ISSN: 2581-3404 (Online)

International Journal of Innovative Research in Technology and Management, Vol-4, Issue-5, 2020.

Power Factor Improvement in Bridgeless landsman Converter fed EV Battery Charger with DSM-PI Controller

Pushpraj[1], Prof. Santosh Kumar[2]

[1]Research Scholar, Department of Electrical and Electronics Millennium Institute of Technology Bhopal (M.P.)

[2]Assistant Professor Department of Electrical and Electronics Millennium Institute of Technology Bhopal (M.P.)

ABSTRACT

This work deals with the design and implementation of a new charger for battery operated electric vehicle (BEV) with power factor improvement at the frontend. In the proposed configuration, the conventional diode converter at the source end of existing electric vehicle (EV) battery charger is eliminated with modified Landsman power factor correction (PFC) converter. The PFC converter is cascaded to a flyback isolated converter, which yields the EV battery control to charge it, first in constant current mode then switching to constant voltage modeIn the thesis a landman PFC converter is modelled with control on the output voltage through voltage-oriented control. The output form the landsman PFC converter is fed to isolated DC-DC converter for charging the battery. The output voltage of the PFC converter is controlled using PI controller to generate specific required DC voltage given as a reference by the user. The isolated DC-DC converter is controlled by current-oriented control with feedback from the battery terminal voltage and current. Even in the isolated DC-DC converter a PI controller is used to control the charging current of the battery. The PI controller is further replaced with DSM-PI controller for better response and settling of the output voltage of the PFC converter. A comparative analysis of the PFC converter characteristics with PI and DSM-PI controller are modelled in MATLAB Simulink environment.

Key words: Landsman converter, PFC converter, Battery, PI Controller, DSM-PI controller, Pulse Generator, MATAB.

I. INTRODUCTION

1.1 OVERVIEW OF BATTERY CHARGER

The charging protocol (how much voltage or current for how long, and what to do when charging is complete, for instance) depends on the size and type of the battery being charged. Some battery types have high tolerance for overcharging (i.e., continued charging after the battery has been fully charged) and can be recharged by connection to a constant voltage source or a constant current source, depending on battery type. Simple chargers of this type must be manually disconnected at the end of the charge cycle, and some battery types absolutely require, or may use a timer, to cut off charging current at some fixed time, approximately when charging is complete. Other batter types cannot withstand over-charging, being damaged (reduced capacity, reduced lifetime), over heating or even exploding. The charger may have temperature or voltage sensing circuits and a microprocessor controller to safely adjust the charging current and voltage, determine the cut off at the end of charge.

A trickle charger provides a relatively small amount of current, only enough to counteract self-discharge of a battery that is idle for a long time. Some battery types cannot tolerate trickle charging of any kind; attempts to do so may result in damage. Lithium ion battery cells use a chemistry system which does not permit indefinite trickle charging.

Slow battery chargers may take several hours to complete a charge. High-rate chargers may restore most capacity much faster, but high rate chargers can be more than some battery types can tolerate. Such batteries require active monitoring of the battery to protect it from overcharging. Electric vehicles ideally need high-rate chargers. For public access, installation of such chargers and the distribution support for them is an issue in the proposed adoption of electric cars.

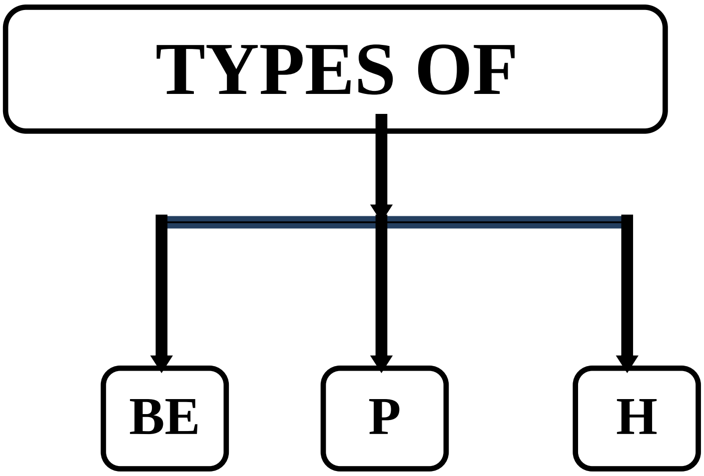
A good battery charger provides the base for batteries that are durable and perform well. In a price-sensitive market, chargers often receive low priority and get the “after-thought” status. Battery and charger must go together like a horse and carriage. Prudent planning gives the power source top priority by placing it at the beginning of the project rather than after the hardware is completed, as is a common practice. Engineers are often unaware of the complexity involving the power source, especially when charging under adverse conditions.

1.1 ELECTRIC VEHICLE BATTERY CHARGER

In recent years the problems of "range anxiety" associated with electric vehicles (EVs) have been alleviated by the introduction hybrids (HEVs) and plug in hybrids (PHEVs) and the development of higher energy density batteries capable of storing more energy in the same space. With the increasing popularity of electric vehicles, "range anxiety" is now being replaced by "charging anxiety". This page addresses the issues associated with providing suitable chargers and the charging infrastructure necessary to support the growing population of EVs.

