Performance enhancement of EV charger with Cuk converter and ABC algorithm

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Abstract. In this manuscript, an enhanced performance of Electric Vehicle (EV) charger (battery) by adopting Bridge Less (BL) Cuk converter and Artificial Bee Colony (ABC) algorithm is investigated. Minimum numbers of switches are employed in this proposed methodology to charge the battery with optimum cost. Steady state input voltages and currents are obtained even though the EV charger operates with unbalanced load i.e. operated in underload, nominal load, or overload. It maintains constant battery parameters even under unbalance in input supply also. Robustness is achieved by operating BL-Cuk converter with ABC algorithm even with variation of 50% rise or decay in input voltage. Proposed technique utilizes reduced number of switches, so conduction losses are less and no need of DC link capacitor. Hence, balance voltage appears across the capacitor over the conventional EV charging approaches. Fly back converters are introduced to synchronize the AC supply, Cuk converter and EV charger.

Keywords. EV charger, ABC algorithm, unbalanced load, power quality.

1. Introduction
There is a rapid growth is going on in the transportation sector since a decade to fulfil its needs and battery based Electric Vehicles (EVs) are playing a crucial role [1-5]. EVs are leading over the traditional mechanical-gasoline vehicles because of its numerous advantages [6-10] such as EVs are ecofriendly, savage of fuel, flexibility to employ GPS, GSM or IoT based smart systems to control the speed of the EV with optimum cost.

In Battery Electric Vehicles (BEVs), the utilisation of AC-DC and DC-DC converters are more significant to charge the battery. The efficient operation of EV is always dependents upon battery. EV charger parameters i.e. battery voltage/current must be maintained constant irrespective of its loaded condition and interruptions of input supply. To get steady state EV charger response, operation of power
converters in Continuous-Conduction Mode (CCM) is highly required. This can be achieved by employing proposed ABC algorithm-based BL Cuk converter fed EV.

The design of BEVs have been already presented by various authors by employing different control strategies such as on-board/off-board converter topologies [7], [11-14]. Where in on-board EVs have high power controllability but its cost is more. Off-board based EVs suppress the weight of the vehicle, easy to recharge and efficient. In [12], [15-21] zero voltage switching based power converters are employed to control the EVs, in this operation the ripple content in output waveforms are more around 45% of THD. This ripple harmonic content has been mitigated by adopting interleaved two phase converters [8], in this obtained power density is less. In [10], [5], diode-based bridge converters are considered to charge the battery, but its dynamic response of the system is sluggish. In [17],[11], single stage and two stage series and parallel operated power converters are used to enhance the performance of EV charger, but they operate at low power factor.

To enhance performance of the EV charger, the modelling of uni-directional DC-DC converter is important. These are available in different configurations such as zeta converter [2], SEPIC converter [6], buck-boost [4], and Cuk converters [1]. In these topologies, Cuk converter provides the continuous output voltages and currents. Hence, in this article bridge less Cuk converter is utilised to get better performance of EV charger. It contains less components, cost is less, and improve the power factor and efficiency of the EV charger.

The next sections of this manuscript is summarized as follows, BL Cuk converter and fly back converter fed EV charger configuration is discussed in section 2, proposed ABC control scheme provided in section 3, MATLAB/simulations are illustrated in section 4 and conclusions are given in section 5.

2. System configuration
The Bridge Less (BL)-Cuk converter and fly back converter based EV charger topologies have been discussed in this section. The modelling and mathematical formulation have been adopted from [13].

2.1. BL Cuk Converter
Proposed BL Cuk converter does not have body diodes. Hence, its conduction losses are zero and improvement of efficiency. A same pulse width modulation (PWM) generator block is employed to operate the BL Cuk converter and fly back converter. It is comparing the current PI controller output to a sawtooth wave to produce the pulses.
It is operating in three modes as depicted below.

