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Design and Simulation of Landsman Converter Fed EV Battery Charger for Power Factor Improvement

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Abstract: This paper describes design and simulation of landsman connected to isolated converter fed to EV battery charger for power factor improvement. Two landsman converters are operated in parallel in the course of positive and negative half cycle in continuous conduction mode in synchronization, reduces ripple input current, followed by flyback converter provides isolation for charging of EV battery during the condition of constant voltage and constant current. The transitional DC link voltage is regulated by maintaining constant voltage using Proportional integral controller to maintain unity power factor by enhancing input voltage and current wave shaping in phase at source side, This supplement power quality of electric vehicle battery charging.

Key Words: Landsman converter, Flyback converter, Electric vehicle, Proportional integral controller, Power factor.

1.Introduction

In the Present scenario, Electric mobility is driving more significant for efficient transport sector also act as battery storage. The main benefit of electric vehicles is to reduce global warming as they do not produce harmful emissions of greenhouse gases, thus contributes to sustainable development. The other advantages are low running cost, low maintenance as Electric vehicles are robust compared to internal combustion engines vehicles.

The common configuration of any Electric vehicle's battery charger incorporates boost converter cascaded with isolated converter [1]. The Reactive power compensation with interleaved converters causes more current stress in switches [2]. The diode bridge rectifier is an eminent Power Factor Correction topology but has poor source power factor as it generates harmonics in the input current drawn during the charging process [3].

The above short comings are eliminated with the efficient power factor correction using landsman converter with PI controller, reduces the steady state error [4]. In order to achieve brightness in LED drive, landsman converter is preferred for power factor correction with pulse width modulation, also to control brightness, improving the power quality parameters [5].

1.1 Landsman converter

The landsman converter mainly comprises input and output inductors, mid capacitors with main switching device and diode. The Improvement of power factor in Landsman converter fed Electric vehicle Battery charger is shown in Fig -1. The Input voltage to converter is of single-phase AC source, Input LC filters eliminates the transients. The configuration has two main stages. The first stage comprise of two landsman converter operates in synchronization respective positive and negative half cycle of main supply voltage. The second stage is of isolated converter preferably flyback converter because of its simple structure provides isolation to the battery during process of charging.

Landsman converter with power factor correction control unit is mainly used to enhance input voltage and current wave shaping in phase to achieve nearly unity power factor. The flyback converter is an Isolated converter consist a single main switching device, mutually coupled inductor for transferring the stored energy from primary to secondary side, The diode at the secondary side rectifies voltage and smoothens out the rectified voltage by the capacitor. Flyback converter is mainly used for Low power application with improved efficiency [6].

The inductors L_{iP} and L_{in} operates in continuous conduction mode thereby reduces the input ripple current. The switching pulses S_p and S_n are obtained from PWM generator through PI controller of power factor control unit. The mid capacitance C_p and C_n operates in continuous conduction mode for complete one switching cycle. whereas the output inductance L_{op} and L_{on} operates in discontinuous conduction mode over one switching cycle. Output voltage obtained from landsman converter is fed as input to flyback converter to step down voltage to 65V and provides isolation to the battery charging as well. The switching pulses to flyback converter are generated from battery control unit.

