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Design of BL Luo Converter for EV Charger

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Abstract : The system proposed in this paper is an advanced solution for efficient charging for the batteries of E – Vehicles and provides a better stabilized voltage for the sake of battery lifetime. The technology behind this solution is Luo converter which is a efficient thing to satisfy the solution and for a less complex circuit and provides us, stressless circuit which also efficiently charges the battery. This project is divided into two parts that involved with the hardware and software. The hardware part involves building the Luo converter and the monitoring part where the input and output readings are displayed and the software part involves circuit formation and simulation using MATLAB Simulink software. The prototype of Bridgeless Luo converter for the Electric vehicle Charger has met all the objectives derived and planned. The project is considered successful completion and ready to implement in the real time system implementations.

IndexTerms **- E vehicles, Batteries and charger, Converters, Voltage and Current Stabilizing.**

I. INTRODUCTION

With alarming pollution levels and increasing petrol diesel prices, switching to electric vehicles are no longer option. It is a necessity for India and world. We need clean air and EV is the solution. The US and Europe market has already adopted to very large scale and other countries are moving towards that. And we see a bright future in the EV segment. The present world is currently dominated by the petrol and diesel cars and bikes and we can assuredly prove that the next vehicle we count over tenth would be a Electric vehicle might be a car or bike or a Scooter. The exact point of EV vehicle is, it is pollution free and it requires a charge for a ride. This process is non-critically simple and we can do that in home or any electricity provided environment. Many companies have also took their step into 50+ of branches and production houses. And specification are also seem so close to an commutator segment bikes. The present bike model bikes are pushing their limits up to 90+ kmph and the companies are working hard to break the present torque level of the vehicle. But there is also another query raised within it. That is whether the charger does its work/task perfectly. In that case, the query remained silent and we actually don't know how efficiently charger is charging the Battery in EV. The only concept to be known is that the charger should provide constant voltage while charging. So that the battery life will be saved as a result. And absolutely it should satisfy some factors such as power factor (needs to be at unity), power quality (ability to function with the applied power) and Harmonics level as well. In that case, we are using Luo based converters instead of present converters for a efficient and better charging.

Starting with the converters, a quality or feature regarded as a characteristic or inherent part of charger direction of the power flow (Unidirectional or Bidirectional), the charging process (onboarding or offboarding is chosen. The Unidirectional charging attributes provides a better layoff to the effective charging, it is less complex and financially better deal for the early adopters of Electric vehicle market. It also resolves the factors involved such as power quality will be improved, power factor is also kept under unity. Even though, it has power factor correction in itself, but it runs with many single stage ac to dc converters, even with widespread configurations such as Bridged, Bridgeless and interleaved. With that stage conversion, we can also conclude that the circuit will also enlarge. It might be non – complex, but the circuit is enlarged which is not persuaded for an compact size chargers. The main centred point of this enlarged size and with single stage multi conversions in the circuit will considerably undergoes heavy current stress, higher output ripple current which generates heat at the large sized end capacitors. There is also another solution for this, which would include the many integrated convertors such as boost flyback offer reduced size of converters and less stress because of including the LC circuit (Moreover required especially in the success of Filtering) , but the cost would be even higher than the traditional enlarged size converter. Therefore, the requirement should mediate stress, complexity, power factor correction behaviour for the selection of the Electric vehicle charger. As a result of this attribute satisfaction, we get a charger with high power density and efficient charging rate. So, two stage conversions are evolved for the compensation of issues occurred in the single stage conversion. As a result, less stress over the components (which can be achieved by implementation over the front end of charger) and less amount of conduction components will be an major advantage. Buck converters and Boost converters are used for the front end purposes which deals with the conversions. But a better result can be attained by the buck-boost converters, since the ac – dc and dc – ac conversions are highly effective, and these converters deal with better wave shaping in input and it has been implemented for various applications. Getting on to the single-phase converter, SEPIC and Zeta converters don't give an effective result on the Power Quality characteristics. In case of Cuk converters, it may come over such limitations of the converters above mentioned, but again also has a separate problem which is lower input and higher output ripples.

