IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 1, Jan 2022

Optimal Intertwine Transformer-based CLLC Resonant Circuit for Electric Vehicles On-Board Charging Applications

Vipul Gupta[1*], Dr. Bhoopendra Singh[2] and Dr. Sachin Tiwari[3]

[1]Research Scholar, Department of Electrical and Electronics Engineering
University Institute of Technology RGPV, Bhopal, Madhya Pradesh 462033, India.
[2]Associate Professor, Department of Electrical and Electronics Engineering
University Institute of Technology RGPV, Bhopal, Madhya Pradesh 462033, India.
[3]Professor, Department of Electrical and Electronics Engineering
Lakshmi Narain College of Technology Excellence (LNCTE), Bhopal, Madhya Pradesh 462021, India.
[*]Corresponding Author Email: vipulguptaap@gmail.com

Abstract

The proposed approach integrates an optimized transformer in an LLC resonant circuit for onboard charging in electric or hybrid electric vehicles (EVs or HEVs). The transformer is designed using an advanced optimization method, Horse Herd Optimization Algorithm (HOA), to minimize core loss, winding loss, and overall cost. A 3D model of the transformer is created and its performance is validated using MATLAB and ANSYS software. The proposed model achieves high power quality, low temperature, and low manufacturing cost. It outperforms other existing algorithms in terms of core loss and cost. The proposed model is well-suited for onboard charging applications in EVs or HEVs.

Keywords: *Onboard charger; CLLC resonant circuit; integrated transformer; core loss; horse herd optimization.*

1. INTRODUCTION

Electric vehicles (EVs) are gaining popularity due to rising oil prices and concerns about oil supplies. Onboard chargers are being explored as a way to enhance EV acceptance, especially for lightweight urban EVs. Phase-Shifted Full-Bridge (PSFB) and LLC resonant converters are commonly used in onboard charging systems. While PSFB converters offer wide voltage adjustment, LLC resonant converters have advantages in achieving higher performance. However, there are challenges and drawbacks associated with both types. The manuscript is organized into sections discussing related work, the proposed transformer modeling, results and comparison, and overall conclusions.

2. RELATED WORK

The literature review highlights various approaches aimed at improving power quality and enhancing the on-board charging capabilities of electric vehicles (EVs). Jothimani et al. [11] proposed a power factor correction modifier based on the Interleaved Negative Output Elementary Luo converter to ensure stable operation under load power variations. Taghizadeh et al. [12] presented an integrated control system for a multipurpose EV charger, addressing challenges such as charging/discharging, voltage regulation, and harmonic reduction. Zou et al. [13] developed a single-phase on-board charger that recycles traction inverter and motor, enabling increased voltage charging. Dao et al. [14] proposed a hybrid LLC resonator converter with three working modes to enhance performance under different load conditions. To address these drawbacks, a novel on-board charging method for EV applications will be introduced in the subsequent section.

2.1. Proposed model for improving PQ in EV's on-board charging application

The integrated dual-output DC/DC converter is commonly used for onboard charging in electric vehicles. To improve power quality and overcome drawbacks like high peak current, the proposed model introduces an integrated transformer topology that intertwines the LLC resonant converter.

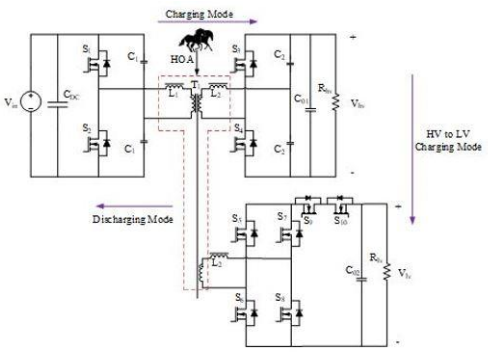


Fig.1 Schematic diagram of the proposed model

2.2. Vehicle to grid operation

Figure 2 depicts the circuit topology of a CLLC resonant converter during the charging period.

