVERTER PARAMETERS SELECTION:

1. **Duty cycle consideration (D)**

   On solving, volt-sec balance of both the inductors $L_1$ and $L_2$, we found;

   $$D = \frac{Vout}{Vin+Vout} = 0.1877$$

   Here, $V_m = 230\sqrt{2}\,V$

   Rectifier output i.e. Input to the sepic converter, $V_{in} = \frac{2Vm}{\pi} = 207.7v$

   And, $V_{out}$=48v

   $\therefore D = \frac{48}{207.7+48} = 0.1877$

2. **Inductor Selection ($L_1$ and $L_2$)**

   To ensure Continuous Conduction Mode (CCM)

   $L_1 \geq \frac{(1-D)^2 Ro}{D \cdot 2Fs} \Rightarrow L_1 \geq 1.004*10^{-4}$

   $L_2 \geq \frac{(1-D)\, Ro}{2Fs} \Rightarrow L_1 \geq 2.32*10^{-5}$

   For simplicity, we assumed;

   $L_1$ = 1 mH

   $L_2$ = 1 mH

3. **Capacitor Selection ($C_1$ and $C_2$)**

   To ensure that the actual voltage ripple is lower than the limit,

   $C_1 \geq \frac{I_o D}{F_s \Delta V_1} \Rightarrow C_1 \geq 8.4*10^{-5}$

$C_2 \geq \frac{I_o D}{F_s \Delta V_2} \Rightarrow C_1 \geq 3.6*10^{-4}$

Assuming 1% ripple in voltages;

$\Delta V_1 = 0.01*V_{in}$

$\Delta V_2 = 0.01*V_{out}$

For simplicity, we assumed;

$C_1 = 4700\mu F$

$C_2 = 4700\mu F$

# Circuit Diagram in MATLAB

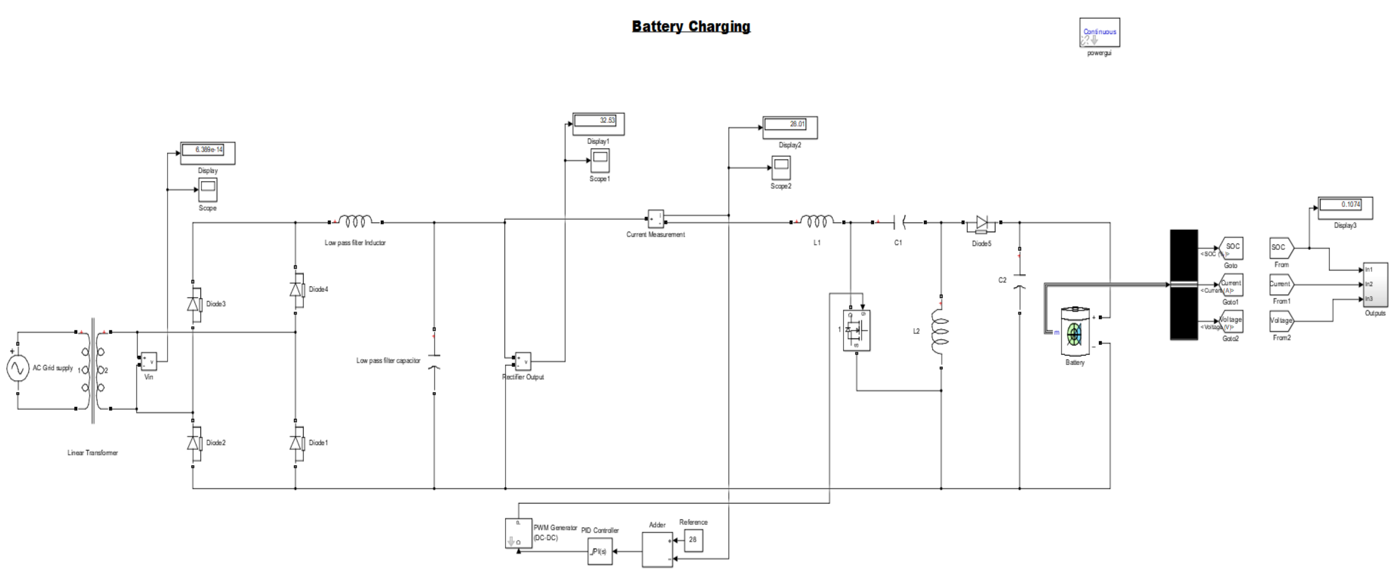

Figure-3: Simulation Diagram in MATLAB

## WAVEFORMS OBTAINED FOR DIFFERENT REFERENCES

The plots and table for the different reference currents have been shown below:

| S.No | REFERENCE CURRENT (A) | INPUT CURRENT (A) |
|---|---|---|
| 1 | 28 | 27.97 |
| 2 | 24 | 23.97 |
| 3 | 20 | 19.95 |
| 4 | 10 | 9.95 |
| 5 | 32 | 31.96 |

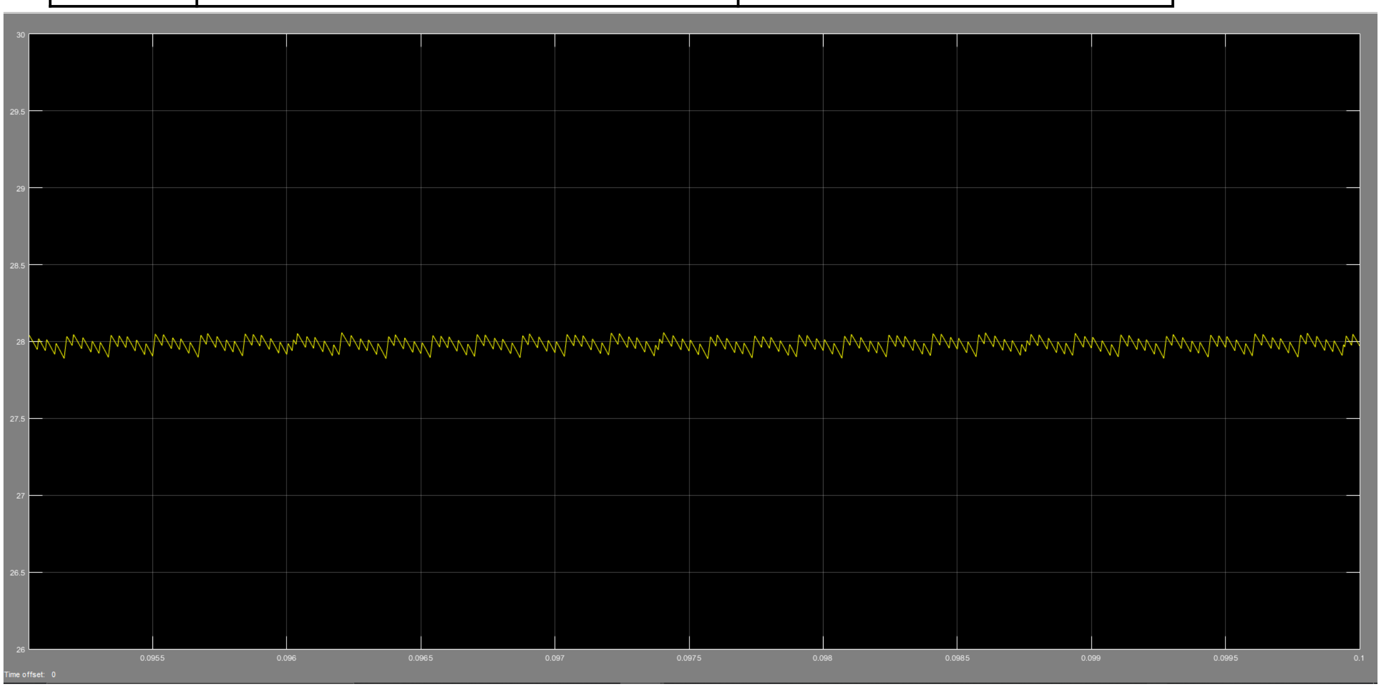

**Figure-4: The plot shows variation of input current (Y-axis) and time (X-axis) for reference current of 28A**

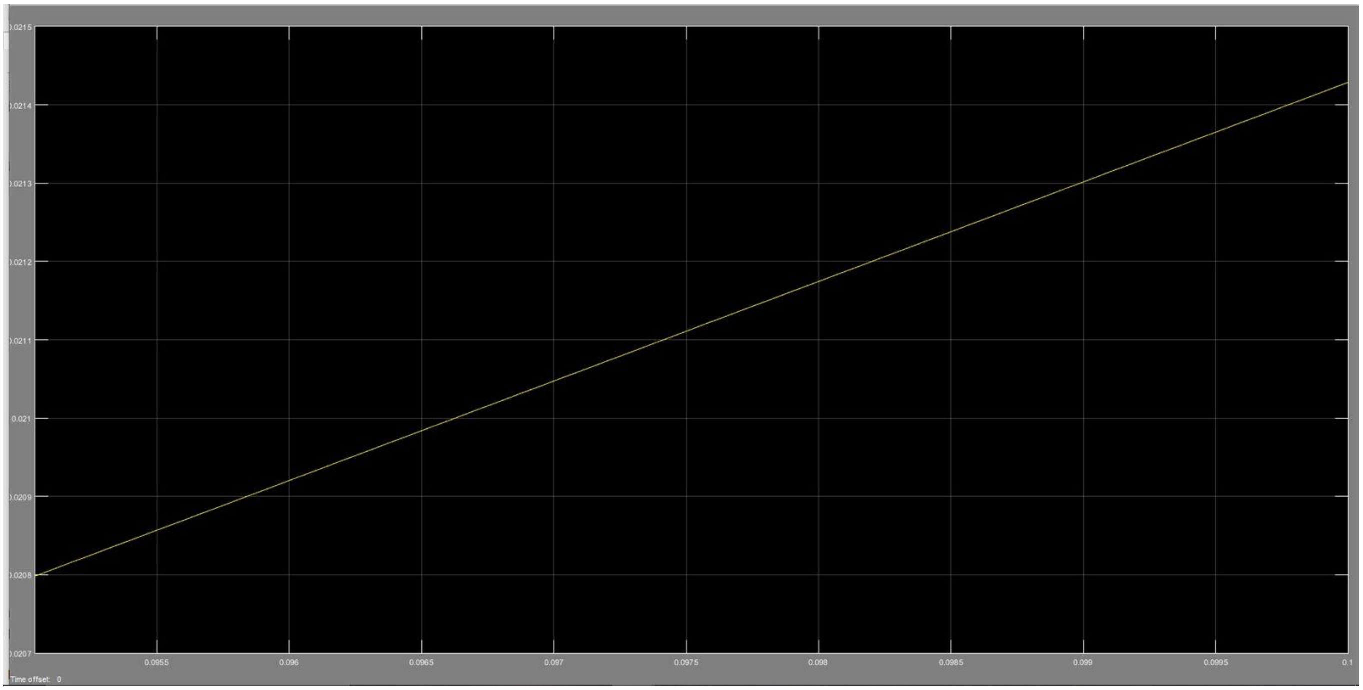