It takes about three minutes fill up a petrol or diesel engined car at a filling station with enough fuel to travel about 300 miles, costing about $35 in th USA and about £52 ($80) in the UK. To travel 300 miles in a small EV passenger car would need three full charges of a typical 25kWh battery used to power these vehicles costing about $2.50 per charge in the USA with electricity priced at $0.10 per unit (kWh) and £2.50 ($3.90) in the UK with electricity priced at £0.10 per unit. The low energy cost is one of the attractions of owning an EV. Unfortunately to put the 25 kWh of energy needed to travel each 100 miles into the battery in the same time (1 minute) that the equivalent amount of diesel fuel is pumped into the tank would require a power supply capable of delivering a power of 1.5 MegaWatts. To put this into perspective, 25 kWh is the amount of energy an average household consumes in a whole day. Providing electrical distribution facilities to allow users to consume this amount of energy from the electricity grid in one minute is not practical and even if it was, no EV battery could accept energy at this rate. On the other hand neither is it practical to take 24 hours to charge the battery in a passenger electric vehicle.

1.2 TYPES OF ELECTRIC VEHICLE BATTERY CHARGER



There are three main types of electric vehicles (EVs), classed by the degree that electricity is used as their energy source. BEVs, or battery electric vehicles, PHEVs of plug-in hybrid electric vehicles, and HEVs, or hybrid electric vehicles. Only BEVs are capable of charging on a level 3, DC fast charge.

1.1.1.1 1.3 Battery Electric Vehicles (BEV)

Battery Electric Vehicles, also called BEVs, and more frequently called EVs, are fully-electric vehicles with rechargeable batteries and no gasoline engine. Battery electric vehicles store electricity onboard with high-capacity battery packs. Their battery power is used to run the electric motor and all onboard electronics. BEVs do not emit any harmful emissions and hazards caused by traditional gasoline-powered vehicles. BEVs are charged by electricity from an external source. Electric Vehicle (EV) chargers are classified according to the speed with which they recharge an EVs battery.

The classifications are Level 1, Level 2, and Level 3 or DC fast charging. Level 1 EV charging uses a standard household (120v) outlet to plug into the electric vehicle and takes over 8 hours to charge an EV for approximately 75-80 miles. Level one charging is typically done at home or at your workplace. Level 1 chargers have the capability to charge most EVs on the market.

Level 2 charging requires a specialized station which provides power at 240v. Level 2 chargers are typically found at workplaces and public charging stations and will take about 4 hours to charge a battery to 75-80 miles of range.

Level 3 charging, DC fast charging, or simply fast charging is currently the fastest charging solution in the EV market. DC fast chargers are found at dedicated EV charging stations and charge a battery up to 90 miles range in approximately 30 minutes.

II PROBLEM IDENTIFICATION

2.1 Problems Statement

The EVs are powered up by the rechargeable batteries to provide the necessary traction force. These batteries are typically recharged using an AC–DC converter known as an EV charger. The most general architecture of EV battery charger, comprises a boost converter at front-end and an isolated converter at the next stage. The performance characteristic of this kind of charger is exclusively decided by the performance of the DC-DC converter due to regulated output voltage and output current. Several interleaved and zero voltage switching (ZVS) PFC (Power Factor Correction) converter based battery chargers are reported in which reduce the inductor size and output current ripple. However, interleaving the PFC converter comes with the cost of high current stress in switches. The full-bridge topology is the prominent for PFC based EV chargers with the advantages like high power density and high efficiency but the arrangement of four switches, makes the charger control complex An LLC (Inductor–Inductor–Capacitor) resonant converter offers an attractive solution with high efficiency, low EMI (Electromagnetic Interference) noise and a high power density at wide input range However, due to added difficulty in design and analysis process of LLC converter, this type of topology is being substituted by unidirectional or bidirectional AC-DC converters in integrated on-board or off-board configurations .Considering AC-DC conversion as the distinguished feature of EV battery chargers, many DBR (Diode Bridge Rectifier) fed unidirectional isolated single stage or two stage converters without isolation. which battery is used as load to show the power quality performance of conventional DBR fed charger. However, the performance of the conventional charger do not match with the prescribed power quality (PQ)). The presence of full-wave Diode Bridge at the input of the charger generates a large amount of harmonics distortion (55.3%) in the input current drawn during the process of battery charging. This makes the source power factor poor. Moreover, the input current shape is no more sinusoidal, resulting in an increase in displacement between source voltage and current. Therefore, an efficient power factor correction (PFC) technique, which eliminates the adverse effects of input DBR as well, is needed at the front-end of the conventional DBR fed charger.

III PROPOSED METHODOLOGY

3.1 PROPOSED SYSTEM

The proposed modified Landsman converter fed battery charger consists of two stages, a modified

BL converter for improved input wave-shaping and an isolated converter for the charging of EV battery during constant current (CC) constant voltage (CV) conditions.