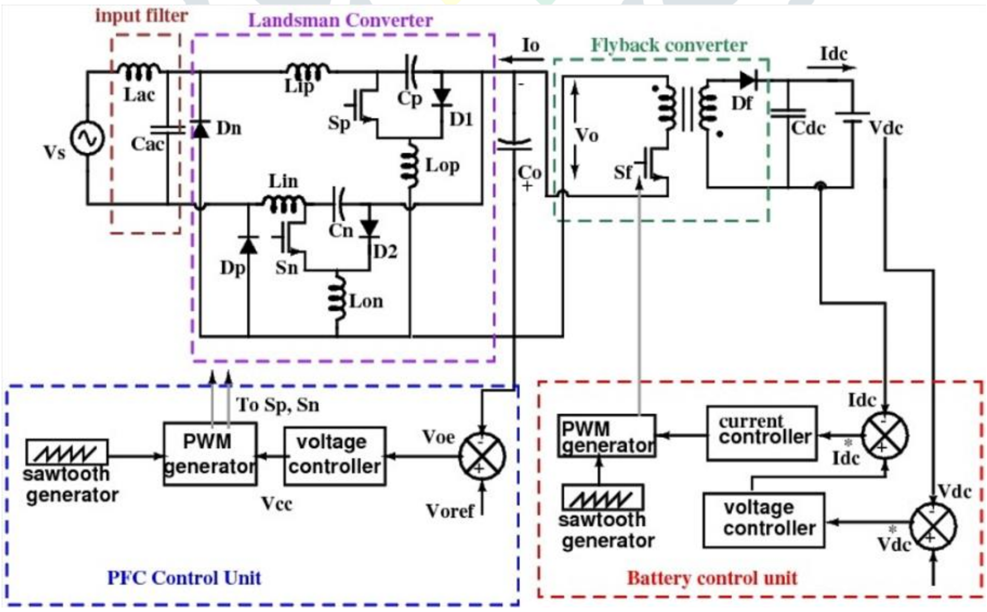

Fig-1 Schematic diagram of Landsman converter

2. PRINCIPLE OF MODE OPERATIONS

There are three Modes of operation in Landsman converter during each in positive and Negative half cycle [4].

Mode 1: During positive half cycle of input voltage applied to the converter, inductance L_{ip} starts charging. The upper switch S_p is turned on, current flows through L_{op} as shown in Fig-2 continues to charge, diode D1 is reverse biased, the transitional capacitor C_o is discharged to the flyback converter connected at load side.

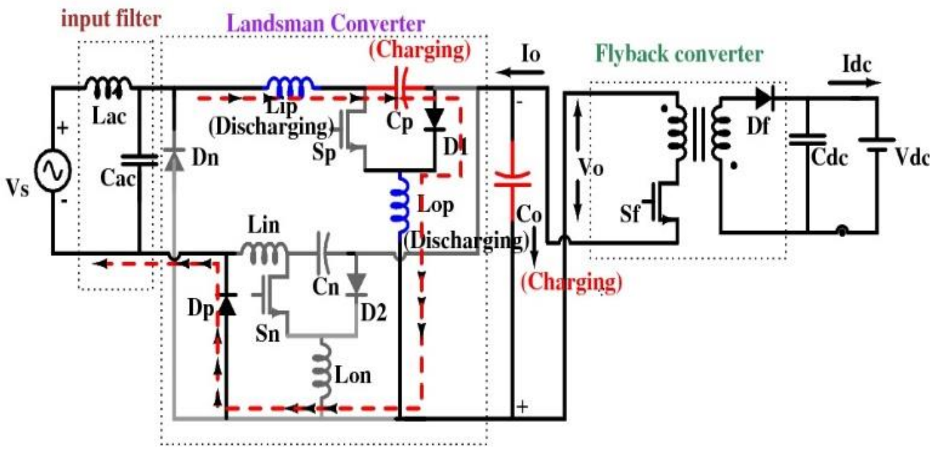

Fig-2: Mode 1 operation during positive half cycle

Mode 2: when there are no switching pulses from the PWM generator, upper switch S_p is turned off, the energy stored in L_{ip}begins discharging to the capacitor for charging. Diode D1 is forward biased, starts conducting Current flow through diode D1 as shown in Fig-3, The transitional capacitance C_o is found charging during this mode.

