

A Novel optimized Control in Wire Less Power Transfer in EV Charging Stations

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Received: 04-10-2025; Revised: 21-10-2025; Accepted: 09-11-2025; Published: 24-11-2025

Abstract

The use of wireless power transfer (WPT) systems is a feasible direction used to charge electric vehicles (EVs) with different power. Nevertheless, in the presence of a large discrepancy between the power ratings of the vehicle assemblies (VAs) and the ground assemblies (GAs) in the charging stations, the overall system efficiency may significantly be reduced. In order to overcome this issue, this paper proposes a dc-link parallel, ac-link series multi-inverter-, multi-rectifier-based architecture, which can be used in high-power WPT applications. The proposed design focuses on the effective power sharing, flexible modulation and increased power transfer capability. The operation of a complex power loss analysis is carried out to develop an efficient control strategy that is based on mutual inductance identification to reduce the losses. In addition, the optimization of the suggested control approach is done using the Golden Jackal Optimization algorithm. The results of MATLAB simulation show that the proposed system makes the system much more efficient and power losses minimal, which can prove the suitability of the control technique in improving system performance.

Keywords: *Renewable energy, smart university, DC-micro-grid, energy management control, fuzzy logic control, fractional order control.*

1.Introduction

Due to the increasing pace of electric vehicles (EVs), several technologies to charge the vehicles have been introduced with wireless power transfer (WPT) becoming a potential solution in the high power, non-contact charging of EVs. WPT has a number of benefits such as the user comfort, minimum mechanical wear, and possibility of dynamic charging, where cars can be charged either when parked or in motion without any physical contacts. Although these advantages are evident, the main fact that constrains the large scale use of WPT systems is that there is a great loss of efficiency due to disparities in power levels between vehicle assembly (VA) and ground assembly (GA) at charging stations. This may cause significant losses in power, longer charging time, and a decrease in the overall system efficiency, and thus it prevents the extensive implementation of WPT-based EV charging infrastructure.

Traditional WPT systems have a strong dependence on coil alignment, system design and impedance matching in order to have an efficient power transfer between the GA (transmitter) and the VA (receiver). EVs run at varying power outputs, which means that the charging stations should be compatible with a vast variety of vehicles. Nevertheless, the power rating differences between the GA and VA tend to cause too much energy wastage and poor performance of the system. Even though some of the existing solutions are trying to alleviate the problem, they do not tend to provide the best results in cases when power classes are widely different.

The recent scholarly studies, industrial innovations, and the international standards have been mainly directed towards the enhancement of control measures, coil and circuit design, and efficiency of power transfer (2)–(4). The common EV WPT system comprises of a VA and a GA, as shown in Fig. 1. A grid-based power is converted to a stable dc voltage with the help of power factor correction (PFC) circuit. Other dc/dc converters might also be added on the GA and VA side to provide the capacity to flexibly regulate the power. To counter the coil reactance, several resonant compensation networks have been suggested such as series, parallel, and hybrid networks (5), amongst which LCC-LCC compensation network is one of the most famous in EV WPT systems (2).