The operation of the modified converter is selected in DCM or CCM mode based on the application requirement of low cost or low device stress, respectively.BL converter fed EV battery charger with regulated DC link voltage at an intermediate stage. The input side of the proposed charger is fed by a single phase AC source. The input DBR is eliminated by two Landsman converters, which operates in parallel during the positive half line and negative half line, separately. Therefore, the conduction losses are reduced to half due to reduced number of components conducting in one switching cycle. For improved performance based switching, two converters, in synchronization.

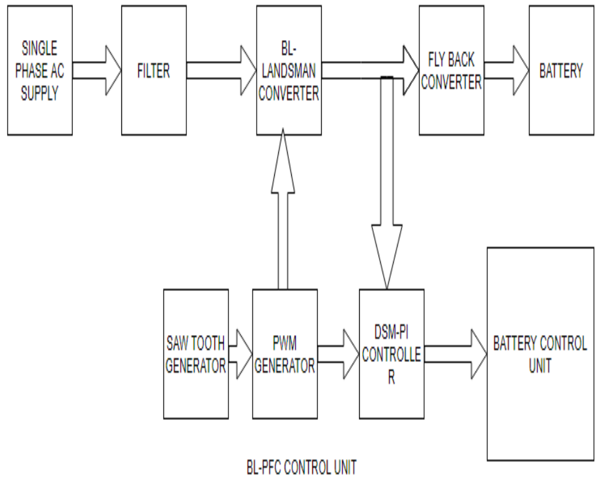


Figure 3.1: Block Diagram of proposed model

3.2 FLYBACK CONVERTER

A flyback converter with an output voltage of 65V is designed to provide the isolation to the battery as well as to control the charging current in two charging modes. The selection of optimum switch rating and the magnetizing inductance L mag, are the significant criteria for the flyback converter. For the required stepping down of the input voltage to 65V, a duty ratio (Dif) of 0.394 is selected to provide the necessary charging voltage to the battery. Therefore, the turns ratio (Nsec/Npri) is calculated

$$V_{dc} = \frac{N_{sec}}{N_{pri}} \frac{D_{if}}{1-D_{if}} V_o$$

$$\frac{N_{sec}}{N_{pri}} = \left(\frac{1-D_{if}}{D_{if}}\right)\frac{V_{dc}}{V_o} = \left(\frac{1-0.394}{0.394}\right)\frac{65}{300} = 0.333$$

During ON time of switch Sf, the current in the magnetizing inductance of the transformer, starts increasing as described in mode-I of the flyback converter operation. The inductor current ILmag f is expressed

$$I_{Lmagf} = \frac{2\times P_i}{V_{dc}\times D_{if}} = \frac{2\times 850}{300\times 0.394} = 14.38A$$

Where, Vdc is the output DC voltage of the PFC bridgeless converter that powers up the flyback converter. ILmag f denotes the current in the primary of the flyback transformer during ON state of switch Sf. Moreover, the size of the transformer is minimized using 50 kHz switching frequency, fsf for flyback converter. The output charging voltage to the battery, corresponding to the full SOC value to near 60% SOC, is provided by wide variation in duty cycle Dif.

3.3. PULSE WIDTH MODULATION (PWM)

Pulse Width Modulation method is a fixed dc input voltage is given to the inverters and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and in this method is known as pulse width modulation (PWM CONTROL)

3.3.1 Advantages of PWM

The output voltage control with method can be obtained without any additional components With this method, lower order harmonic can be eliminated or minimized along with its output voltage control. It reduces the filtering requirements

3.4 SM-PI control:

SM-PI Control Sliding mode control is a nonlinear control having properties of robustness, accuracy and easy implementation. The two main benefits of sliding mode control are i. The dynamic behavior of system can be customized by choosing a specific sliding function. ii. The response of the closed loop becomes completely insensitive to specific uncertainties. This principle holds out to nonlinearity, disturbance and some parameter uncertainties which are bounded. The SMC allows the control of nonlinear processes which are thread to heavy model uncertainties and external disturbances.

Define a sliding surface depicted by

$$\sigma = c\ e_v + \dot{e}_v \qquad (3.1)$$

where $e_v = v_c^* - v_c$, $\dot{e}_v$ is its subsidiary, and c is a positive steady.

To demonstrate the dependability of the proposed SM − PI at the beginning (σ =0), let the Lyapunov competitor be

$$V\ (e_v) = \frac{1}{2} e_v^2 \qquad (3.2)$$

Accordingly, its time subsidiary can be communicated as

$$\dot{V}\ (e_t) = e_v \dot{e}_v = e_v(-c\ e_v) = -c\ e_v^2 < 0. \qquad (3.3)$$

Since steady c is certain, the proposed control is asymptotically steady. In view of these soundness confinements, the controller additions can be dictated by utilizing the accompanying exchanging laws:

$$\widetilde{k_p} = [(1 + \mathrm{sgn}(\sigma))\ k_p^+ - (1 - \mathrm{sgn}(\sigma))\ k_p^-\ ] + k_p^{av} \qquad (3.4)$$

$$\widetilde{k_i} = [(1 + \mathrm{sgn}(\sigma))\ k_i^+ - (1 - \mathrm{sgn}(\sigma))\ k_i^-\ ] + k_i^{av} \qquad (3.5)$$

where k_p^+ , k_p^-, k_i^+, k_i^-, k_p^{av}, and k_i^{av} are sure constants decided as an element of the ideal system execution (these increases can be acquired by utilizing a standard PI structure approach, e.g., root locus). The scientific capacity sgn(σ) restores the qualities 1 for σ> 0 or −1 for σ< 0.

