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HYBRID COMPENSATION-BASED EFFICIENT WIRELESS CHARGING SYSTEM WITH PV INTERFACE

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ABSTRACT: This research enhances the wireless charging capabilities of electric vehicles and other portable electronics that are powered by solar energy. The hybrid compensatory design enhances the efficiency and dependability of energy transmission. The majority of the system's electricity is generated by the photovoltaic panels. It is advantageous for the environment to disconnect from the power grid during the recharge process. Modified solar energy can be transmitted through inductive power transfer (IPT). a hybrid compensation network fuses the Series-Series (SS) and Series-Parallel (SP) topologies to enhance performance under fluctuating loads and when coils are not aligned. Combining the two methods can improve the efficacy of power transfer, reactive power transmission, and impedance matching. Real-time monitoring of voltage and current levels, as well as algorithms for maximum power point tracking (MPPT), are indispensable for optimizing solar panel performance. Hybrid compensation, as demonstrated in MATLAB/Simulink simulations, has the potential to enhance the efficacy, power quality, and reliability of off-grid wireless charging networks in renewable energy.

Keywords: Solar-powered charging, wireless power transfer (WPT), inductive power transfer (IPT), hybrid compensation, series-series (SS), series-parallel (SP), photovoltaic (PV), MPPT, off-grid charging, energy efficiency, MATLAB/Simulink.

1. INTRODUCTION

The imperative necessity for renewable energy sources has been underscored by the proliferation of electric vehicles and other portable electronic devices. This has resulted in an acceleration of research into wireless charging. Solar-powered wireless charging systems are a modern alternative that offer sustainable energy and flexible power transmission. These technologies enable the more efficient and environmentally friendly operation of numerous electrical devices by eliminating the necessity for tangible connections and grid infrastructure. It is imperative to address the issue of naturally variable solar energy supply and inefficiencies in wireless energy transfer in order to enhance the system's performance and realize its advantages.

The success of wireless charging methods can be attributed to their hybrid adjustability. Compensation networks are implemented in WPT systems to regulate the power output of the transmitter and receiver coils. A hybrid compensation technique may automatically adjust to alignment and load concerns by employing series-parallel and LCC-LCC topologies. This technology enhances stability by increasing the distance of charging, reducing interference from electromagnetic fields, and increasing the efficacy of power transfer. Without the capacity to adapt to solar influences, hybrid correction is unable to maintain its exceptional performance.

Utilizing cutting-edge hybrid compensating circuits to leverage solar energy enhances the reliability and efficiency of wireless charging devices that operate on solar power. These technologies have the capacity to enhance the infrastructure of electric vehicles, off-grid recharge stations, and smart city initiatives. The primary objective of this integration is to establish a decentralized, environmentally friendly energy system that is environmentally beneficial, has minimal transmission loss, and is collected and utilized locally. In order to advance the development of environmentally friendly wireless charging devices, additional research is required to resolve concerns regarding energy storage and temperature.

2. LITERATURE SURVEY

Raman, A., & Mehta, R. (2024). In order to enhance the efficiency of energy transmission, we investigate a solar-powered EV wireless charging system that implements a mixed compensation network. In order to resolve alignment and load variance concerns, the proposed solution implements compensatory arrangements in both parallel and series configurations. At the outset, photovoltaic (PV) modules that are controlled by MPPT are employed to convert solar energy into DC. Next, they will implement wireless communication via high-frequency alternating current (AC). To convert this, two stages are necessary. The modeling and testing indicate that the method is 92% effective in all circumstances, irrespective of irradiance or direction. The objective of this research is to identify solutions that will enhance the safety of public electric vehicle charging stations by minimizing electromagnetic interference.

Kumar, S., & Jain, T. (2024). This research implies that electric vehicles in urban areas may benefit from solar-powered inductive charging. The LCL topology is employed in the hybrid compensation design to ensure that the transfer of reactive power between the receiver and transmitter coils remains consistent, regardless of coil distance or misalignment. The output voltage is maintained by the control mechanism, which adjusts the modulation of switching frequencies in response to fluctuations in solar radiation. In partially dim environments, the prototype device outperformed conventional correcting methods by 30%. The authors delve into the subject of thermal impacts and investigate strategies to improve coil design in densely populated urban areas.

Nayak, P., & Verghese, L. (2023). This investigation determined that a dual-compensation network that integrates parallel and series components can effectively manage a solar-powered wireless electric vehicle charging. High-Q resonant circuits wirelessly transmit power, while MPPT-capable DC-DC converters accumulate solar energy. The hybrid corrective effectively mitigates reactive power losses by promptly responding to fluctuations in demand. The researchers have demonstrated that highway charging stations are the optimal locations for the strategy, which is effective in accommodating a diverse fleet of vehicles and experiencing variable degrees of sunshine. It is remarkable that 90% of the data is successfully transferred, and the system effectively manages any complications.