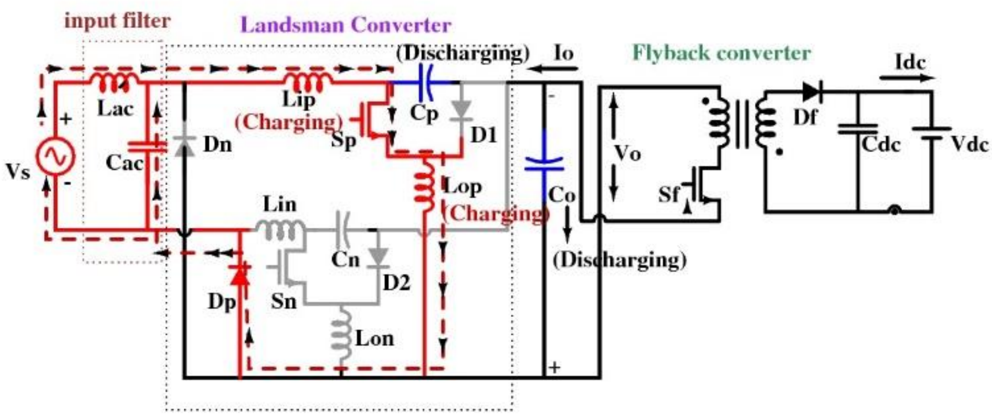

Fig-3: Mode 2 operation during positive half cycle

Mode 3: The process of discharging the stored energy in L_{ip} continues in mode 3. Discontinuous conduction of inductor current of I_{lop} as stored energy in L_{op} completely depleted at the end of switching cycle. Transitional capacitor C_o delivers output power to the isolated converter is shown in Fig-4.

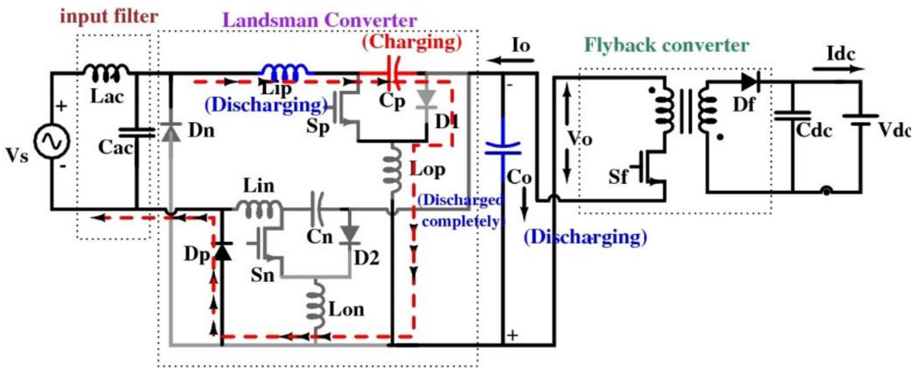

Fig-4: Mode 3 operation during positive half cycle

The operating principle during negative half cycle is explained as follows:

Mode 4: During Negative half cycle of the input voltage, the inductance L_{in} begins to charge as shown in Fig-5. switch S_n is turned off, the current flows through L_{on} as shown in fig, mid capacitor C_n discharges the stored energy. Transitional capacitor $C_o$starts charging to store energy.

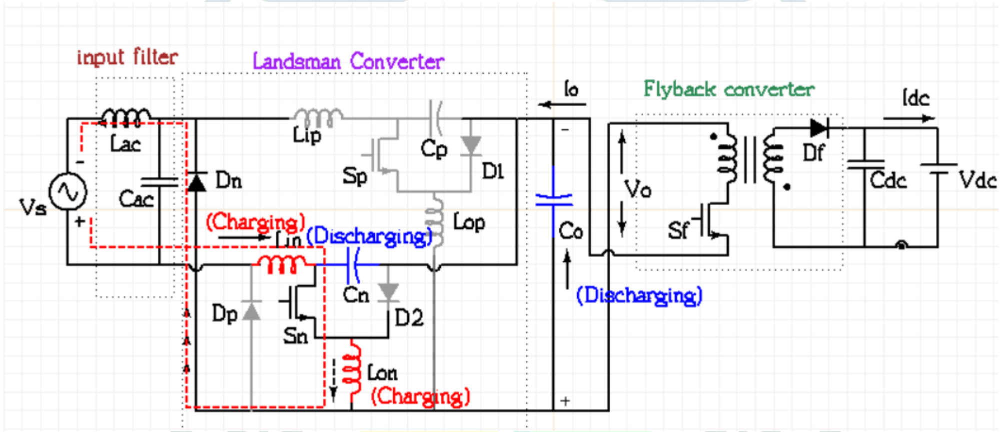

Fig-5: Mode 4 operation during negative half cycle

Mode 5: At the time switching pulses are prevented from the PWM generator, switch S_n is in OFF condition. The stored charge in L_{in} is transferred to capacitor C_n , Hence D_2 is forward biased current continues to flows through L_{on} shown in Fig-6, transitional capacitor $C_o$is charged.