And thus, we have entered Luo converter which is commonly known as super lift converter. These Luo converters manifest clearly excellent performance for the Power quality and for the transfer gain, which is simple ratio of the output voltage to the input voltage of circuit and also indicates that maximum how much output voltage can produce with respect to a particular input voltage and also for lesser amount of ripple content. It is used in bridged circuit, can also be converted to an bridgeless converter, which reduces the conduction losses and stress over the circuit and it can be further discussed. Therefore, the main motto of this project is to create a converter which provides less ripple content in Bridgeless circuit for the Electric vehicle chargers. Since the input diode bridge is overall neglected and so the conduction of single stage is done over with the help of fewer components and offers many advantages

II. Proposed Configuration And Operation

2.1 Configuration:

The Aspect of Bridgeless Luo converter, is preferred to conduct and work in discontinuous mode in order for the efficient charging and hence the power factor is improved to unity. Also an flyback converter is used to control the battery current, the whole circuit is configured and implemented as an circuit diagram (Figure -1)

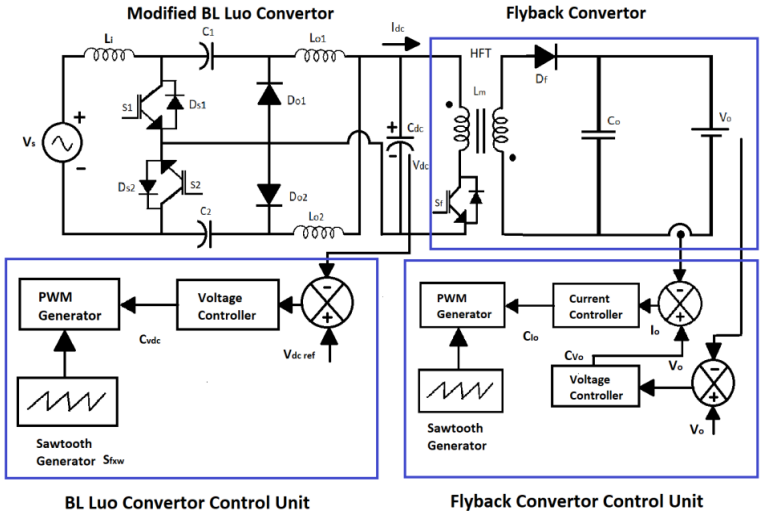


Fig. 1 Configuration Diagram of BL Luo Converter for EV Charger

This configuration consists of an inductor which eliminates the input filter for further switching configurations. The input diodes are eliminated and replaced with IGBT, since we are using for high power applications. And so many components and sensors have been eliminated and therefore current flows through lesser number of components. The gating sequence will be same for both the switching devices, which gives a simplicity in arrangements. As per configuration, the line diodes are neglected and so we get an low level of conduction losses. And improves the efficiency of charging rate With, a cycle of one switching, working and current flow and characteristics of the configured circuit is shown in following content.

2.2 Modes of Operation:

The operation of the configured Bridgeless Luo converter undergoes three functional modes during Positive and negative half cycle each

2.2.1 ***Mode 1(t1-t2)****: Mode 1 starts at extremely short period of time at t1. When the upper most switch s1, which is depicted in the figure – 2 will turn on. This shows the circuit is under conduction mode during the positive half. The whole path of current is depicted in the Figure - 2.*

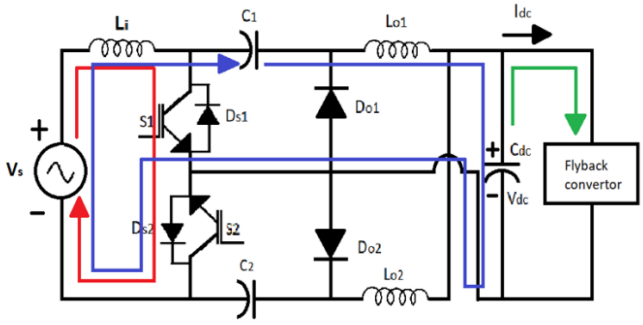


Fig. 2 Mode 1 Positive Half Cycle

2.2.2 ***Mode-2 (t2-t3):*** After the instance time t1 the switch s1 which is turned on will be turned off in this mode 2. And the output diode D01 conducts in forward biased at the same switching time in t2. The capacitor that is configured as shown in the Figure starts charging with the help of input inductor. The capacitor current conduction path is shown in the Figure - 3. This charging of capacitor terminates at the end of starting period of t3 where the whole configuration and the circuit enters into the discontinuous conduction mode