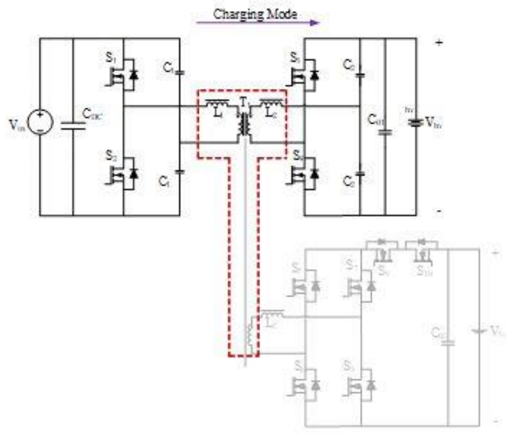
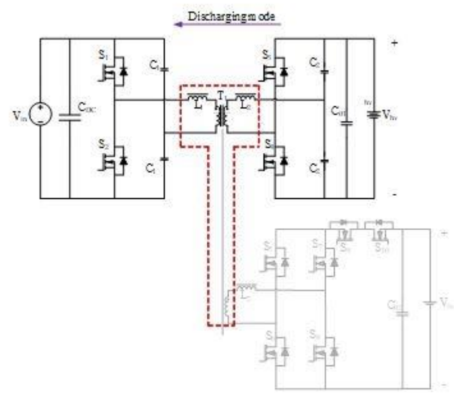


Fig. 2 During G2V charging, the circuit architecture of a half-bridge CLLLC resonant converter

During this time, synchronous rectification upon that tertiary side is unplugged, and switches (S_9 and S_{10}) on the LV side are switched off. The power transmission occurs from the input voltage (V_{in}) to the primary side of the transformer via switches S_1 and S_2.

2.2.1. G2V operation

For V2G operation, the full-bridge rectifier upon that tertiary side is still shut by switching off S_9 and S_{10}. The half-bridge CLLLC resonant converter, as seen in Fig. 3, which works in the opposite direction.



IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 1, Jan 2022

Fig. 3 The half-bridge CLLLC resonant converter's circuit architecture for V2G operation

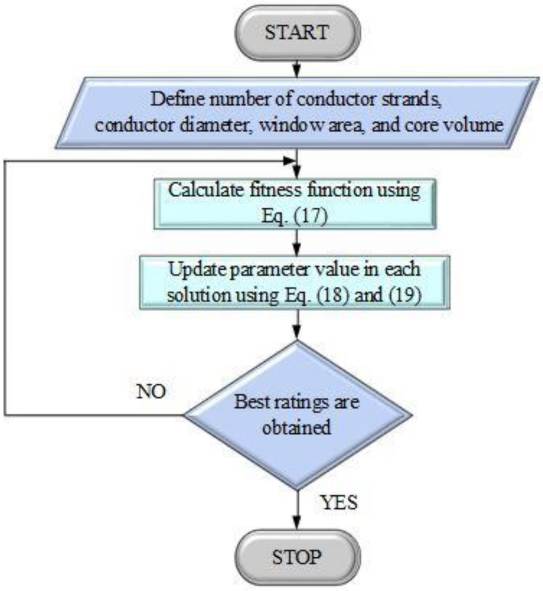


Fig.4 Flow chart of the proposed method for parameter selection

3. RESULT AND DISCUSSION

Table 1 summarizes the optimal ranges of transformer modelling variables.

Table 1. Comparison of optimal value

Variables	Proposed HOA	MA	ALO
Window Area	10.04 mm	17.29 mm	20.09 mm
No. of strands	700	820	780
Diameter of a conductor	79.5 mm	50.75mm	50.75mm
Volume of core	75.09 cm^3	60.4 cm^3	58.5 cm3

The parameter ranges of the proposed model are outlined in Table 2, and Figure 5 illustrates the convergence curve. Table 2 provides a comparative analysis of fitness functions.