![Figure 1. Structure of BL Cuk converter based EV charger.](image)

(a) Mode-I
In this mode of operation, switch (S1) is fed with positive half cycle (P1) of AC mains, so switch (S1) is triggered. In this, inductor (L01) is charges up to its peak value i.e. Vs/ Li1. Conduction path is depicted as Vs(+ve)- Li1-S1- Diode (Dp)-Vs(-ve) and represented in Fig. 2. The maximum current across switch (S1) is mathematically expressed as
\[ I_s = \frac{v_0 D T_s}{L_{eq}} \]  

(1)

(b) Mode-II

In this mode of operation, switch (S1) is turned and Diode (D01) starts conducting because inductor releases its storage energy. The conduction path of BL Cuk converter in this mode is depicted as \( V_s(+) - L_1 - D01 - Dp - V_s(-) \) and configuration represented in Fig. 3. The current through inductor is expressed as

\[ \frac{d i_L}{dt} = \frac{V_0}{L_{eq}} \]  

(2)

Where \( V_0 \) is the output voltage appear across Cuk converter. The off-time period is expressed as \( T_{off} \)

\[ T_{off} = \frac{V_s T_{on}}{V_0} \]  

(3)

(c) Mode-III

This mode is configured the Dis-Continuous Mode (DCM) operation of the BL Cuk converter. In this mode, current stored in inductor in mode-I is same as current released by the inductor in mode-II, hence no current flows in the inductor in this time period. Inductor current zero causes the output voltage across output diode (D01) is zero. The operation of BL-Cuk converter in DCM mode is configured in Fig. 4. Inductor needs current settings to conduct from mode-III to mode-I and switch (S1) is to be triggered.
2.2. Fly back converter

To synchronize the BL Cuk converter and EV charger, fly back converter plays a vital role [3],[14]. To match input and output quantities, fly back converters composed of a linear transformer (LT). Based on BL Cuk converter operation, fly back converter operates in three modes.

In mode-I, S1 is turn-on and magnetising inductor \( L_{mf} \) is charged to its peak value. The magnitude of current in switch \( S_f \) is expressed as

\[
I_{sf} = \frac{V_0}{L_f} (t_1 - t_2) + I_{L_f}(0) \tag{4}
\]

The maximum current across switch \( S_f \) is

\[
I_{sfm} = \frac{V_0D}{L_{ffs}} + I_{L_f}(0) \tag{5}
\]

where \( f_s \) is the switching frequency \( f_s = 1/T_s \)

In mode-II, S1 is turn-off and inductor \( L_{mf} \) discharge and releases the energy. The current through switch \( S_f \) is zero [15],[16]. So, it acts as open circuit, which means switch \( S_f \) is turned off. In this operation

\[
I_{sf} = 0 \tag{6}
\]

The current through inductor \( L_{mf} \) is expressed as

\[
I_{Lmf} = \frac{V_{batt}}{L_f} (t_3 - t_2) + I_{sf} = \frac{V_0}{L_f} (t_1 - t_2) + I_{L_f}(0) \tag{7}
\]

where \( V_{batt} \) is output voltage of the charger.

In mode-III, it is DCM mode operation switch \( S_f \) is still in off position and there is no release energy from inductor \( L_{mf} \) so output current is zero.

\[
I_{sf} = I_0 = 0 \tag{8}
\]

In this mode, battery does not charge, battery always charge in CCM mode of operation only.

3. Design of proposed CUK converter and ABC algorithm

In modern electrical industries almost 90-95% industries are involved with PI controllers to operate power converter switches in an efficient manner. It is a challenge to all the engineers to extract PI parameters exactly and to improve the dynamic performance. In conventional control methods such as Genetic Algorithm (GA), Relative GA (RGA), Particle Swarm Optimization (PSO), etc., an error is considered as an objective function in terms of PI controller values. The PI controller parameters are then computed such that the objective function is minimized. These approaches provide best tracking response but speed of recovery response with any disturbances is low. Such limitations may be overcome by expert control algorithms [22-27].

ABC algorithm is a hybrid expert-based control approach: this approach enhances the closed loop performance. This is done by adopting an intelligent system to track optimum PI values; it prohibits good supervisory control regulatory response, disturbance rejection and robust performance of the system [28-31].