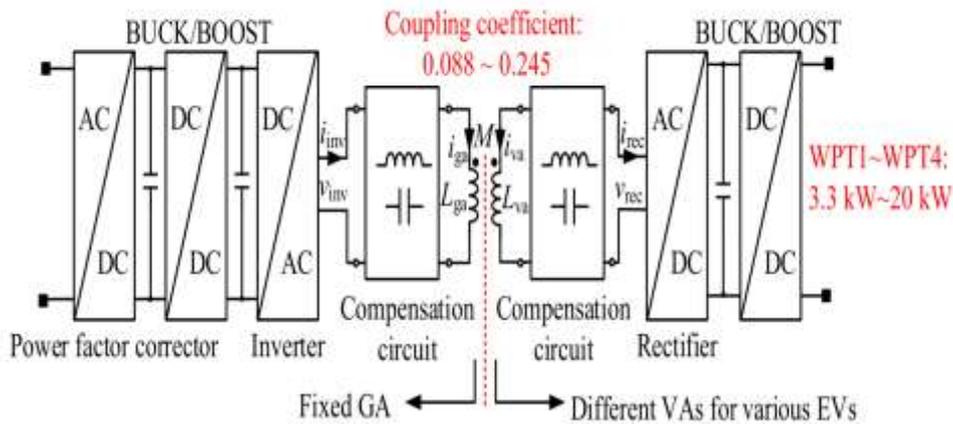


FIGURE 1 Conventional EV WPT system

To overcome the issues of power mismatch, this paper will present a new architecture of high-power WPT design using a series of parallel, ac-linked, multi-inverter multi-rectifier (DPAS-MIMR) design. The proposed structure will particularly be crafted to increase the efficiency of power transfer between the VA and GA even when there is a large power class difference. Better modulation schemes and power-sharing schemes are used to ensure that the vehicle and the charging station are much more closely aligned and transmit power better. The main characteristic of the proposed system is a power loss optimization control (PLOC) strategy that relies on mutual inductance identification and that dynamically changes the parameters of the system to obtain an optimal performance.

The principal goals of the study will be:

1. Design: Design a multi-inverter multi-rectifier system that is capable of operating at high power levels and eliminating issues of power class mismatch between VAs and GAs.
2. Maximization of power transfer performance: Dynamic modulation strategies and power transfer efficiency: SD to guarantee dependable power delivery at the varying VA and GA power ratings.
3. Stabilization of the power system: Suggest and analyze the means of enhancing power sharing between two or more inverters and rectifiers to minimize losses and maximize the stability of the system.

Though this can be done with an enhancement of power levels by using several transmitter (Tx) coils, receiver (Rx) coils and modular cells (7)- (10), the size of the GA and VA components is limited rigidly by vehicle manufacturers in terms of size, weight, and cost. As an example, Hongqi states that the 10-kW VA employed in its E-HS9 model should not have more than 17 kg and should not exceed 37 cm x 37 cm x 6 cm in dimensions. As stated in the SAE J2954 standard (6), acceptable misalignments are reduced to less than 100 mm in the Y direction and less than 75 mm in the X direction. As a result, EV WPT systems are generally implemented to a one-to-one configuration in which Tx coil is large and Rx coil is small because a large Tx coil can tolerate inconsistency in parking locations due to misalignment. This design trend has been embraced by the industry giants like WiTricity, ZTE and VIE. Current WPT systems are thus commonly optimized to particular power ratings and power transmission ranges.

In order to be able to operate with large differences in both output power and coupling coefficient, a number of methods have been suggested, such as dc/dc converters (11), active rectifiers (13), phase-shifted capacitors (14), and variable inductances (15). Several modulation techniques have been explored including duty-cycle modulation (16), phase-shift modulation (17), frequency-shift modulation (18), pulse-density modulation (19) and ON- OFF keying (20). Research indicates that 50-kW and 100-kW WPT systems with a transmission distance of 160 mm reported efficiencies of over 95.5% to the dc/ dc conversion of power (11) and (12). Although such systems are highly efficient, powerful and most are intended to be used in home charging, they do not sufficiently cater to interoperability issues.

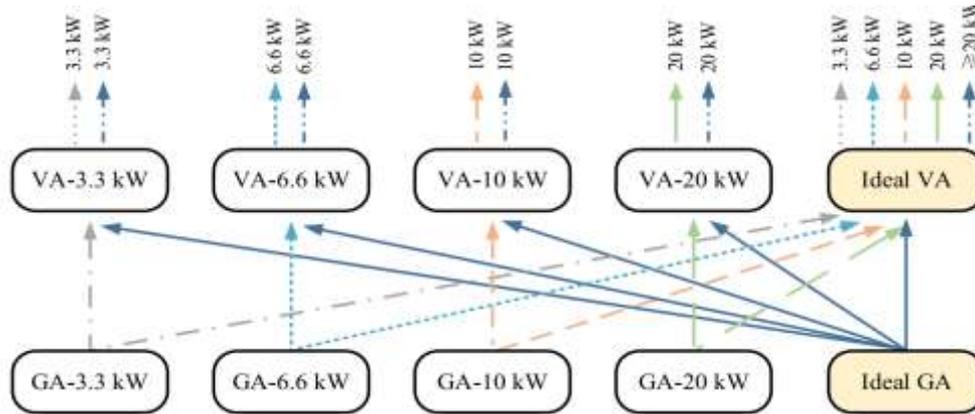


FIGURE 2 Interoperability of different GAs and VAs in charging stations.