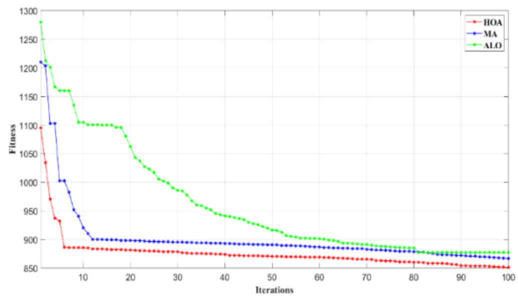


Fig. 5 Comparative analysis of fitness function

Table 2. Comparison of fitness function

Techniques	No. of iteration	Fitness
HOA	95	850
MA	100	875
ALO	81	890

i) Finite element analysis of the proposed model

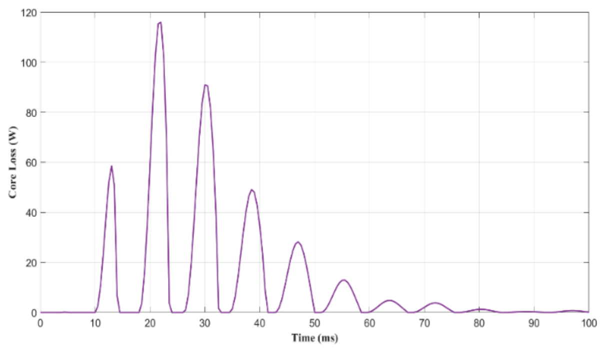
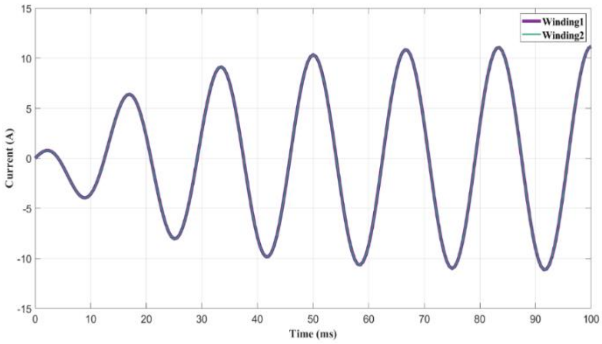
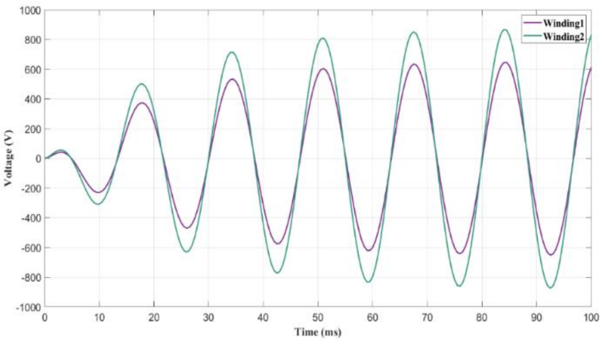


Fig.6 Core loss

The observed core loss is illustrated in figure 1. The peak value of the core loss is considered as 110 kW that is reached at 21^{st} ms. After that, the loss is gradually decreased to reach 2 W at the 83^{rd} ms. The proposed model provides a good power quality due to low core loss.



(a)



(b)

Fig.7 Current and voltage flows of winding 1 and 2

In Figure 7, the proposed model illustrates the current and voltage waveforms of winding 1 and 2 for the transformer. The proposed model provides a stable current and voltages with low temperatures.

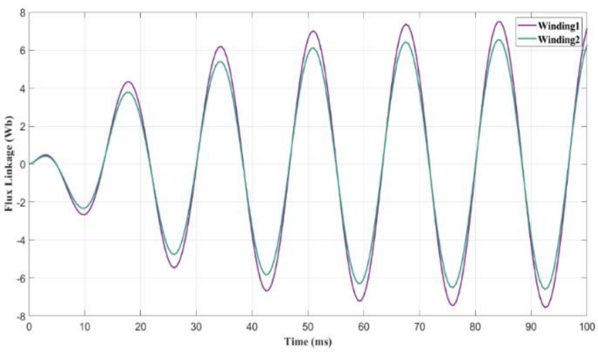


Fig.8 Flux linkages of winding 1 and 2

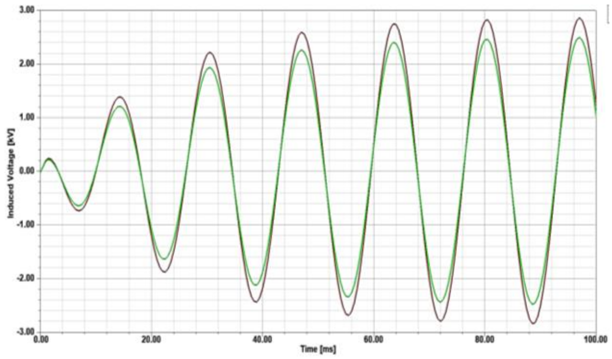


Fig.9 Analysis of induced voltage of winding 1 and 2.