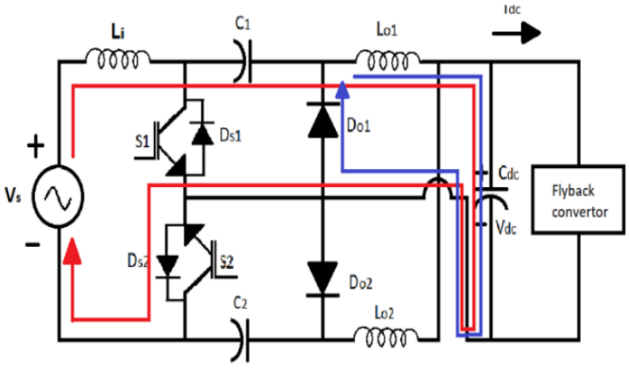


Fig. 3 Mode 2 Positive Half Cycle

2.2.3 ***Mode-3(t2 – t3):*** As shown in the figure the output inductor Lo1 of bridge less convertor, is discharging completely. The convertor thus operating in discontinuous conduction mode during switching interval t3 – t4. The convertor current independently free wheels through the capacitor and the input inductor with the help of body diode Ds1. Link capacitor used in the circuit provides the current to the flyback converter which is depicted in the Figure - 4. The same switching sequence is performed in the negative half cycle and same modes will be undergone to supply required current to the fly back convertor which is clearly shown in the Figure – 5.

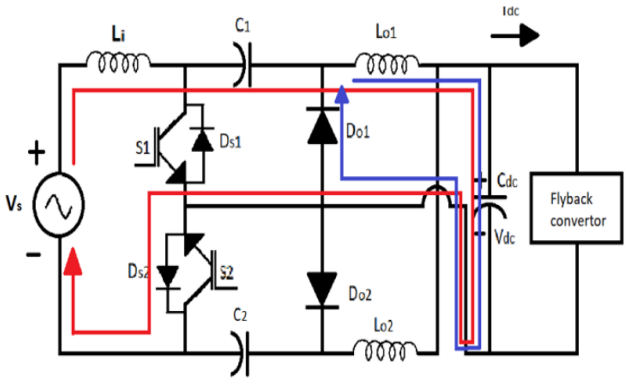


Fig. 4 Mode 3 Positive Half Cycle

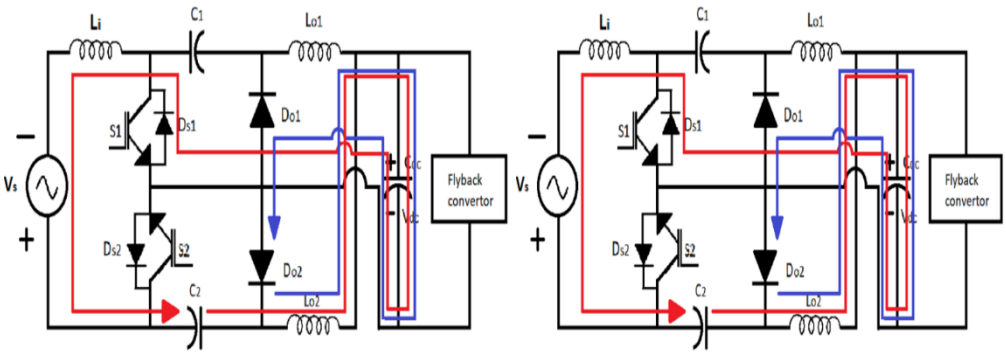


Fig. 5 Modes of operation in Negative Half Cycle(Mode-3 similar to Mode2)

The graphical representation is also included in Figure - 6. From the Figure. we can see the wide range and theorical accuracy in the graph. From the graph, we can find out the values based on the modes of operation which is switching period of transistor. The Graph also shows only the transitions and up downs of the convertor only during the positive half cycle, which also has negative cycle in a vice versa manner. So from the Graph, the parameters such as Inductor current, Capacitor voltage and current, Diode voltage, etc., are marked on the y – axis and the time t, on the x – axis.