Within the actual charge scenario in the public, one GA should be able to be used with multiple VAs of varying power ratings, as shown in Fig. 2. When the GAs and VAs are coupled together with their mismatched power classes, the equivalent impedance of the resonant tank is no longer within the optimal range causing large decreases in the output power and system efficiency (21), (22). As an example, an efficient 20-kW GA can be used to output 20 kW to a corresponding 20-kW VA with little losses, but combining it with a 3.3-kW VA will cause severe impedance mismatch with significant loss of efficiency. The interoperability requirements of SAE J2954 showed that efficiency can reduce to about 75 percent with a rise in the difference in power classes. With the increasing commercialization of wireless EV charging, interoperability, particularly in high-power public charging stations, has been a highly important aspect.

In high-frequency, high-power WPT systems, power loss optimized control (PLOC) could be of special concern because when this system becomes a problem, it might be due to high dissipation (heating) levels (27)–(31). The current strategies tend to use either dc/dc converters or active rectifiers with optimization algorithms that include perturb-and-observe (P&O), simulated annealing, traversal algorithms or online parameter identification. Nonetheless, it is still difficult to reach wide-range soft switching that would be applicable to all working conditions. Hard switching adds switching losses, whereas extra stages of power doubles the size of the system, its cost, and complexity. Moreover, the difficulty of high-frequency synchronization which is necessary when using active rectifiers or phase-shifted capacitors may lower the charging reliability.

In order to address these shortcomings, this paper presents a dc-link parallel, ac-link series multi-inverter multi-rectifier (DPAS-MIMR) design of EV WPT systems. The key findings of the work are as follows:

1. A flexible and durable DPAS-MIMR model that facilitates high power EV WPT charging station interoperability.
2. An easy and efficient PLOC solution founded on mutual inductance identification.
3. The adaptive, high-efficiency EV WPT system of 20 kW has been experimentally validated.

Simulations carried out using MATLAB are aimed at testing the main design parameters, such as modulation strategies, power transfer characteristics, as well as power loss optimization. The simulation findings have shown that the system can be made very efficient with minimal amounts of power lost and less time to charge, especially with big power classes mismatch. In general, the study will help develop scalable, efficient, and reliable wireless charging platforms to charge EVs since it will tackle the issues associated with changes in the power rating of the WPT systems.

In a standard EV WPT system, the power flow within the system involves inductive coupling of the GA to the VA without any physical connection between the two. Although this non-contact scheme is better in terms of convenience and durability, efficiency may be seriously impaired when the power needs of the vehicle are not well aligned with the charging infrastructure. The Golden Jackal Optimization (GJO) algorithm is one type of optimization algorithm offering a useful solution to the problem of optimization and dynamically adjusting system parameters to produce optimal performance and reduce power loss.

2. DPAS-MIMR WPT System Topology

Fig. 3 displays the suggested system's schematic. The input and output dc-link voltages are denoted by V_{bus} and V_{bat} , respectively. The numbers of rectifiers and inverters are denoted by m and n , respectively. The MOSFETs