3.5 DSM-PI control:

The hitch in the SM-PI control is that even though the performance is good in transient state, when steady state is reached it has a side effect. Because of sliding mode control switching laws which are used to determine the proportional and integral gains, chattering is originated. In order to mitigate the chattering the gains should be fixed. It is obtained by opting for the transition rule in controller structure.

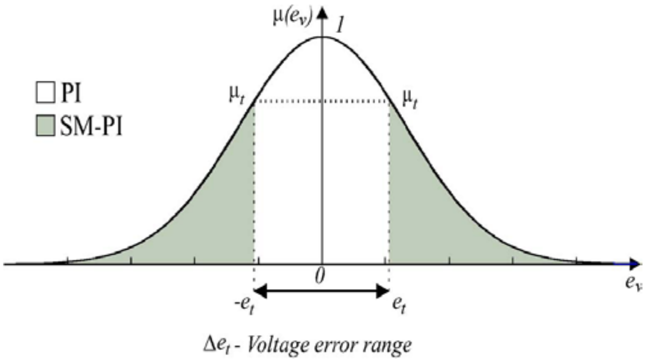


Fig 3.1: Graph of the transition criterion μ.

In the graph threshold value is allied to speed error where the transition occurs. By using equation (4) the value of is constantly calculated for speed error .If the calculated value is less than , the chosen control is SM-PI controller and if it is higher than , controller with fixed gains is opted. The important aspect is the value of . For larger values of the sensitivity of to the speed error is less and for lower values of the sensitivity of to the speed error is high.

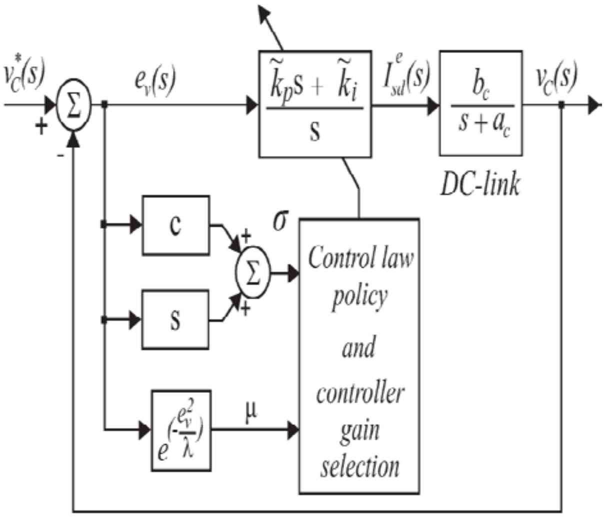


Fig. 3.2: Block diagram of the DSM − PI control scheme.

3.5 comparative analysis between PI and DSM-PI controller

A PI controller has proportional and integral gains fixed at one particular value, which remains constant even for higher value or lower value of error. Whereas in DSM-PI controller the values of gains and are variable w.r.t. the error generated. If the speed error is high, value of gains and are increased and if it's low the gain values are decreased so as to reduce the settling time.

IV.SIMULATON RESULT AND DISCUSSION

The implementation of the proposed algorithm is done over MATLAB (R2016). The signal processing toolbox helps us to use the functions available in MATLAB Library for various methods like Windows, shifting, scaling etc.

4.1 SYSTEM PARAMETER

4.2 simulation model of Bridgeless Landsman Converter Fed EV Battery Charger With PI-Controller

Here show in fig.no. 4.4 PFC test system with PI controller charging the battery with state of charge (SOC 20%). The PFC converter uses voltage oriented control with PI controller which generates duty ratio for the switches Sp and Sn. The switches Sp and Sn operate alternatively with respect to the input voltage. The Sp switch operates during positive cycle and Sn operates during negative cycle of the input voltage. This is controlled by pulse generator with time period 1/50 and time of conduction of 50%.

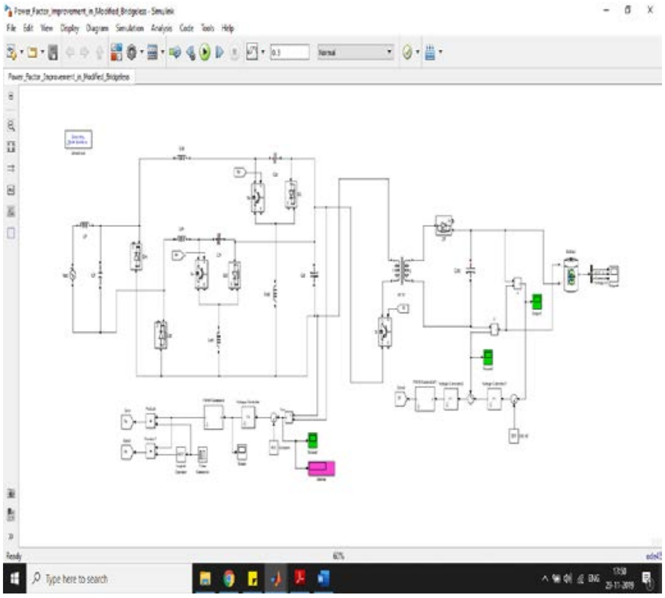


Fig. 4.1: modelling of proposed topology with PI controller.