So, in Mode – 1, the time period is denoted as (t1-t2). The transistor will be on state and so as per the circuit current flow diagram, the inductor Lo1,2 current will be raised. Capacitor also starts to store the energy, where voltage is raised and it is denoted in the graph. The Diode, Do1,2 are remained in reverse bias, since no current is flow in this mode.

In Mode – 2, the time period is denoted as (t2-t3).

The transistor will be on OFF state and so as per the circuit, the current stored in the Inductor starts to reduce and, the stored energy in the capacitor is full and it is ready to pass out to the circuit. This is the mode, where the diode Do1, will be forward biased and the circuit is levelled to the flyback converter, where circuit also enters into discontinuous conduction mode.

In Mode – 3, the circuit works in discontinuous conduction mode, and so the inductor current is fully emptied. Then again, the circuit run in the same manner in the negative cycle. In this mode of operation, another transistor is made ON, and the process repeats.

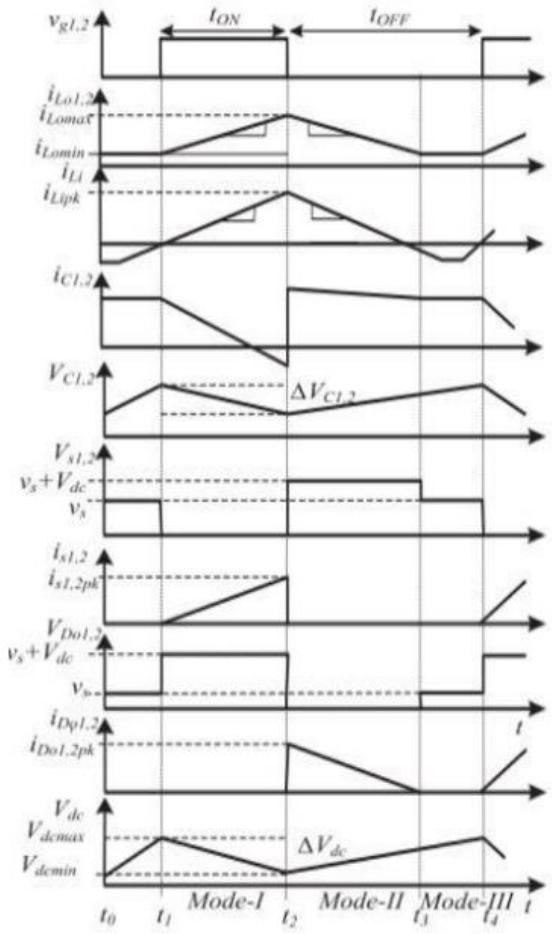


Fig. 6 Positive Half Cycle Timing Diagram

In case of operation and finding characteristics, we can conclude about flyback as, It is basically a dc-to-dc converter which increase or decrease the voltage compared to the input one. The main speciality is it has a transformer which is flyback transformer, so in case of previous converters, there is no electrical isolation provided, but in this case, we have isolation since we transformer. Reason why we use flyback converter is because when there is no primary current flow through the coil, secondary voltage is induced and consequently power will be delivered to the load by the dot conversion used. The following Figure - 7 shows a concept used in flyback converter and the main purpose of choosing the flyback circuit.

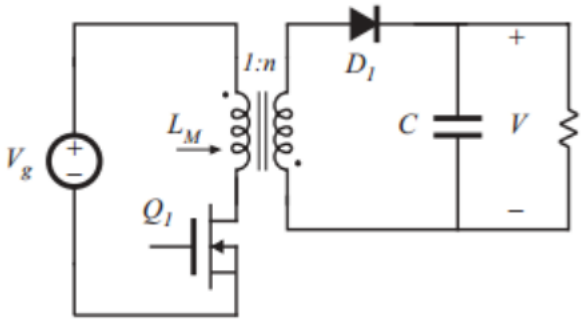


Fig. 7 Flyback Converter

Let us assume that the current will be flowing from Edc to the transformer which has a dot conversion in it. In this case, the transformer is considered by the vision of inductor. So the operation works on three modes basically.