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of the #*i* inverter are *S*_{1*i*}–*S*_{4*i*}. The MOSFETs and diodes of the #*j* rectifier are denoted by *Q*_{1*j*}–*Q*_{2*j*} and *D*_{1*j*}–*D*_{2*j*}, respectively. The #*i* inverter's resonant voltage and current are denoted by *v*_{*p**i*} and *i*_{*p**i*}, respectively. The #*j* rectifier's resonant voltage and current are denoted by *v*_{*s**j*} and *i*_{*s**j*}, respectively. *C*_{*b*} is a dc blocking capacitor that can tolerate high inverting current at 85 kHz and has a capacitive reactance of less than 0.5 Ω. There is no dc component on *v*_{*p**i*} when employing symmetrical phase shift control techniques, and *C*_{*b*} is not required. However, a big phase shift angle results in hard switching and a narrow regulatory range. As a result, the half-bridge mode is presented together with an asymmetric control strategy. A dc-blocking capacitor is necessary since this mode contains a dc component. All of the rectifiers and inverters can have dc-blocking capacitors installed. However, the #1 inverter can be utilized with asymmetric modulation schemes like half-bridge duty cycle control because only one capacitor needs to be added in order to reduce the number of these capacitors. The controllers should be synced since active rectifiers and numerous inverters are used. In this article, the first inverter serves as the slaver and the master, producing a square-wave synchronization signal. The compensating capacitors in the LCC-LCC circuits are *C*_{*f*_{*ga*}}, *C*_{*ga*}, *C*_{*va*}, and *C*_{*f*_{*va*}}. The coupling coils' inductances are *L*_{*ga*} and *L*_{*va*}. Resonant inductor integrated transformers (RIITs) on the GA and VA have primary and secondary winding turns, *n*_{*p**1**i*} (*n*_{*s**1**i*}) and *n*_{*p**2**i*} (*n*_{*s**2**i*}), whose turns ratios, *m*_{*i*} and *n*_{*j*}, are specified as

$$m_i = n_{p1i} / n_{s2i}$$

$$n_j = n_{s1j} / n_{s2j}$$

$$M = k \sqrt{L_{ga} L_{va}}$$

The analogous circuit for the suggested DPASMIMR WPT system is displayed in Fig. 4. The primary and secondary parasitic resistances of #*i* RIIT on the GA are *R*_{*p**1**i*} and *R*_{*p**2**i*}, respectively. The principal parasitic resistances of #*j* RIIT on the VA are *R*_{*s**1**j*} and *R*_{*s**2**j*}, respectively. The coupling coils' parasitic resistances are denoted by *R*_{*ga*} and *R*_{*va*}. The total equivalent parasitic resistances of the DPAS-based rectifiers and inverters are denoted by *R*_{*f*_{*va*}} and *R*_{*f*_{*ga*}}, respectively. The leakage inductances of #*i* and #*j* RIITs on the GA and VA are denoted by *L*_{*f*_{*gai*}} and *L*_{*f*_{*vaj*}}, respectively. Additional resonant inductors are still required even though a sandwich structure can produce a very modest leakage inductance. The RIITs' leakage inductance is utilized as the resonant inductors in order to minimize both size and cost. With a 5% accuracy rate, the total reactance may be computed using the traditional LCC-LCC topology. Consequently, the total leakage inductances of the GA and VA can be found as