In this ABC control approach, to calculate PI gain parameters, artificial honey bees considered are employee bee, onlooker bee and scout bee. In this, error is predicted/estimated in very advance and PI gain values are varied. The dynamic error of the network is taken as function of food source and
fitness of the bees is the solution to the source. This algorithm needs a data of initialization of number of parameters, maximum/minimum number of cycles and colony dimensions. Initialization of high population size is better to track optimum PI values. Fitness parameters are varied based on the error. It is expressed as

$$ \text{Fitness} = \sum_{k=0}^{n} e^2(t) $$  \hspace{1cm} (9)

Where \( e(t) \) is the dynamic error of the system, the proposed ABC algorithm flowchart is shown in Fig. 5.

![Proposed ABC flowchart](image)

**Figure 5.** Proposed ABC flowchart.

4. **Simulation Results and Analysis**

The Simulink model of BL Cuk converter EV charger is shown in Fig. 6.

![Simulink model of EV charger](image)

**Figure 6.** Simulink model of EV charger.
4.1. Performance of EV charger with balanced input

The enhanced performance parameters such as supply voltage ($V_s$), current ($I_s$) and battery voltage ($V_{bat}$) and current ($I_{bat}$) is shown in Fig. 7. These output results are obtained, if the BL Cuk converter is operated under steady state Continuous Conduction Mode (CCM). Observe that the battery is constant charging at around 45V and 8 A.

![Figure 7. EV Charger supply and battery parameters.](image)

The constant voltage of 277.5 V appears across at DC link and is shown in Fig. 8. Voltage is regulated as a constant and corrected power factor hence enhanced performance of EV charger with proposed ABC control technique.

![Figure 8. Voltage at DC Link.](image)

The switching quantities, switching voltages ($V_{s1}$, $V_{s2}$), currents ($I_{s1}$, $I_{s2}$) are described in Fig. 9. There is negative drop in voltage and current waveforms so there is no conduction loss in the proposed network.

![Figure 9. output waveforms of switching parameters at different zero crossing.](image)

The current in inductor at different zero crossing i.e. 24A is shown in Fig. 10. From the waveform, it is evident that there is no production of circulating currents in the proposed BL Cuk converter topology.
The output voltages of capacitors $V_{c1}$, $V_{c2}$ and currents across inductors $I_{L1}$ and $I_{L2}$ at different zero cross switching is shown in Fig. 11. It is shown that there is no return in inductor to negative cycle means corrects the PF.

4.2. Performance of EV charger with unbalanced input
In this condition a wide range of unbalanced line voltage is fed to the EV charger. This condition is examined for two scenarios. In first scenario, rise in line voltage transient is created in at t=0.4 sec, initially supply voltage is 110V at t = 0s to t = 0.4s, at t = 0.4s rapidly the line voltage is increased to 220 V then the corresponding supply current is varied that is shown in Fig. 12. Even also there is no alteration, fluctuations in battery voltage and battery currents are shown in Fig. 13 and Fig. 14. Proposed ABC control technique produces robustness and tracks the battery voltage and current is constant.
In the next scenario, dip in line voltage is created at t=0.4 sec, initially consider the supply voltage is 220V at t=0s to 0.4s, at t=0.4s suddenly the voltage is suppressed to 110 V then corresponding supply current is reduced that is shown in Fig. 15. Even though there is no alteration, fluctuations in battery voltage and battery currents are shown in Fig. 16 and Fig. 17. Proposed ABC control technique prohibits the robustness to track the battery voltage and current is constant.

From the above discussion it is summarized as even a wide variation in supply parameter due to any abnormal conditions there is no variation in battery charging quantities. The proposed ABC control technique-based BL Cuk converter enhances the PQ.

4.3. Performance of EV charger with variable loads
The load variation on EV charger how the supply quantities are suffered to reach the load demand is presented here. In this, load variation on EV is composed as underload, nominal load, and overload.

(a) Underload
In this, load is suddenly removed on the EV the output voltage and current are varied that is shown in Fig.18. As decay in load the input current offers from supply terminals are suppressed as shown in
Fig. 18. From the waveforms it is observed that supply voltage is mismatch with the supply current, so it leads to poor PF, voltage regulation and sluggish the overall performance of the system.

**Figure 18. Variation of input Voltage and current in underload.**

The non-sinusoidal harmonic current and voltages are created at source side. Its harmonic content (THD) is obtained as 4.06% is shown in THD plot in Fig.19.