Figure 9 demonstrates the induced voltage waveforms of winding 1 and 2, it shows winding 1 induced voltage is higher than the winding 2 induced voltage.

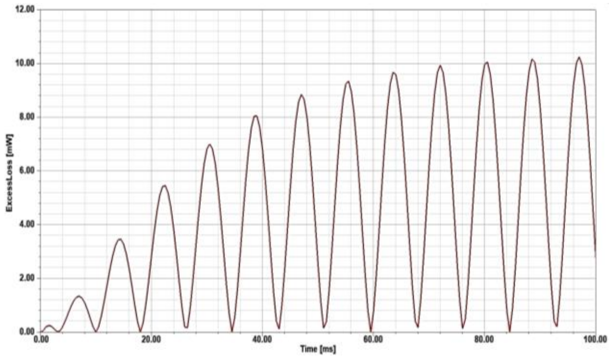


Fig.10 Analysis of excess loss of proposed model

Then the proposed optimal core based transformer model's excess losses are analysed which is sketched in figure 10.

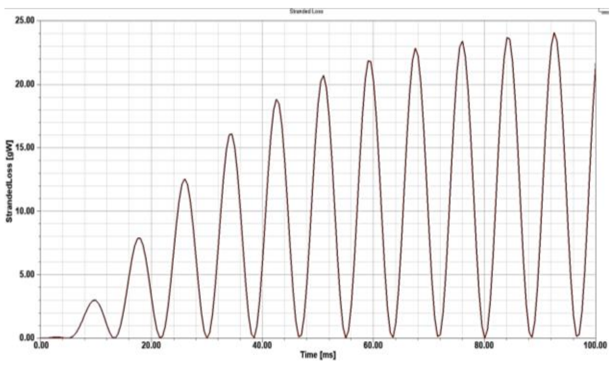


Fig.11 Analysis of stranded loss

IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 1, Jan 2022

The stranded loss of the proposed optimal transformer was shown in figure 11.

.

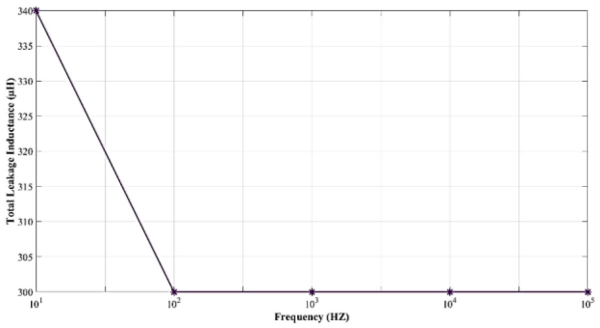


Fig.12 Inductance leakage analysis of the proposed HOA model

At last the total winding resistance of the proposed HOA transformer is observed and plotted in figure 12.The analysis values show at the variation of frequency cause an improvement in winding resistance capacity. That is the proposed transformer provides 0.0161 Ω at the 10^5 Hz frequency.

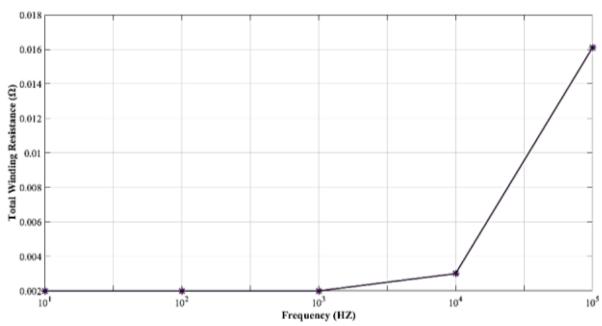


Fig.13 Total winding resistance of the proposed HOA model

2.3. Comparative analysis

GA based optimal designing of the transformer provide high core losses, it contains 13.2 W. Similarly, HTS winding model have 64.52 W core loss. Another method of two electrical steels combined model have4.15 kW core loss, M5-type silicon steel core model provides 401 W core loss at power transferring period, Harmonic field model of transformer provides 12.41 kW core loss. But in the proposed approach, the core loss contains 2 W which is demonstrated in table 3.