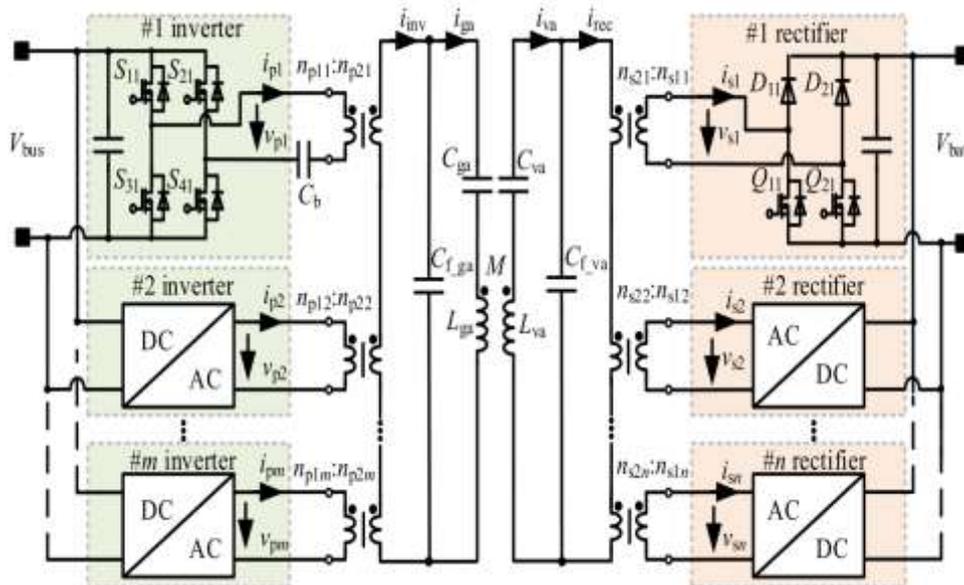


FIGURE 3 Proposed-MIMR WPT System

3.Simulation Results