Mode 1 starts with the current flowing from Edc to the Primary side of the circuit, where the switch S is kept closed. The current from primary side of the transformer is passed to the secondary side pointing the dot. But the current will not flow on the rest of the circuit from secondary side, since an diode is included and it is reverse biased where the current is in opposite direction to make the diode ON.

In Mode – 2, the Switch S is turned OFF, so there will be no current flowing in the circuit, and assuming that the front part of circuit has some amount of voltage which is passed to the secondary side. But the specialty of the converter is the current is induced without any voltage at the secondary side. So, the current will also be in direction which makes diode in forward biased

mode. So the current will flow throughout the capacitor and load. The capacitor used is also huge in size and also in parameter, where energy is stored. The transition of the polarity changes within milli or microseconds.

The last stage, Mode – 3, where the Switch is made on again, but the capacitor releases the energy. Since the capacitor is massive, the current flow to the load will be larger and so the output voltage and current would remains constant and this is the reason, we chose this flyback converter.

III. Design And Control Of Luo And Flyback Converter

3.1 Luo Converter

This frontmost part of Luo converter, is designed in a manner so as to maintain link voltage strictly at 485 V. The switching frequency fs of the converter used is of 20KHz. Let us consider as the rated output voltage Vdc and the peak value of input voltage. So,

$$M = Vdc/ (Vi*\sqrt{2}) = 485/325\sqrt{2} = 1.055 \quad (1)$$

Where M= voltage conversion ratio.

For a characteristics to wave shape by itself, the critical value of conduction parameter, Ka,critic, is obtained as

$$Ka \text{ critic} = 1/2(M + n)* 2 = 1/2(0.964 + 1) *2$$
$$=0.11837$$

For bridgeless non-isolated converter, n is considered as unity(1). For the calculation of components to operate in Discontinuous Conduction mode, the value of conduction parameter, Ka is chosen as 0.08.

Therefore, the required duty for link voltage(dc), is calculated as

$$Da = \sqrt{2}*M*Ka = 0.513 \quad (2)$$

The equivalent inductance of this BL Luo converter, with an emulated dc load, Rdc, is estimated as

$$Le = Ka*Rdc/(2*fs)$$
$$= Ka\ (Vdc* 2 /P)/2*(/2 \times 20000)$$
$$= 553.4\ \mu H \quad (3)$$

To operate and continue the same state of a discontinuous operation over wide input voltage, an inductance of 200 µH is considered for this purpose. The input inductor design, Li requires a constant current as both the Power Factor Correction switches share the same inductor in the respective half of the cycle.

Therefore, to provide a same constant current through the input inductor over single cycle, the calculation for the input inductance, is done by

$$Li = Vs* Da /\Delta iLi \times fs$$
$$= 325 \times 0.513/ 0.4 \times (850/311) \times 20000$$
$$= 7.62mH \quad (4)$$

where the highest current ripple is considered as 40% of the peak input current of the circuit. Therefore, the value of input inductance is selected as 4milliHertz to confirm the Current Conduction Mode function.

Further, the estimated value of lowest output inductance Lo1,2 in Discontinuous conduction Mode is obtained as

$$Lo1,2 \leq ((Le*Li)/ (Le – Li))$$
$$= 4 + .2 /4– 0.2mH$$
$$= 0.222mH. \quad (5)$$

Therefore, the value of output inductance is 0.15mH to confirm the power factor correction over the full switching time and for larger range of input voltages.

The capacitor selection, C1,2 is chosen and therefore, the energy transfer capacitor, C1,2 is calculated as

$$C1,2 = 1/\omega r2\ (Li + Lo1,2\ )$$
$$= 1/(2 \times \pi(\text{i.e. } 3.1415)\times 1500)* 2 *(4.15)\ mH$$
$$= 2.71\ \mu F \quad (6)$$

where ωr = resonant frequency of the oscillations in radian per second (2πfr).

Therefore, centre level capacitor is selected as 3 µF so that the voltage remains constant for the whole switching period. The dc-link capacitor Cdc of proposed converter, is made as

$$Cdc = Idc/2*(2\pi fr)\Delta Vdc$$
$$= 2.833/2 \times 314 \times .01 \times 300 = 1.5\ mF \quad (7)$$

So, 2 mF is used as the dc-link capacitor as per calculation.