**Figure 19. THD plot.**

(b) **Nominal load**

In this, rated voltage is applied on the EV so there is no variation in input voltage and currents in the source side. It improves the PF of the system and overall dynamic response of the system. The variation of input parameters at nominal load is shown in Fig. 20.

**Figure 20. Variation of input Voltage and current in under load.**
By operating EV at rated load obtained almost sinusoidal voltages and currents at source side is almost steady state. Its harmonic content (THD) is obtained as 2.33\% is shown in THD plot in Fig. 21.

(c) Overload
In this load is suddenly inserted on EV the output voltages and current variation is shown in Fig. 22. As increment in the load, input current from main terminals increases that is shown in Fig. 22. From the waveforms it is observed that supply voltage is mismatch with the supply current, so it leads to poor PF, voltage regulation and sluggish the overall performance of the system.

The non-sinusoidal harmonic current and voltages are created at source side. Its harmonic content (THD) is obtained as 3.70\% is shown in THD plot in Fig. 23.

The summary is EV is operates at under load, overload or at rated load almost constant performance of EV charging is obtained. At nominal load, obtained less THD value compared to underload and overload scenarios.
5. Conclusion
Enhance PQ of EV charger with BL Cuk converter and ABC algorithm is discussed in this article. Obtained simulation results for different conditions of EV charger such as performance of EV charger with balanced input, performance of EV charger with unbalanced input, performance of EV charger with unbalanced load i.e. under load, rated load and overload and proven in each condition EV charger parameters provides steady state output. EV charger is examined for variation in source side quantities or variation on load side parameters above or below 50% obtained constant battery parameters and enhance the PQ. Improved PF and robustness also achieved in output waveforms with proposed ABC based BL Cuk converter fed EV charger.

6. References
[1] Fardoun A A, Ismail E H, Sabzali A J and Al-Saffar M A 2012 New efficient bridgeless Cuk rectifiers for PFC applications IEEE Transactions on Power Electronics 27(7) 3292–3301
[2] Jha A and Singh B 2017 Bridgeless zeta PFC converter for low voltage high current LED driver International Conference on Computer Applications in Electrical Engineering Recent Advances (CERA) 539–544
[3] Sudhakar AVV, Rajababu D and Sathyavani B 2019 Analysis of the power losses in both DC side and AC side cascaded converters International Journal of Recent Technology and Engineering 8(1C2) 897-899
[4] Zhao B, Abramovitz A and Smedley K 2015 Family of bridgeless buckboost PFC rectifiers IEEE Transactions on Power Electronics 30(12) 6524–6527
[5] Li C and Xu D 2017 Family of enhanced ZCS single-stage single-phase isolated AC–DC converter for high-power high-voltage DC supply IEEE Transactions on Industrial Electronics 64(5) 3629–3639
[6] Simonetti DSL, Sebastian J, dos Reis F S and Uceda J 1992 Design criteria for SEPIC and Cuk converters as power factor preregulators in discontinuous conduction mode Proceedings of the 1992 International Conference on Industrial Electronics, Control, Instrumentation, and Automation I 283–288
[7] Musavi F, Edington M, Eberle W and Dunford W G 2012 Evaluation and efficiency comparison of frontend AC-DC plug-in hybrid charger topologies IEEE Transactions on Smart Grid 3(1) 413–421
[8] Choi H 2013 Interleaved boundary conduction mode (BCM) buck power factor correction (PFC) converter IEEE Transactions on Power Electronics 28(6) 2629–2634
[9] Kuperman U, Goren J, Zafransky A and Savernin A 2013 Battery charger for electric vehicle traction battery switch station IEEE Transactions on Industrial Electronics 60(12) 5391–5399
[10] Limits for harmonics current emissions (Equipment current ≤ 16Aper Phase). International standards IEC 61000-3-2, 2000
[11] Petersen L and Andersen M 2002 Two-stage power factor corrected power supplies: The low component-stress approach IEEE Applied Power Electronics Conference and Exposition 2 1195-1201
[12] Yilmaz M and Krein P T 2013 Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles IEEE Transactions on Power Electronics 28(5) 2151–2169
[13] Radha Kushwaha, and Bhim Singh A 2019 Power quality improved EV charger with bridgeless Cuk converter IEEE Transactions on Industry Applications 55(5) 5190-5203
[14] Rajababu D and Raghu Ram K 2019 Load current observer and adaptive voltage controller for standalone wind energy system with linear and non-linear loads International Journal of Engineering and Advanced Technology 9(1) 5491-5496
[15] Rajababu D and Raghu Ram K 2019 Voltage control of isolated wind energy conversion system using adaptive voltage controller for non-linear loads International Journal of Recent Technology and Engineering 8(3) 3214-3219
[16] Rajababu D and Raghu Ram K 2019 Voltage control strategy for three-phase inverter connected standalone wind energy conversion systems *International Journal of Innovative Technology and Exploring Engineering* **8**(11) 2164–2168