4.3 simulation model of Bridgeless Landsman Converter Fed EV Battery Charger with DSM-PI-Controller

Power factor improvement in bridgeless landsman converter fed EV Battery charger with using fuzzy logic controller. The proposed model is shown in fig. no.4.2

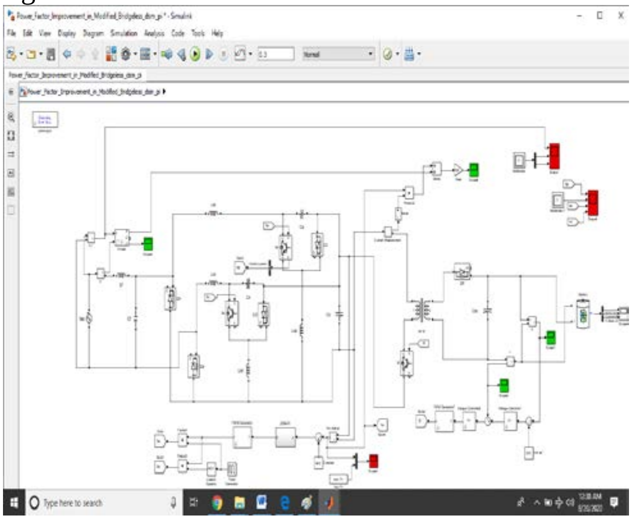


Fig. 4.2: Modelling of proposed topology with DSM-PI controller.

The reference voltage of PFC converter is take as 400V and the reference voltage of the interleaved converter is taken as 300V as the battery used is a 300V battery. The results for the same are observed below.

Case I: Simulation result of Power factor improvement in bridgeless landsman converter fed EV Battery charger with PI controller

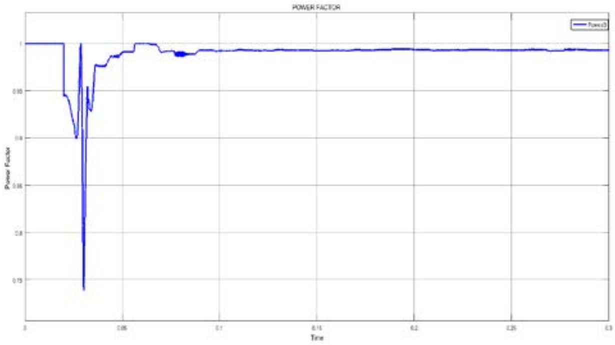


Fig. 4.3: Power factor of source with PI controller.

Case II: Simulation result of Power factor improvement in bridgeless landsman converter fed EV Battery charger with DSM-PI controller

Power factor improvement in bridgeless landsman converter fed EV Battery charger with using DSM-PI controller. The proposed model is shown in fig. no.4.2

The interleaved converter is controlled by a switch Sf which reduces or increases the voltage at the output. The output of the converter is controlled by current oriented control with voltage and current feedback from the output. TheDSM- PI controller generates required duty ratio for the interleaved converter with respect to charging current of the battery.

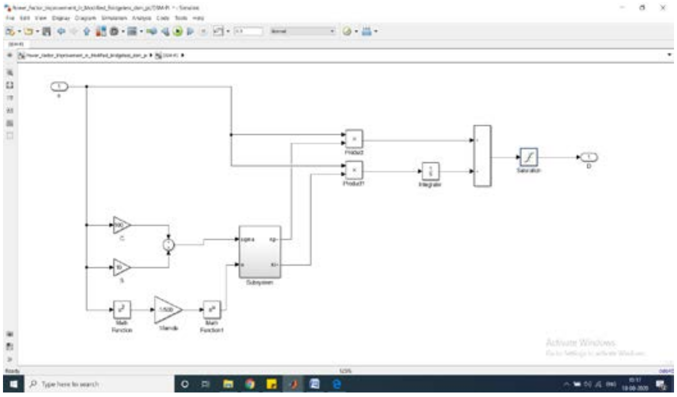


Fig. 4.4: DSM-PI controller

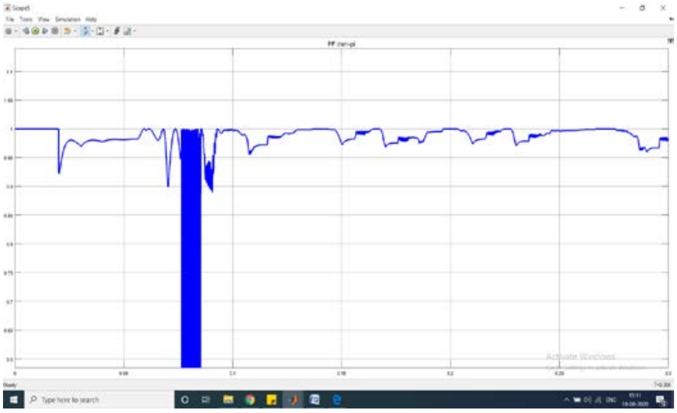


Fig. 4.5: Power factor of source with DSM-PI controller.