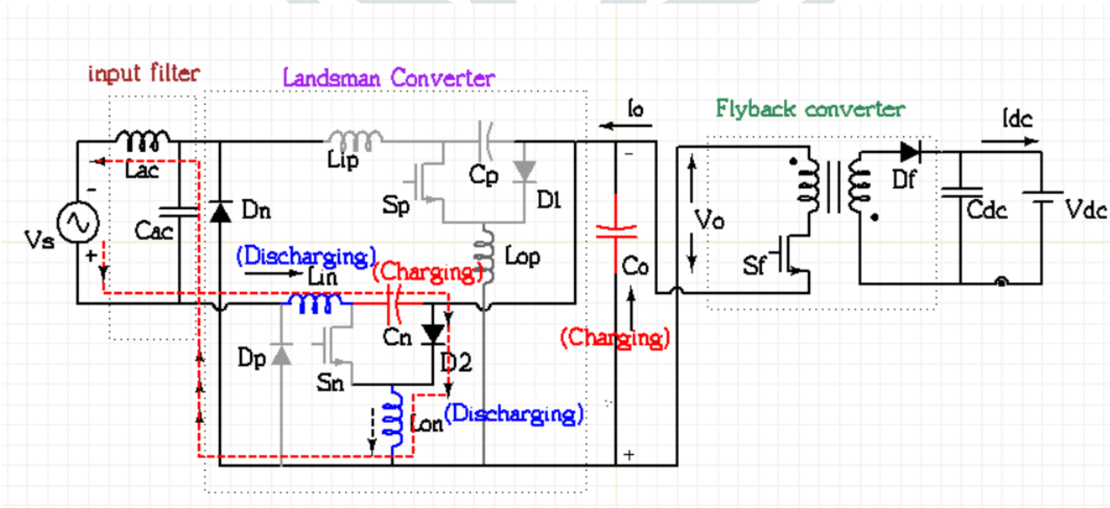

Fig-6: Mode 5 operation during negative half cycle

Mode – 6: The stored energy in L_{in} is discharged, discontinuous conduction of inductor current I_{Lon} is completely depleted at the end of switching cycle. Transitional capacitor C_o delivers output power to the isolated converter is shown in Fig-7

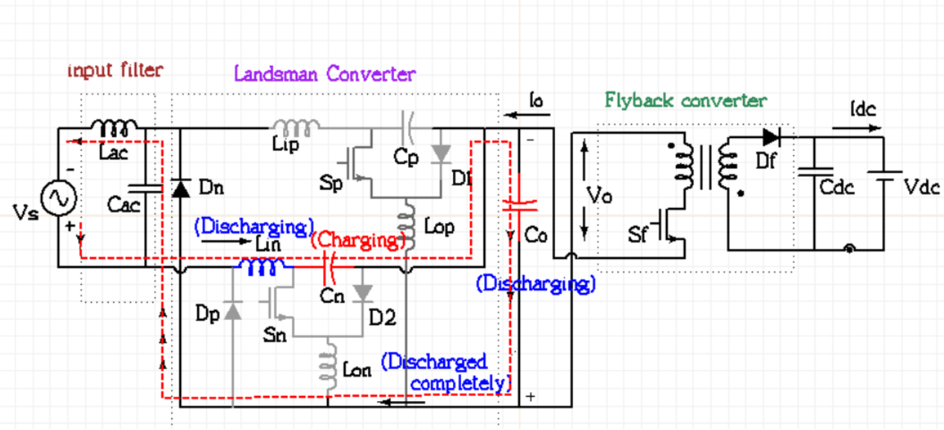

Fig-7: Mode 6 operation during negative half cycle

2.1 Flyback converter

The Output voltage of landsman converter across transitional capacitor C_o is fed as input to flyback converter provides isolation to the battery charging with the output voltage of 65V. The flyback converter is preferred because of its simple structure. The main Parameter required for operation of flyback converter are switching rating and magnetizing inductance [6].