[17] Chen S, Li Z R and Chen C 2012 Analysis and design of single-stage AC/DC LLC resonant converter *IEEE Transactions on Industrial Electronics* **59**(3) 1538–1544

[18] Li S G, Sharkh S M, Walsh F C and Zhang C N 2011 Energy and battery management of a plug-in series hybrid electric vehicle using fuzzy logic *IEEE Transactions on Vehicle Technology* **60**(8) 3571–3585

[19] Williamson S S, Rathore A K and Musavi F 2015 Industrial electronics for electric transportation: Current state-of-the-art and future challenges *IEEE Transactions on Industrial Electronics* **62**(5) 3021–3032

[20] Hsieh Y, Hsueh T and Yen H 2009 An interleaved boost converter with zero-voltage transition *IEEE Transactions on Power Electronics* **24**(4) 973–978

[21] Rajababu D, Sudhakar A V V and Sathyavani B 2019 Development of technology for high-power industry converters *International Journal of Innovative Technology and Exploring Engineering* **8**(10) 3130–3132

[22] Vedik B, Shiva C K and Harish P 2020 Reverse harmonic load flow analysis using an evolutionary technique *SN Appl. Sci.* **2**, 1584 https://doi.org/10.1007/s42452-020-03408-4

[23] Vedik B, Ritesh K, Deshmukh R and Shiva C K 2020 Renewable energy based load frequency stabilization of interconnected power systems using quasi-oppositional dragonfly algorithm *J Control Autom Electr Syst.* https://doi.org/10.1007/s40313-020-00643-3

[24] Vedik B, Naveen P and Shiva C K 2020 A novel disruption based symbiotic organisms search to solve economic dispatch *Evol. Intel.* https://doi.org/10.1007/s12065-020-00506-5

[25] Kumar R, Sahu B, Shiva C K and Rajender B 2020 A control topology for frequency regulation capability in a grid integrated PV system *Archives of Electrical Engineering* **69**(2) 389–401

[26] Basetti V, Chandel A K and Subramanyam K B 2018 Power system static state estimation using JADE-adaptive differential evolution technique *Soft Computing* **22**(21) 7157-76 https://doi.org/10.1007/s00500-017-2715-3

[27] Shiva C K, Vedik B and Kumar R 2019 Integration of distributed power sources to hydro-hydro power system subjected to load frequency stabilization *International Journal of Engineering and Advanced Technology* **8**(2) 128–32

[28] Rajasri I, Gupta AVSSKS and Rao YVD 2016 Generation of Egt5: Hamming number approach *Procedia Engineering* **144** 537-542 10.1016/j.proeng.2016.05.039

[29] Rajasri I, Gupta AVSSKS and Rao YVD 2014 Symmetry and its effects on structures of planetary gear trains *Journal of The Institution of Engineers (India): Series C* **95**(1) 77-81 10.1007/s40032-014-0101-9

[30] Rajasri I, Gupta AVSSKS and Rao YVD 2012 Structural aspect of symmetry and its effect on generation of planetary gear trains *Applied Mechanics and Materials* **110** 2619-2622 10.4028/www.scientific.net/AMM.110-116.2619

[31] Ch Vinay Kumar Reddy, Rajasri I and V Mahesh 2020 Comparison between hamming method and modified path matrix approach to identify isomorphism in PGTs *Materialstoday: Proceedings* https://doi.org/10.1016/j.matpr.2020.06.158