**Figure-5: The plot shows variation of State of Charge (Y-axis) and time (X-axis) for reference current of 28A**

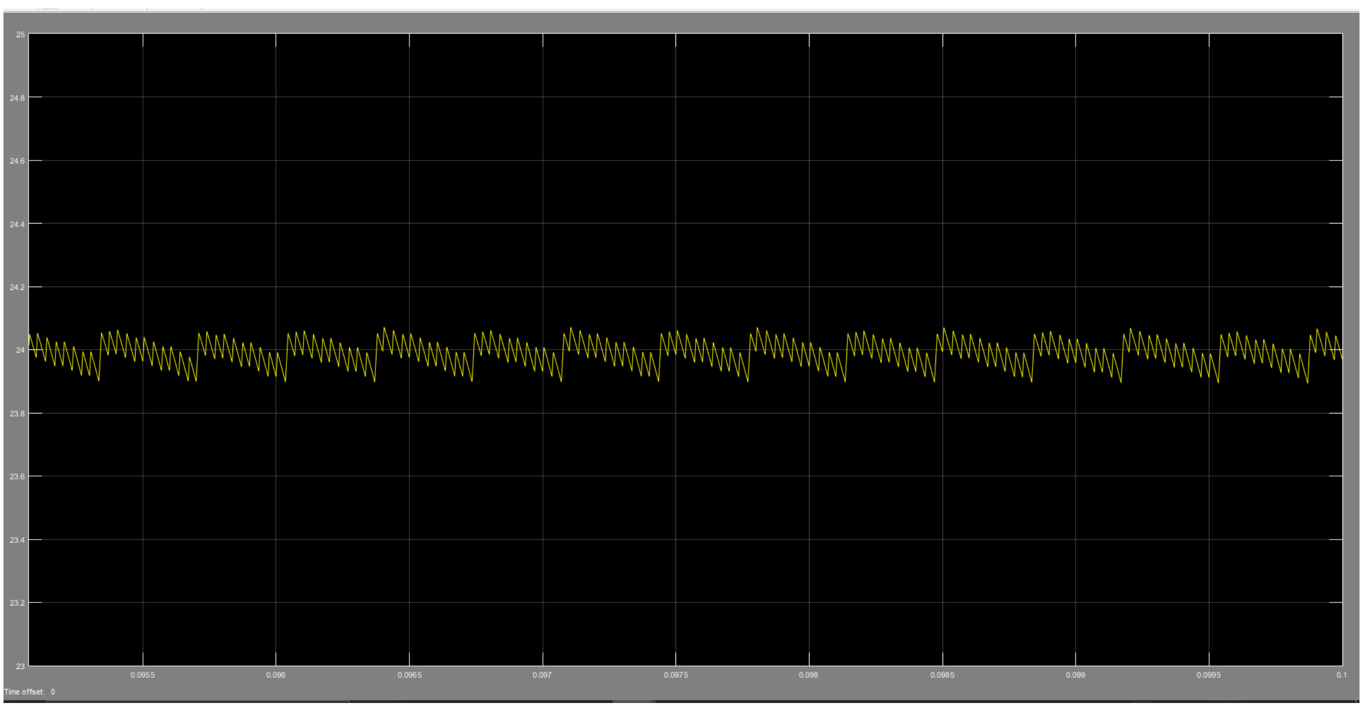


**Figure-6: The plot shows variation of input current (Y-axis) and time (X-axis) for reference current of 24A**

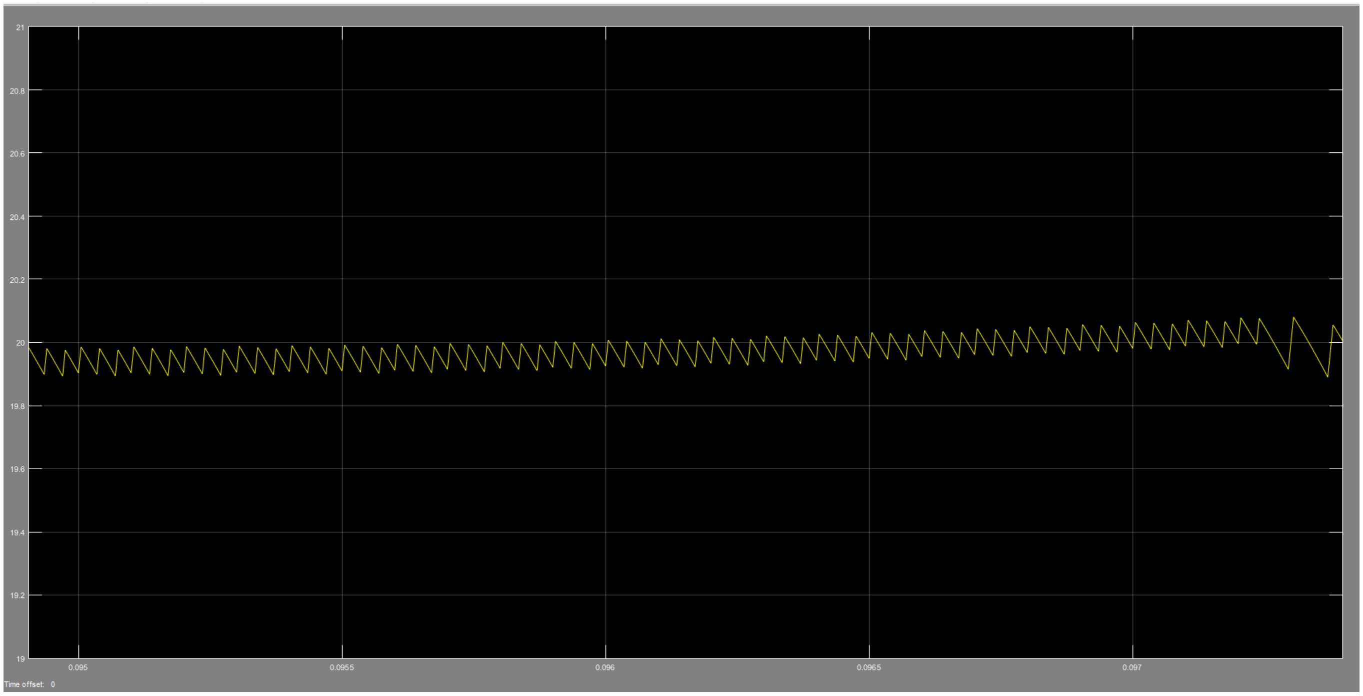


**Figure-7: The plot shows variation of input current (Y-axis) and time (X-axis) for reference current of 20A**

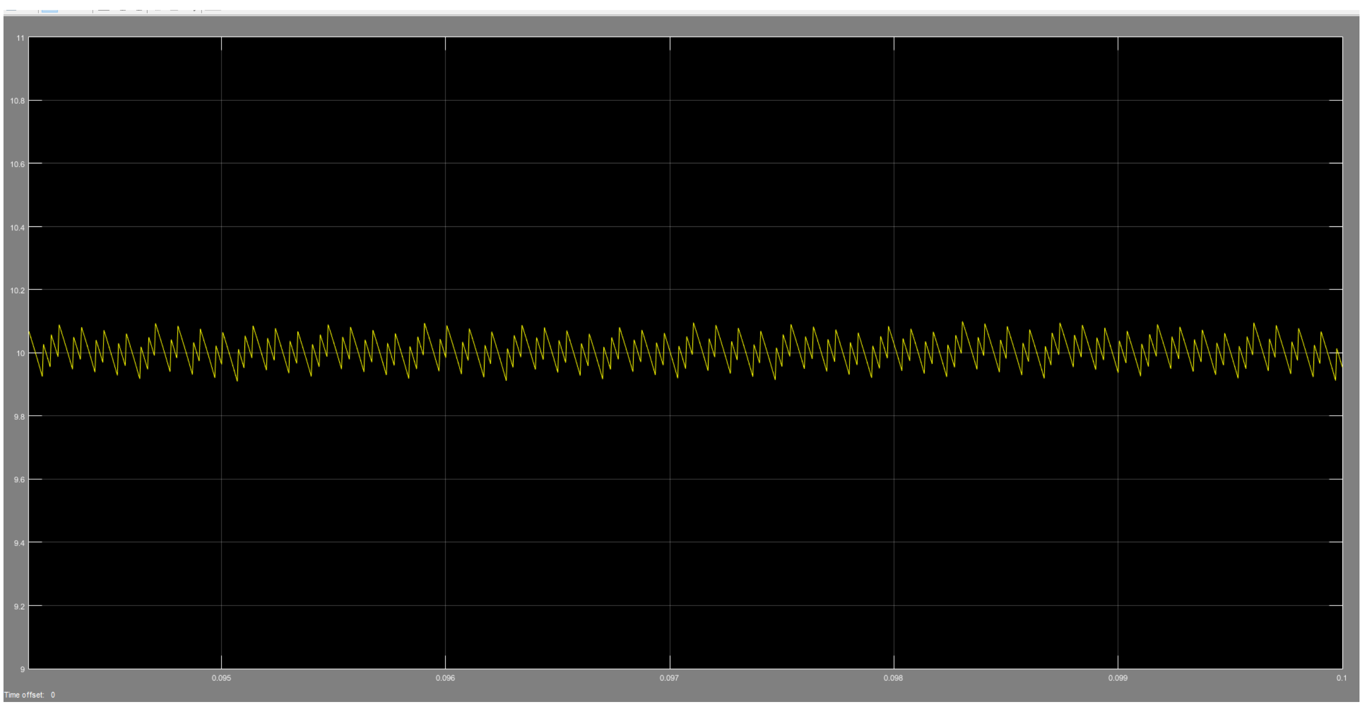