Table 3. Comparison of core loss

Techniques	**Core loss**
HTS winding [22]	64.52 W
GA based transformer [13]	13.2 W
Two electrical steels [23]	4.15 kW
M5-type silicon steel core [24]	401 W
Harmonic field model [25]	12.41 kW
Proposed optimal transformer	2 W

3. CONCLUSION

The proposed approach integrates an optimal transformer using the Horse Herd Optimization Algorithm (HOA) into a CLLC resonant circuit for on-board charging applications. The transformer design is crucial for reducing costs and losses. The proposed model exhibits fast convergence and improved power quality with low cost and loss. MATLAB and ANSYS software are utilized to develop and validate the performance of the transformer. The 3D model of the transformer is created using ANSYS, and its mesh and temperature contour are validated. The performance is compared to other existing methods, and the proposed optimal transformer demonstrates superior results, such as a low core loss of 2W.

REFERENCE

[1] Fridstrøm, L., & Østli, V. (2021). Direct and cross price elasticities of demand for gasoline, diesel, hybrid and battery electric cars: the case of Norway. *European Transport Research Review*, *13*(1), 1-24.

[2] Das, H. S., Rahman, M. M., Li, S., & Tan, C. W. (2020). Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. *Renewable and Sustainable Energy Reviews*, *120*, 109618.

[3] Yildirim, D., Öztürk, S., Çadirci, I., & Ermiş, M. (2020). All SiC PWM rectifier-based off-board ultrafast charger for heavy electric vehicles. *IET Power Electronics*, *13*(3), 483-494.

[4] Sam, C. A., & Jegathesan, V. (2021). Bidirectional integrated on-board chargers for electric vehicles—A review. *Sādhanā*, *46*(1), 26.

[5] Chothe, S., Ugale, R. T., & Gambhir, A. (2021, December). Design and modeling of Phase Shifted Full Bridge DC-DC Converter with ZVS. In *2021 National Power Electronics Conference (NPEC)* (pp. 01-06). IEEE.

[6] Xue, B., Wang, H., Liang, J., Cao, Q., & Li, Z. (2020). Phase-shift modulated interleaved LLC converter with ultrawide output voltage range. *IEEE Transactions on Power Electronics*, *36*(1), 493-503.

[7] Al Attar, H., Hamida, M. A., Ghanes, M., & Taleb, M. (2022). Llc dc-dc converter performances improvement for bidirectional electric vehicle charger application. *World Electric Vehicle Journal*, *13*(1), 2.

[8] Maheswari, L., & Sivakumaran, N. (2020). An isolated single-switch high step-up DC/DC converter with three-winding transformer for solar photovoltaic applications. *Electrical Engineering*, *102*, 1383-1392.

[9] Abolqasemi-Kharanaq, F., Alipour-Sarabi, R., Nasiri-Gheidari, Z., & Tootoonchian, F. (2018). Magnetic equivalent circuit model for wound rotor resolver without rotary transformer's core. *IEEE Sensors Journal*, *18*(21), 8693-8700.

[10] Olowu, T. O., Jafari, H., Moghaddami, M., & Sarwat, A. I. (2019, September). Physics-based design optimization of high frequency transformers for solid state transformer applications. In *2019 IEEE Industry Applications Society Annual Meeting* (pp. 1-6). IEEE.

[11] Jothimani, G., Palanichamy, Y., Natarajan, S. K., & Rameshkumar, T. (2021). Single-phase front-end modified interleaved Luo power factor correction converter for on-board electric vehicle charger. *International Journal of Circuit Theory and Applications*, *49*(9), 2655-2669.

[12] Taghizadeh, S., Hossain, M. J., Lu, J., & Water, W. (2018). A unified multi-functional on-board EV charger for power-quality control in household networks. *Applied energy*, *215*, 186-201.

[13] Zou, S., Lu, J., Mallik, A., & Khaligh, A. (2018). Modeling and optimization of an integrated transformer for electric vehicle on-board charger applications. *IEEE Transactions on Transportation Electrification*, *4*(2), 355-363.

[14] Dao, N. D., & Lee, D. C. (2020). High-efficiency hybrid LLC resonant converter for on-board chargers of plug-in electric vehicles. *IEEE Transactions on Power Electro*

[15] *nics*, *35*(8), 8324-8334.