The power factor of the source is near to unity with DSM-PI controlled feedback system as compared to PI controller.

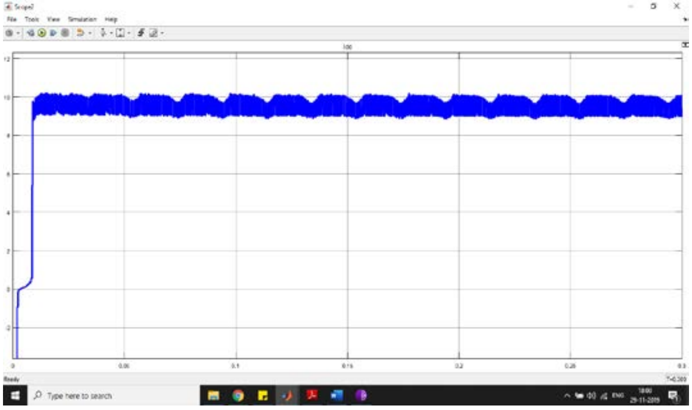


Fig. 4.6: DC-DC Isolated converter current (Idc).

The Isolated converter current is maintained at reference value given by the user with current oriented feedback control system.

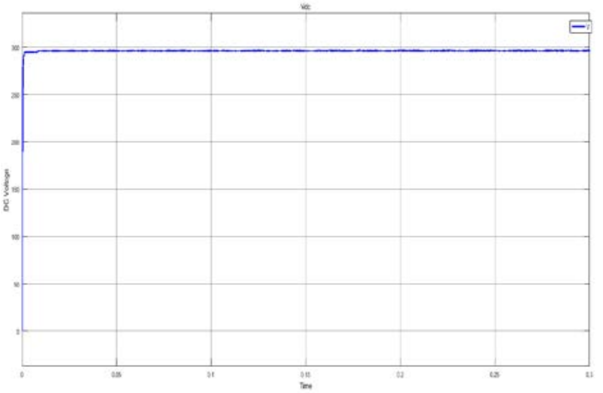


Fig. 4.7: DC-DC isolated converter output voltage (Vdc).

The DC-DC isolated converter output voltage is maintained at 300V at stable condition charging the battery connected to it. it is shown in fig no 4.7.

4.3 Battery characteristics:

If the battery is charging mode then graph of state of charging (%soc) will be increased with respect to time t.and current will go to negative direction. The Voltage is constant maintain at 300V. Which is shown in fig.4.8 of the battery characteristic.

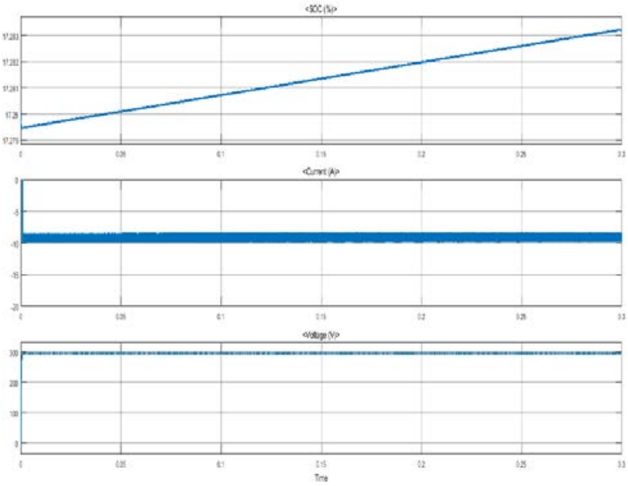


Fig. 4.8: Battery characteristics.

4.4 Comparative analysis between PI and DSM - controller:

The model is updated with DSM-PI controller replacing PI controller and the output voltages of the PFC converter are compared below.

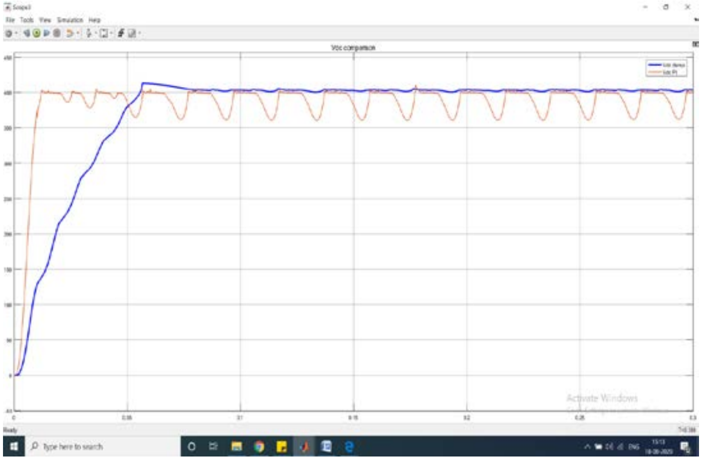


Fig. 4.9: Output voltage comparison of landsman PFC converter with PI and DSM-PI.