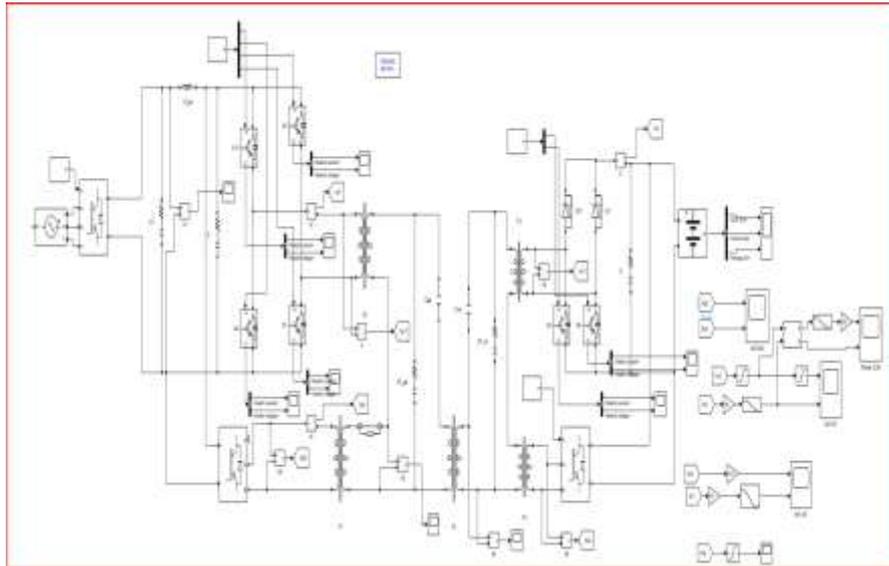
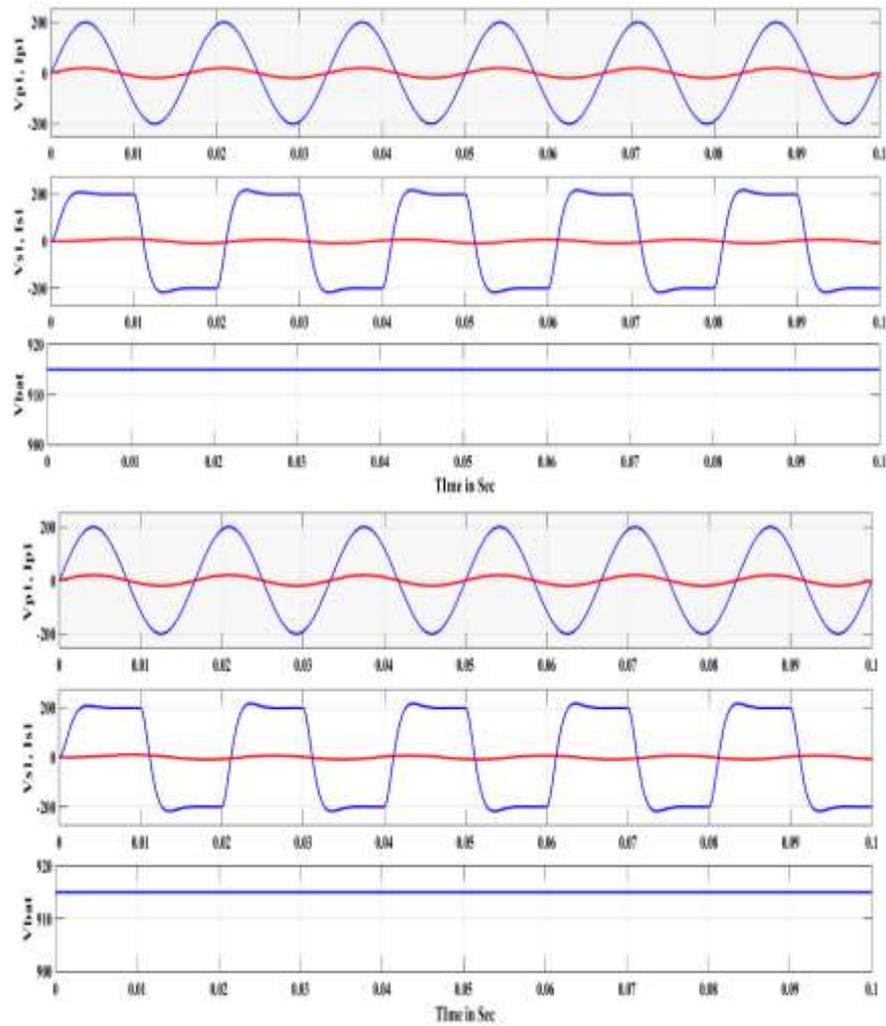