Reddy, V., & Thomas, S. (2023). In order to establish a wireless, intelligent charging station, the researchers integrated hybrid compensating coils with rooftop solar panels. This station conducts consistent power transfers. This work demonstrates the real-world modification of the parking coupling coefficient through the use of phase-shift modulation as a power-control method. The frequency of alterations in fuzzy logic controllers is influenced by variations in temperature and light intensity. The simulation results indicate that the system maintains a consistent voltage and has a lengthy lifespan. This article investigates the potential applications of this technology in energy monitoring systems for smart cities that are based on the Internet of Things.

Iqbal, Z., & Fernandes, J. (2022). The investigation explores a mixed-compensation design for solar-powered wireless electric vehicle charging systems that are specifically designed for residential and light-commercial applications. It is equipped with a dual-H-bridge inverter that employs soft-switching to minimize switching losses. Reduces voltage stress and harmonics by fine-tuning the compensating

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architecture with a genetic algorithm. The researchers reported that the system outperformed single-compensation systems by 25% in low-irradiance and misalignment circumstances. The results are substantiated by MATLAB/Simulink simulations and a modest experimental setup.

Patel, H., & Roy, K. (2022). In this research, it is recommended that a secure and effective method of charging e-bikes, e-scooters, and other lightweight electric vehicles be employed by combining modification techniques with a tiny wireless solar charger. The authors employ resonant inverters that are frequency-regulated to power solar panels. The impedance-matching controller of the system enables the real-time adjustment of capacitance and inductance. Based on the results of test beds and simulations, this charger is optimal for use at public bike-sharing stations, as it consistently maintains a consistent charging current, irrespective of the load.

Sharma, N., & Pillai, M. (2021). The concept of a hybrid-compensation wireless power device that is powered by solar energy is currently under investigation. An intermediary DC link and a high-frequency converter are employed to establish a dependable wireless charging network for medium-range electric vehicles. In order to optimize power transmission, the hybrid method employs parallel capacitance and series inductance. The magnetic core and coil's shape and size are modified to result in improved coupling and reduced leakage inductance. The models suggest that the device's efficacy exceeds 88% at a distance of 20 cm.

Rao, B., & Dey, S. (2021). The objective of this research is to enhance comprehension of wireless charging for electric vehicles in partially cloudy or overcast conditions. Through the implementation of model predictive control, dynamic hybrid corrective tuning is achieved. By pumping and monitoring the maximal power point, solar energy can be connected to the grid via a DC-DC boost converter. By analyzing frequencies, the authors have the ability to modify the system's resonance frequency in real-time. The investigation determined that load control could be enhanced. The power supply can now be managed by the hybrid correction system, even in the presence of rapid fluctuations in solar input and vehicle load.

Das, A., & Choudhury, N. (2020). As a proof-of-concept, this initial experiment constructs a solar-powered wireless charging system by employing a straightforward series-parallel hybrid compensating mechanism. The primary objectives are to demonstrate the feasibility of the concept and to investigate the impact of weather and other environmental factors on coil coupling losses. The prototype is capable of operating at a sluggish 75% efficiency by employing conventional solar panels and ferrite-core coils. Adaptive control systems are prioritized, and additional research is required to investigate irradiance forecast models that are powered by AI.

Basu, R., & Nair, K. (2020). This investigation introduces an ecologically favorable, low-cost, and straightforward wireless electric vehicle charger. The charger's efficiency is facilitated by a novel LCC adjustment system and solar panels. The target audience for this method is developing regions that lack a stable grid infrastructure. Passive components and inexpensive microcontrollers can be employed to maintain a constant voltage in simpler circuits. Experiments and simulations are conducted to investigate community-scale microgrids that utilize solar energy for wireless charging.

3. RELATED WORK

HYBRID COMPENSATION TOPOLOGIES

Carefully designed circuit layouts that use series and parallel reactive elements, such inductors and capacitors, on the main transmitter and/or secondary receiver sides are known as hybrid compensation topologies in wireless power transfer (WPT) systems. These designs aim to maximize energy transfer over the wireless gap by minimizing losses, increasing system flexibility, and preserving resonance. When dealing with real-world scenarios, such as wireless electric vehicle (EV) charging, where coil alignment and load conditions can vary greatly, hybrid compensation is preferred over pure series or parallel compensation. This is because it allows for better control over power flow, efficiency, and voltage gain when operating conditions change.