Flyback converter operates in two modes. The first mode begins with the switch S_f in ON condition. Initially energy is stored in primary inductance. When switch S_f is in OFF condition, energy is transferred to secondary side, diode D_f is forward biased. Thus, output voltage is obtained. Powder core is generally used as transformer core in flyback converter

3.DESIGN OF CONVERTER

Landsman converter is designed [4] to operate for input power of 850W. AC input voltage 311V peak is applied to the converter with 50Hz frequency is shown in Table-1.

Table-1 Input Parameter specification

SL no.	Design parameters	Specifications
1	Input power, P_i	850W
2	Input voltage, V_{in}	220V
3	Input current (I_{in})	3.A
4	Intermediate DC link voltage,V_o	300V
5	Flyback converter output voltage, V_{fl}	65V

The design of Landsman converter mainly includes input and output inductance values and transitional capacitance design. Constant input voltage is considered as switching frequency f_{sw} of converter is selected as 20kHz.

Low pass LC Input filter eliminates the circulation of higher order switching current.

$$\text{Filter capacitance, } C_f = \frac{I_P * tan\boldsymbol{\theta}}{\boldsymbol{\omega} * V_p} \quad (1)$$

$I_p$and $V_p$represent the maximum values of supply current and voltage. In order to make input PF equal to unity, the displacement angle θ has to be as small as possible is the angle between input voltage and current.

$$\text{Filter Inductance}, L_f = \frac{1}{4\pi * {f_c}^2 * C_f} \quad (2)$$

D is the duty ratio of the landsman converter to control voltage across transitional capacitor at 300V.

$$\text{Duty Ratio, D} = \frac{V_0}{V_0 + V_{in}} \tag{3}$$

Input inductance of landsman converter ($L_i = L_{ip} = L_{in}$) is designed to operate in continuous conduction mode, also to reduce ripple input current thus, higher value of inductance is selected by considering the ripple current of 30%.

$$\text{Input inductancce, } L_i = \frac{{V_{in}}^2 * D}{P_i * 0.3 * f_{sw}} \tag{4}$$

The mid capacitors $C_i = C_p = C_n$ are designed to operate in continuous conduction mode in respective half cycle of input voltage.

$$\text{Capacitance, } C_i = \frac{P_i}{\Delta v * V_p * f_{sw} (\sqrt{2} * V_{in} + V_0)} \tag{5}$$

The output inductance $(L_o = L_{op} = L_{on})$ is designed to operate in discontinuous conduction at the end of switching cycle as stored energy is completely depleted. therefore, the required inductance value is selected less than the calculated value.

$$\text{Output Inductance, } L_o = \frac{{V_{in}}^2 * D}{P_i * 2 * f_{sw}} \tag{6}$$

Transitional capacitance C_o is designed to operate in continuous conduction mode, is regulated to maintain constant at 300V from the PI controller, reduces the steady state error.

$$\text{Transitional capacitance, } C_o = \frac{P_i}{2 * \Delta v * \boldsymbol{\omega} * {V_0}^2} \tag{7}$$

Δv is the ripple voltage

The Input voltage of flyback converter is obtained from transitional capacitor of landsman converter 300V, In order to step down voltage to 65V, the duty cycle of 0.4 is considered to obtain turns ratio of the flyback converter.

$$\text{Turns Ratio }, \frac{N_2}{N_1} = \frac{(1 - D_{fl}) * V_{fl}}{D_{fl} * V_o} \tag{8}$$

Magnetizing Inductance initially stores energy as switch S_f is turned ON and delivers energy to secondary side in OFF condition. This operates in discontinuous conduction mode over each switching cycle

$$\text{Magnetizing Inductance } L_{mag} = \frac{V_{o} * D_{fl}}{I_{lmag} * f_{fl}} \tag{9}$$

The output capacitance of Flyback converter is calculated by considering 1% of ripple voltage,

$$\text{Capacitance, } C_{dc} = \frac{P_i * D_{fl}}{\Delta v_{fl} * f_{fl} * {V_{fl}}^2} \tag{10}$$

4. SIMULATION ANALYSIS AND RESULT

The Landsman converter is provided with an input voltage V_i of 220V to obtain 300V across transitional capacitor is maintained constant also fed as input to the flyback converter provides isolation to the battery charging. The circuit diagram of landsman converter cascaded with Flyback converter is shown in Figure. The converter is simulated with the designed values. The simulation is executed in the MATLAB software.