3.2 Flyback Converter

The purpose of this converter is to provide an open circuit voltage of 65 V across the output end. The estimations are done as per the calculations to operate in discontinuous conduction mode and to maintain a constant voltage and to acquire the output voltage. The turns ratio of transformer to be used in flyback circuit which is (ns/np (n)), which is chosen as 0.333. The main aspect to chose this estimation is to provide the duty cycle.

The varying duty cycle adjusts the output voltage and charges an emptied battery. Hence, duty cycle is calculated as 0.394 for sake of converter to function in Discontinuous conduction mode

IV. Test Results

4.1 Simulation Results

A Modified BL Luo converter is designed and simulated on a MATLAB for EV battery charger. Elimination of line diodes and same inductor during single switching of an half cycle operation of BridgeLess Luo converter, the losses in the converter comes out to be lesser and the voltage applied at input side is 325 volts with a current of 80 amps which is then boosted up to 486 volts. and passed to a high frequency transformer and passing to the flyback converter it is fed as 48 volts constantly to the battery.

Moreover, elimination of input filter, also results in size of the charger as compact with lesser sensors in circuit and also charges the emptied battery in Constant Current and Constant Voltage phase modes.

A Simulation of this improved converter-based battery charger is developed and implemented. The detail discussion on results is given in subsequent sections.

The Figure - 8 represents the input current and input voltage. By referring to the graph, the voltage and current are almost in phase with each other, this proves the power factor of this converter is near to unity. Therefore, the Power Quality (PQ) of this converter is improved.

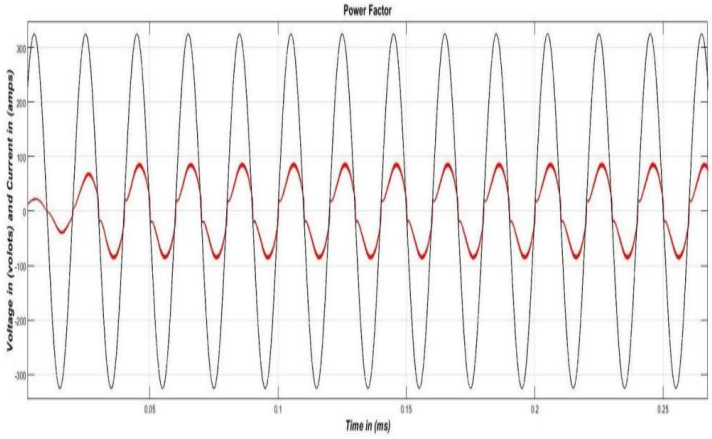


Fig. 8 Input Voltage and Input current

The output voltage of Luo convertor is fed to the flyback converter for output of the charger to charge the battery in Constant Current and Constant Voltage phases of charging and the above Figure - 9
represents the test results of output voltage (Vo).

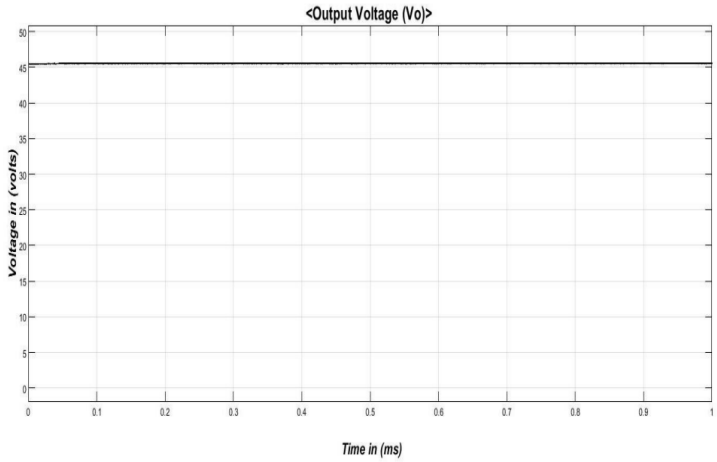


Fig. 9 Output Voltage

Similarly, the Figure - 10 represents the test results of output current (Io). This function is done only with the help of flyback converter as we have discussed before.