FIGURE 4 Simulation Diagram of the conventional EV WPT System



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Fig. 1. Typical waveforms of the DPAS-MIMR architecture with primary side control under different power levels and battery voltages where $k = 0.155$. (a) $P_o = 3.3$ kW, $V_{bat} = 650$ V and 915 V. (b) $P_o = 6.6$ kW, $V_{bat} = 650$ V, and 915 V. (c) $P_o = 10$ kW, $V_{bat} = 650$ V, and 915 V. (d) $P_o = 20$ kW and $V_{bat} = 650$ V and 915 V.

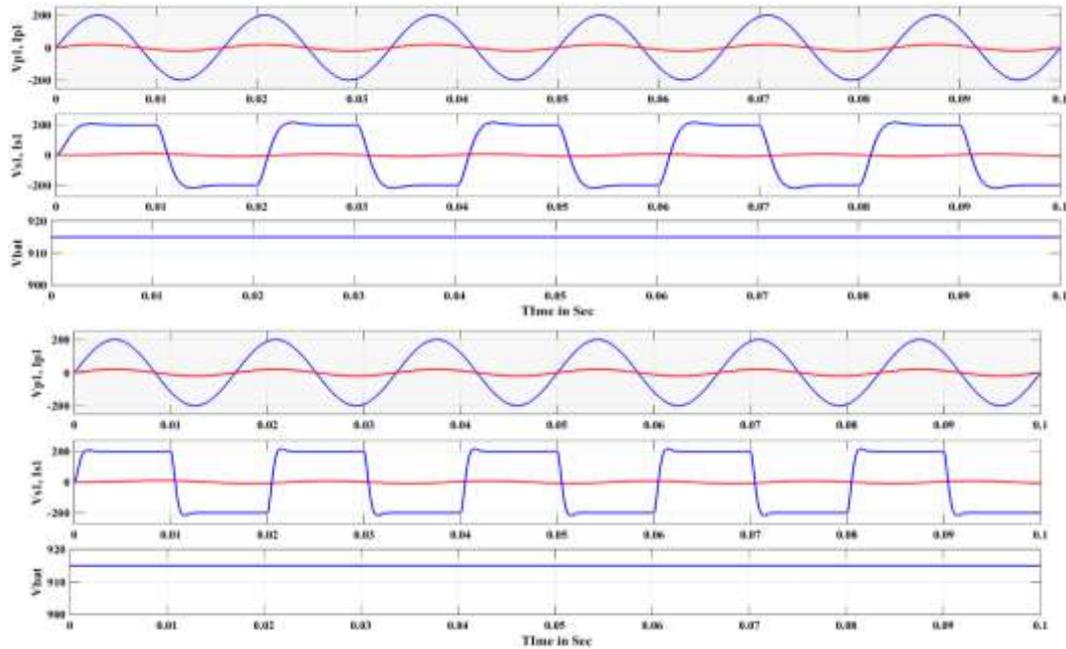


Fig.2. Typical waveforms of the DPAS-MIMR architecture with simplified GJO method at different power ratings and battery voltages where $k = 0.26$. (a) $P_o = 3.3$ kW and $V_{bat} = 650$ V and 915 V. (b) $P_o = 6.6$ kW and $V_{bat} = 650$ V and 915 V. (c) $P_o = 10$ kW and $V_{bat} = 650$ V and 915 V. (d) $P_o = 20$ kW and $V_{bat} = 650$ V and 915 V.]

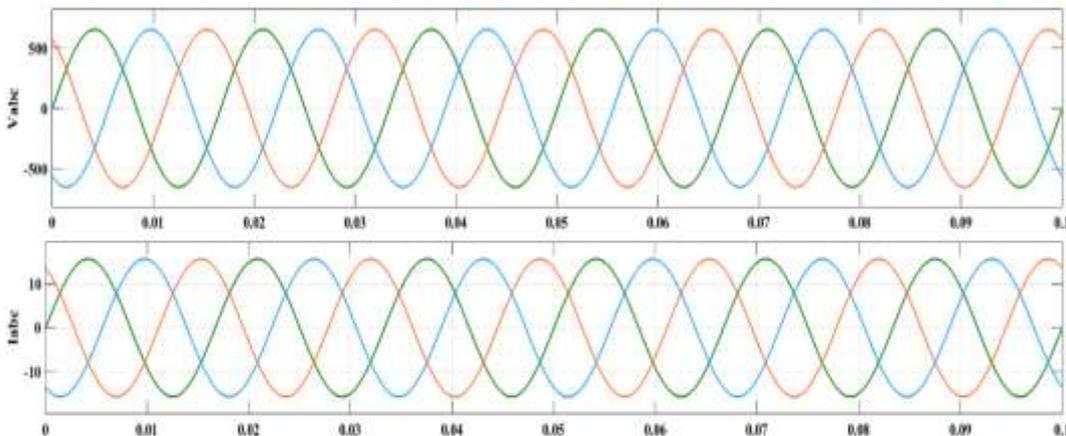


FIGURE 5 Typical wave forms of a Vabc, Iabc with with 15.6A of Currents

5. Conclusion and Future work

Recently effective and with little or no research on it, the Golden Jackal Optimization (GJO) algorithm algorithm is a metaheuristic optimization method based on the hunting and foraging behaviour of gold jackals. It investigates the solution space by keeping an adequate trade-off between exploration and exploitation that makes it especially effective in complex optimization problems where other approaches can fail. GJO can be of particular use in the case of wireless power transfer (WPT) systems to reduce losses in power and enhance system efficiency. GJO can maximize the performance of power transfer even in the case of different output powers by effectively tuning critical parameters including operating frequency, spacing between coils and alignment.

The main benefits of GJO algorithm are as follows:

Global search ability: The exploration mechanism of it allows a thorough search of the solution space, which enhances the chances of finding near-optimal or global optimum solutions.

Local search refinement GJO is effective in refining candidate solutions in the exploitation phase where it narrows on promising regions identified during the search phase thus enhancing efficient convergence.

Simplicity and flexibility: The algorithm is simple and can be easily adapted to a broad selection of optimization problems in various areas of application.

Through the implementation of the Golden Jackal Optimization algorithm, a problem of power loss in WPT systems can be minimized, optimization of energy transfer can be achieved, and the overall performance of the system can be greatly improved. Due to this balanced search approach and flexibility, GJO is an effective and efficient optimization method of solving complex problems in the real world, especially in any field of electrical, robotics, and system design.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

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