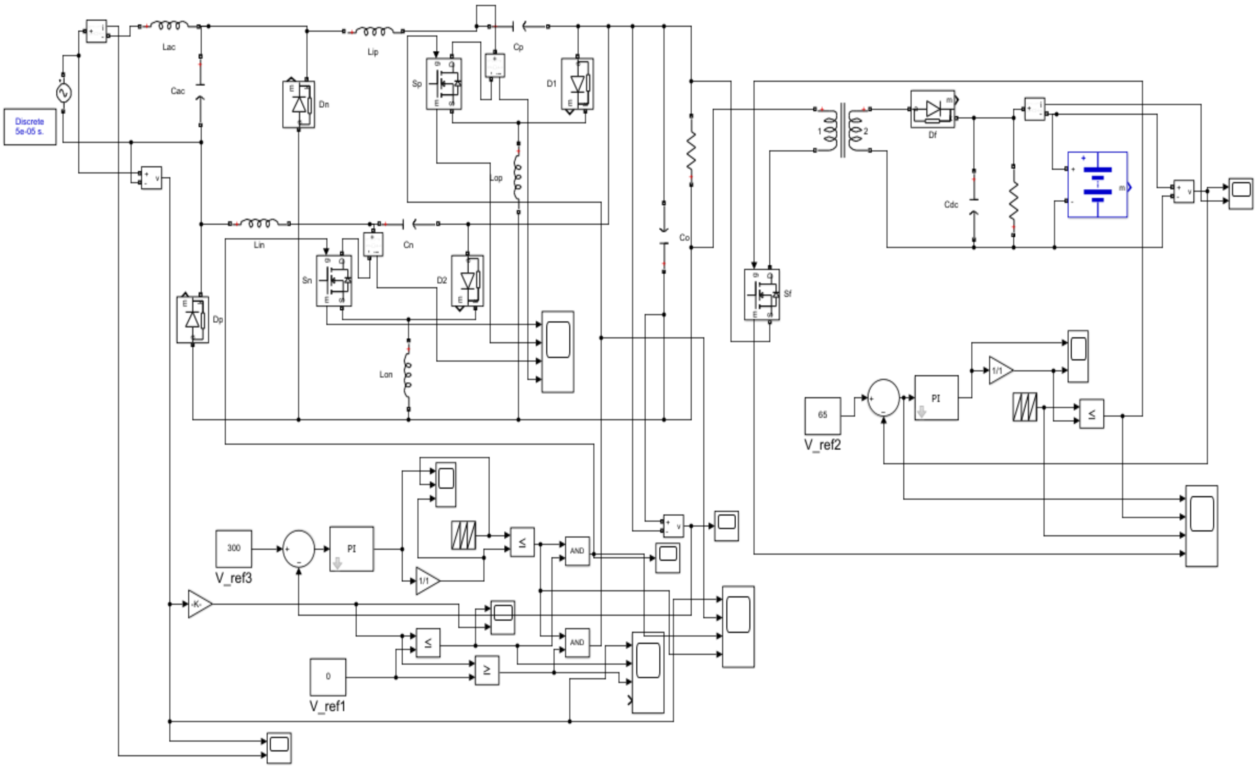

Fig-8: Simulation circuit of Landsman converter

The Landsman converter output voltage across transitional capacitor is maintained constant at 300V is represented in waveform shown in Fig-9