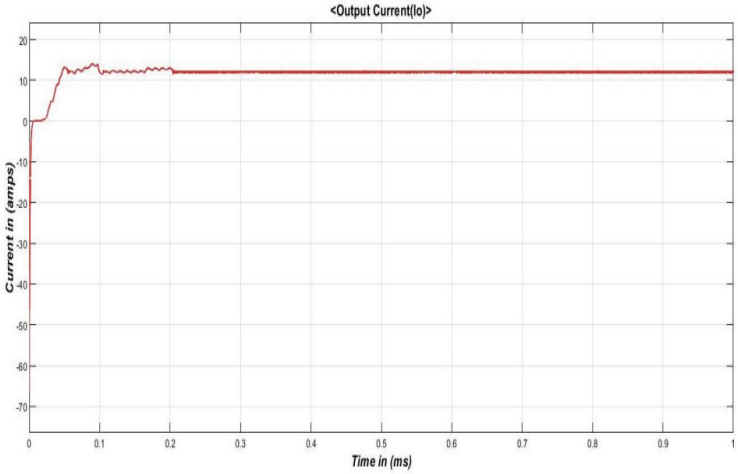


Fig. 10 Output Current

The Figure - 11 shows the output voltage and current of DBR Based Luo converter. By referring Figure - 11, comparing with the DBR system, ripples in output of the proposed system are less. Comparison of Power factor between proposed BL Luo converter with DBR based Luo converter is also shown in Figure - 11. It is represented that the power factor of proposed system is close to unity.

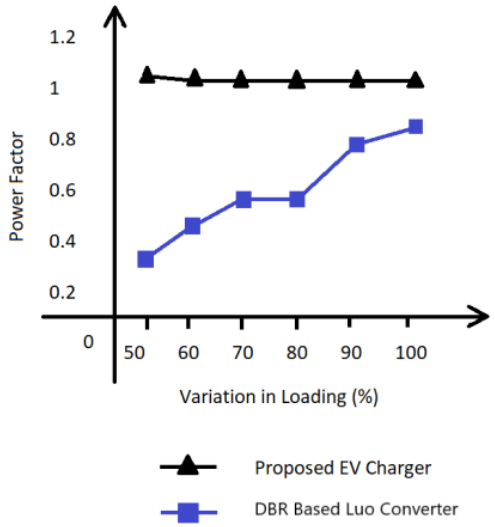


Fig.11 Comparative Power factor analysis of BL Luo PFC converter with existing DBR-based PFC

4.2 Hardware Configuration

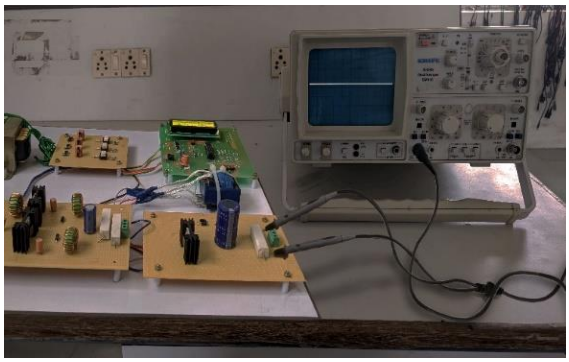


Fig.12 Photography of experimental setup and work bench

The above diagram (Figure – 12) shows the photography of the experimental setup. For our requirement, Cathode Ray Oscilloscope is used and also the circuit is formally divided into 4 groups, where each group has a major part in it such as Flyback part, the board with LED is used for the pulse generation, Luo converter and the Output part.

The pulses are varied and the output is carried out to the Cathode Ray Oscilloscope with the help of connecting probes which is placed in the output part as shown in the Figure – 12.

V. Conclusion and Future Work

Thus, from the above configuration we have created a circuit where a converter efficiently charges the battery of an Electric vehicle. Since we are neglecting the bridge circuit with diodes, the conduction losses are reduced and with a inductor, the losses occurred are lesser than previous diode bridged rectifier and in our circuit it coms out to be 486 volts which is actually stepped up from 325 volts with a current rating of 80 amps. With the help of flyback converter, the amplified input is reduced and fed as 48 volts to the battery. Thus, the Bridgeless Luo converter with flyback converter, assists the charger to charge the emptied battery in constant current (CC) and constant voltage (CV) phase modes of charging.

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