**Figure-8: The plot shows variation of input current (Y-axis) and time (X-axis) for reference current of 10A**

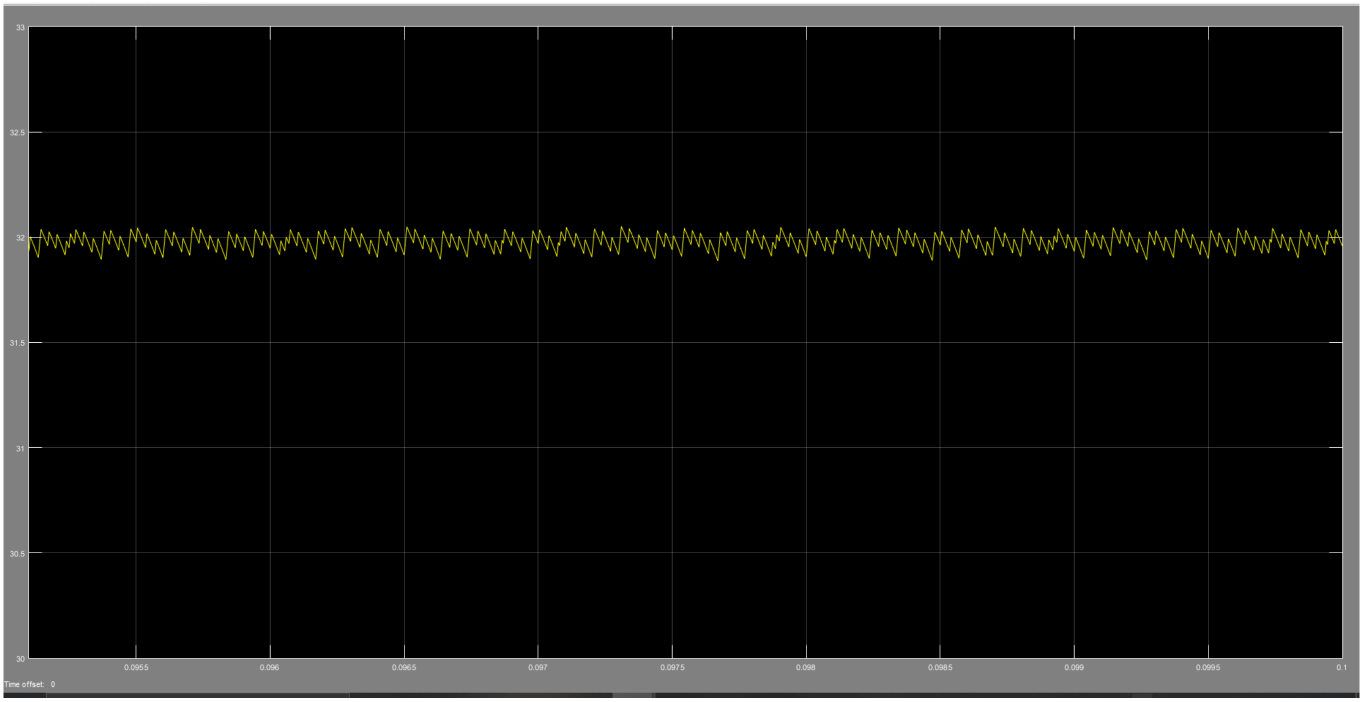


**Figure-9: The plot shows variation of input current (Y-axis) and time (X-axis) for reference current of 32A**

## Conclusion:

The unidirectional battery charger feeding power from the grid is made using the SEPIC converter.The circuit is designed according to the specifications given in the problem statement. The inductances and capacitances values used in the converter circuit are; $L_1$ = 1 mH, $L_2$ = 1mH and $C_1$ = 4700µF, $C_2$= 4700µF respectively. The filter inductance and capacitance are 1mH and 4700µF. The charging current control is done for the circuit using closed-loop control with a PI controller. The proportional parameter and the integrative parameter used are 10 and 1, respectively, after fine-tuning by conducting different experiments. The current settled down to a near steady-state for 5 different values of given references shown in table above and State of charge for given parameters is found to be increasing.