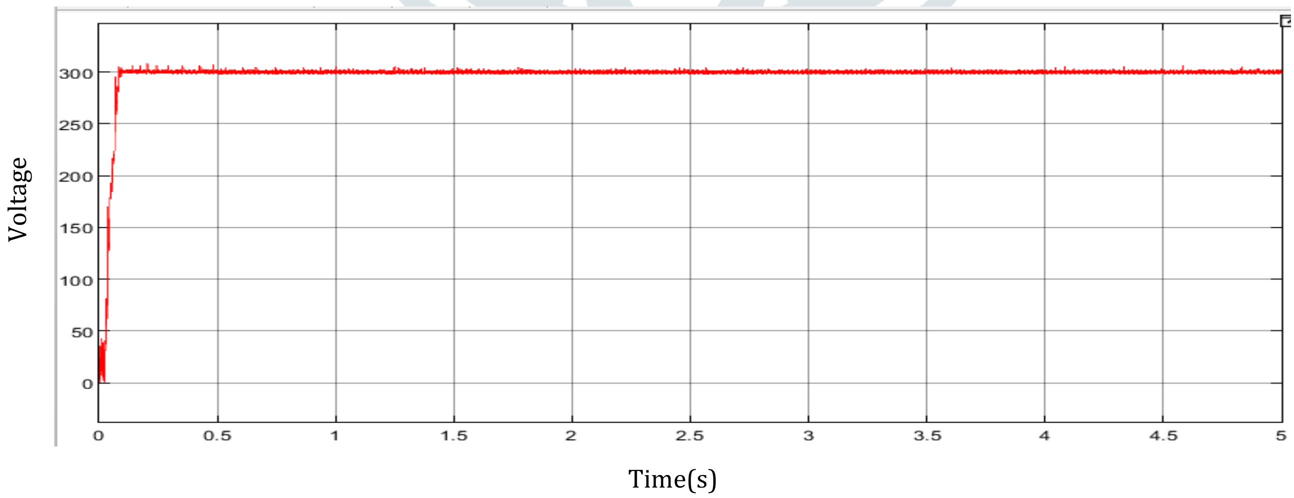

Fig-9 Output voltage across transitional capacitor of Landsman converter

The output voltage of the Flyback converter 65V is shown in the waveform represented in Fig.10.

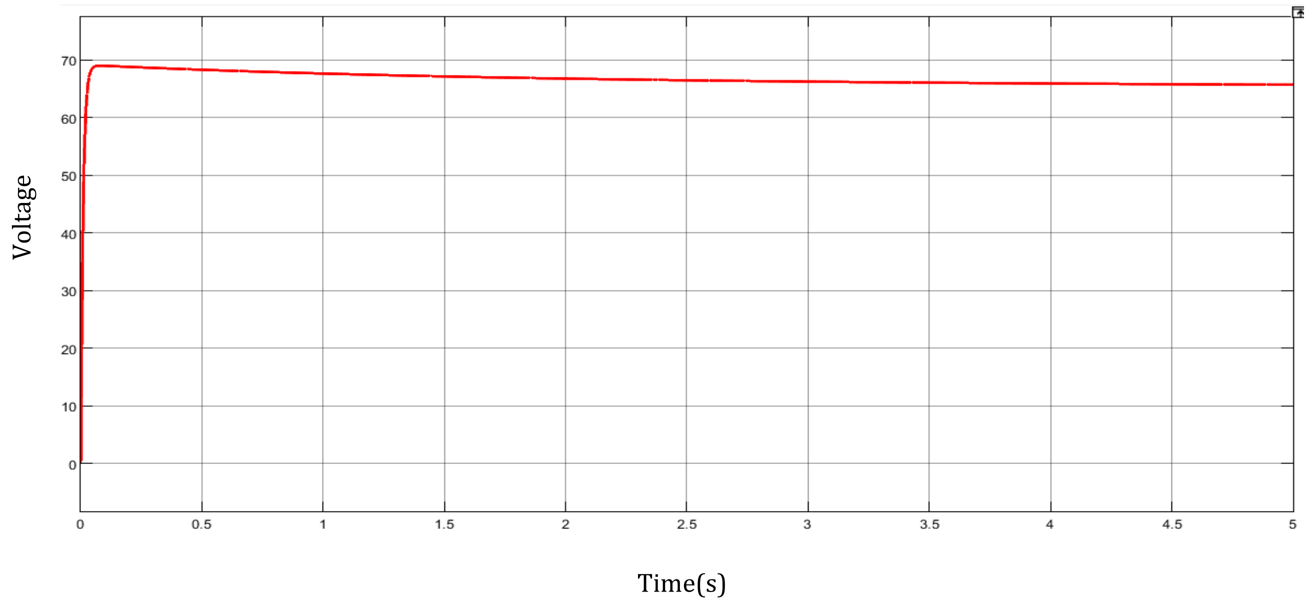

Fig-10: Flyback converter output voltage

The Input voltage and current waveform are sinusoidal and in phase implies the power factor is nearly unity is shown in Fig-11.