As per the graphs generated with respect to time the power factor of the source is more stable at the initial stage with DSM-PI controller as compared to PI controller. The DSM-PI controlled updated in voltage-oriented control of the landsman PFC converter is increasing the stability in input power factor and also the output voltage of the converter. The ripple in the output DC voltage is also suppressed in the updated DSM-PI interface controlling system.

V CONCLUSION AND FUTURE SCOPE

The power factor correction has been effectively implemented using the Bridge less Landsman Converter followed by a fly back converter. In this work to charge an Electrical vehicle battery with inherent power factor correction. The proposed EV charger in discontinuous mode has offered the advantage of reduced number of sensors at the output. Moreover, the proposed BL converter has reduced the input and output current ripples due to inductors both in input and output of the converter. The simulation model is a developed by matlab software. As per the graphs generated with respect to time the power factor of the source is more stable at the initial stage with DSM-PI controller as compared to PI controller. It is show that the performance of proposed charger is found satisfactory for improved power quality based charging of EV battery. The proposed BL converter fed charger aims at cost effective, reliable and suitable option to replace the conventional lossy and inefficient EV battery charger.

The controller can further be updated with adaptive controlling systems or optimization controllers. The PFC landsman converter is also be used for different applications like operating DC machines or AC machines with controllable AC inverter. The future scope for the proposed work is enlisted as follows.

- The efficiency and power level could be increased to provide fast charging to the battery. Variable frequency control and modular construction approaches might aid in the optimization of the efficiency curve.
- The use of soft switching circuits for further reduction in switch voltage and currents tress.
- The input and output ripple could further be reduced using interleaving of the Landsman converter cells.
- The use of wide band gap semiconductor devices (SiC and GaN based devices)leads to better converter efficiency at high power rating owing to reduced voltage drops and switching transition times.
- This work can be extended to control motor drives like BLDC and SRM motor drive for EV propulsion.

REFERENCES:

[1] Julio C. Dias and Telles B. Lazzarin, “A family of voltagemultiplier unidirectional single-phase hybrid boost PFC rectifiers,” IEEE Transactions Industrial Electronics, vol. 65, no. 1, pp. 232241, Jan. 2018.

[2] Alessandro Malschitzky, Felipe Albuquerque, Eloi Agostini and Claudinor B. Nascimento, “Single-stage integrated bridge lessboostnonresonant half-bridge converter for led driver applications,” IEEE Transactions Industrial Electronics, vol. 65, no. 5, pp. 3866-3878, May 2018.

[3] Yeonho Jeong, Jae K. Kim and Gun W. Moon, “A bridgeless dual boost rectifier with soft-switching capability and minimized additional conduction loss,” IEEE Transactions Industrial Electronics, vol. 65, no. 3, pp. 2226-2233, March 2018.

[4] Siddharth Kulasekaran and Raja Ayyanar, “A 500-kHz, 3.3-kW power factor correction circuit with low-loss auxiliary ZVT circuit,” IEEE Transactions Power Electronics, vol. 33, no. 6, pp. 4783-4795, June 2018.

[5] Hao Wu, Grantham K. H. Pang, King L. Choy and Hoi Y. Lam, “An optimization model for electric vehicle battery charging at a battery swapping station,” IEEE Transactions Vehicular Technology, vol. 67, no. 2, pp. 881-895, Feb. 2018.

[6] Muntasir Alam, Wilson Eberle, Deepak S. Gautam and Chris Botting, “A soft-switching bridgeless AC–DC power factor correction converter,” IEEE Transactions Power Electronics, vol. 32, no. 10, pp. 7716-7726, Oct. 2017.

[7] Chuan Shi, Haoyu Wang, SerkanDusmez and AlirezaKhaligh, “A SiC-based high-efficiency isolated onboard PEV charger with ultrawide DC-link voltage range,” IEEE Transactions Industry Applications, vol. 53, no. 1, pp. 501-511, Jan.-Feb. 2017.

[8] Chuan Shi, Yichao Tang and AlirezaKhaligh, “A single-phase integrated onboard battery charger using propulsion system for plug-in electric

vehicles," IEEE Transactions Vehicular Technology, vol. 66, no. 12, pp. 10899-10910, Dec. 2017.

[9] MuntasirAlam, Wilson Eberle, Deepak S. Gautam, Chris Botting, Nicholas Dohmeier and FariborzMusavi, "A hybrid resonant pulse-width modulation bridgeless AC–DC power factor correction converter," IEEE Transactions Industry Applications, vol. 53, no. 2, pp. 1406-1415, March-April 2017.

[10] XinxinZheng, Xintian Liu, Yao He and GuojianZeng, "Active vehicle battery equalization scheme in the condition of constantvoltage/current charging and discharging," IEEE Transactions Vehicular Technology, vol. 66, no. 5, pp. 3714-3723, May 2017.

[11] Anjanee K. Mishra and Bhim Singh, "Control of SRM drive for photovoltaic powered water pumping system," IET Electric Power Applications, vol. 11, no. 6, pp. 1055-1066, 7 2017.

[12] Wencong Su, HabiballahEichi, WenteZeng and Mo-Yuen Chow, "A survey on the electrification of transportation in a smart grid environment," IEEE Transactions Industrial Informatics, vol. 8, no. 1, pp. 1-10, Feb. 2012.

[13] DevendraPatil and VivekAgarwal, "Compact onboardsinglephase EV battery charger with novel low-frequency ripple compensator and optimum filter design," IEEE Transactions Vehicular Technology, vol. 65, no. 4, pp. 1948-1956, April 2016.

[14] Adria Marcos-Pastor, Enric Vidal-Idiarte, Angel Cid-Pastor and L. Martinez-Salamero, "Interleaved digital power factor correction based on the sliding-mode approach," IEEE Transactions Power Electronics, vol. 31, no. 6, pp. 4641-4653, June 2016.

[15] Jae-Hyun Kim, Chong-Eun Kim, Jae-Kuk Kim, Jae-Bum Lee, and Gun-Woo Moon, "Analysis on load-adaptive phase-shift control for high efficiency full-bridge LLC resonant converter under lightload conditions," IEEE Trans. Power Electron., vol. 31, no. 7, pp. 4942–4955, Jul. 2016.

[16] KarimSoltanzadeh, HoseinKhalilian and MajidDehghani, "Analysis, design and implementation of a zero voltage switching two-switch CCM flyback converter," IET Circuits, Devices & Systems, vol. 10, no. 1, pp. 20-28, 2016.

[17] Hye-Jin Kim, Gab-Su Seo, Bo-Hyung Cho, and Hangseok Choi, "A simple average current control with on-time doubler for multiphase CCM PFC converter," IEEE Trans. Power Electron., vol. 30, no. 3, pp. 1683–1693, Mar. 2015.

[18] Khairul S. B. Muhammad and Dylan D. C. Lu, "ZCS bridgeless boost PFC rectifier using only two active switches," IEEE Transactions Industrial Electronics, vol. 62, no. 5, pp. 2795-2806, May 2015.

[19] Ben Zhao, Alexander Abramovitz and KeyueSmedley, "Family of bridgeless buck-boost PFC rectifiers," IEEE Transactions Power Electronics, vol. 30, no. 12, pp. 6524-6527, Dec. 2015.

[20] Ahmed M. Al-Gabri, Abbas A. Fardoun, and Esam H. Ismail, "Bridgeless PFC modified SEPIC rectifier with extended gain for universal input voltage applications," IEEE Transactions Power Electronics, vol. 30, no. 8, pp. 4272–4282, Aug. 2015.

[21] Bhim Singh and VashistBist, "A BL-CSC Converter-Fed BLDC Motor Drive With Power Factor Correction," IEEE Transactions Industrial Electronics, vol. 62, no. 1, pp. 172-183, Jan. 2015

[22] Hong-Tzer Yang, Hsin-Wei Chiang and Chung-Yu Chen, "Implementation of bridgeless cuk power factor corrector with positive output voltage," IEEE Transactions Industry Applications, vol. 51, no. 4, pp. 3325-3333, July-Aug. 2015

[23] MarcinRucinski, PiotrMusznicki and Piotr J. Chrzan, “Electromagnetic interference frequencies prediction model of flyback converter for snubber design,” IET Power Electronics, vol. 8, no. 6, pp. 994-999, 2015.

[24] Junjun Deng, Siqi Li, Sideng Hu, Chunting C. Mi and Ruiqing Ma, “Design methodology of LLC resonant converters for electric vehicle battery chargers,” IEEE Transactions Vehicular Technology, vol. 63, no. 4, pp. 1581-1592, May 2014.

[25] VashistBist and Bhim Singh, “An adjustable-speed PFC bridgeless buck–boost converter-fed BLDC motor drive,” IEEE Transactions Industrial Electronics, vol. 61, no. 6, pp. 2665-2677, June 2014.

[26] Abbas A. Fardoun, Esam H. Ismail, Nasrullah M. Khraim, Ahmad J. Sabzali and Mustafa A. Al-Saffar, “Bridgeless high-powerfactor buck-converter operating in discontinuous capacitor voltage mode,” IEEE Transactions Industry Applications, vol. 50, no. 5, pp. 3457-3467, Sept.-Oct. 2014.

[27] KaushikRajashekara, “Present status and future trends in electric vehicle propulsion technologies,” IEEE J. Emerg. Sel. Topics Power Electronics., vol. 1, no. 1, pp. 3–10, Mar. 2013.

[28] Bhim Singh, Sanjeev Singh, Ambarish Chandra and Kamal AlHaddad, “Comprehensive study of single-phase AC-DC power factor corrected converters with high-frequency isolation,” IEEE Transactions Industrial Informatics, vol. 7, no. 4, pp. 540-556, Nov. 2011.