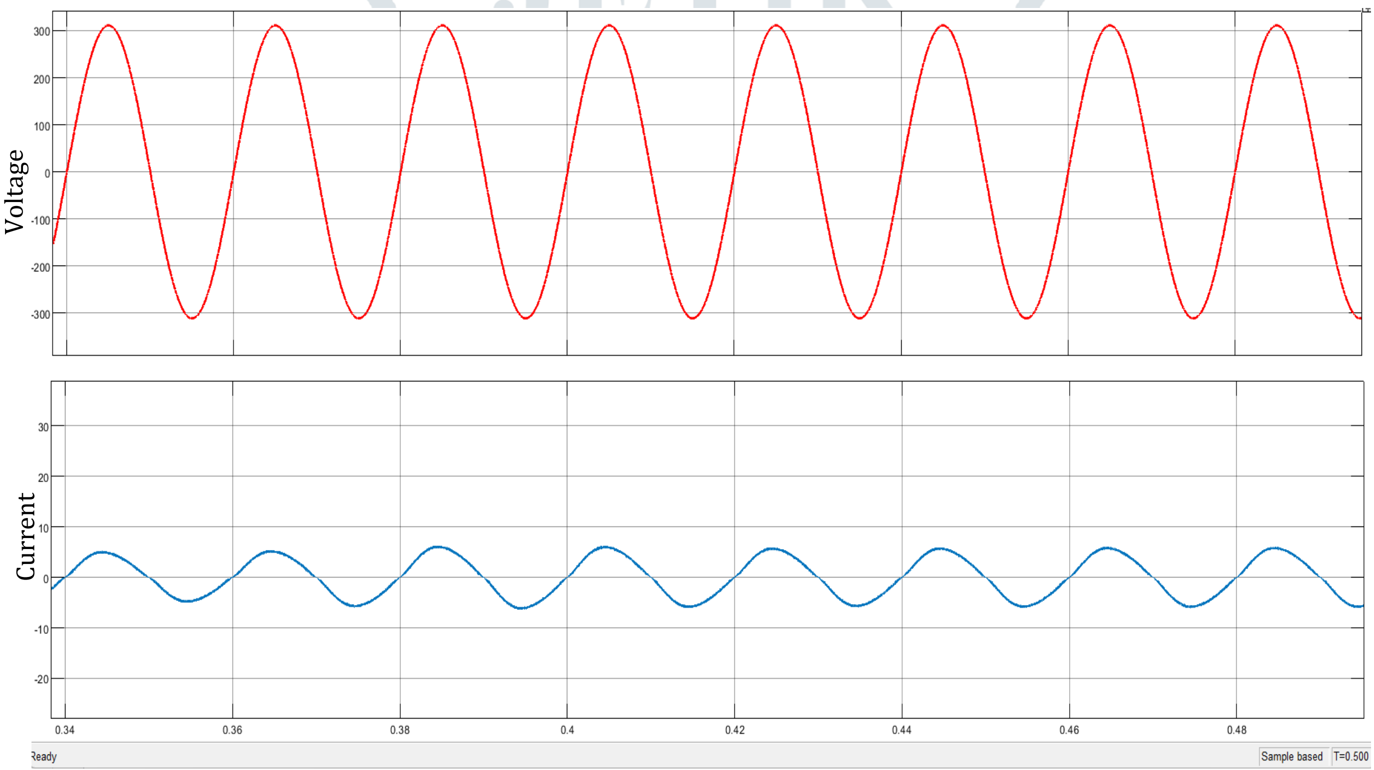

Fig-11: Input voltage and current waveform of Landsman converter

5. CONCLUSION

Landsman converter is mainly used to improve the power factor at the source end is cascaded to flyback converter provides the flexibility of high voltage conversion using high frequency flyback transformer and isolation for the battery charger. Hence this converter has significant advantage over conventional boost dc-to-dc converter in Electric vehicle application. The use of Flyback transformer has multiple function such as isolation and reduction of current ripple thereby passive filter components are reduced also reduces the implementation cost.

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