Series–Series (SS) Compensation

The Series-Series (SS) compensating grid incorporates series capacitors into both the main and secondary coils. It's easy to think of and implement, and it's one of the simplest methods of paying individuals. By allowing the primary and secondary coils to resonate at the working frequency independently, the SS design enhances energy transfer when properly configured. But, because its utility may diminish under changing load conditions, it is best used in cases when the load is constant. Its voltage gain is small and its resistance to coil misalignment is lower than that of other hybrid topologies. For simple, low-power jobs, SS is still a go-to due to its user-friendliness.

Series–Parallel (SP) Compensation

Two types of capacitors, one utilized on the main side and one on the secondary side, make up the Series-Parallel (SP) design. With its receiver-side parallel correction, this system outperforms SS in dynamic load conditions by maintaining a constant voltage across the load. When the load impedance is small, SP produces a larger voltage gain. When there is no load, the SP design can improve load regulation and reduce the danger of overvoltage. In medium-power scenarios with anticipated fluctuations in load, it outperforms the SS model in terms of alignment tolerance.

Parallel–Series (PS) Compensation

An important distinction between the SP paradigm and the Parallel-Series (PS) architecture is the presence of a series capacitor on the receiver side and a parallel capacitor on the transmitter side. Given PS's extensive experience with high-power applications and its high input current, it is easier to transmit power across bigger gaps or misalignments. The primary side parallel correction in fast-charging systems, such as those used in electric automobiles, reduces the source impedance, allowing more current to pass. The PS design's increased resistance to system interruptions and ability to handle a wide variety of loads make it ideal for dynamic environments. Stopping further harmonic distortion requires careful correction.

LCL–LCC Hybrid Compensation

On the primary and secondary sides of the LCL-LCC hybrid topology, there are numerous types of inductors (L) and capacitors (C) configured in intricate ways. Typically, an LCL network is present on the broadcaster side and an LCC network is present on the listener side. Maximizing efficiency, stability, and power density are the three primary design goals of this hybrid system. The LCL-LCC design minimizes switching losses, particularly at high frequencies, and makes it easier to manage resonant frequencies. It also keeps the system stable under a wide range of load and alignment conditions. Compatible wireless systems that are integrated with the power infrastructure and high-capacity wireless electric car chargers are a good fit. However, because to its complexity, it necessitates more intricate control systems, more precise design, and more costly components.

ADVANTAGES OF HYBRID COMPENSATION TOPOLOGIES

Improved Tolerance to Misalignment

Hybrid compensation designs excel at dealing with coil misalignment, which is a major plus. Optimal alignment of the transmitter and reception coils is not always guaranteed in real-world applications of wireless power transfer (WPT), such as in consumer items, medical implants, and electric vehicles (EVs). Poor power transfer efficiency and fluctuating output voltage result from misalignment weakening the

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mutual inductance between the coils. Some examples of hybrid topologies that aim to take use of variations in mutual inductance include combinations of LCC and SP, as well as LCL and LCC. For this, they either optimize the distribution of voltage and current across the system or dynamically adjust the resonance settings. This ensures that electricity is consistently transmitted, regardless of a specific proportion of coils being out of line in either direction, making the system more practical and dependable in real-world scenarios.

Stable Operation Under Variable Loads

Maintaining optimal operation in the face of fluctuating loads is a major strength of mixed compensation networks. In many wireless power systems, the quantity of power a load needs might vary over time. Charging an electric vehicle with fluctuating battery levels or running an intermittent power device can cause this. Resonance detuning or variations in output voltage can occur with traditional single-mode correction methods such as SS or PP when the load is changed. More controllable voltage and consistent power flow regardless of load variations are advantages of hybrid systems like SP or LCL-LCC. To prevent delicate electrical components from being damaged by overvoltage or undervoltage, this is crucial in systems where stable voltage and power quality are paramount.

Better Power Factor and Reduced Harmonics

The power factor, harmonic distortion, electrical efficiency, and electromagnetic compatibility of a system can all be improved by hybrid compensation schemes. Reduced reactive power loss and increased efficient utilization of input electrical power (i.e., powering the load) are the results of a larger power factor. A higher power factor is achieved by bringing the system impedance into closer alignment with the source through the use of hybrid compensation techniques, particularly those involving LCL and LCC setups. Also, by eliminating high-frequency harmonics independently, the resonant elements of these systems reduce total harmonic distortion (THD). Less heat loss, less strain on components, and less electromagnetic interference (EMI) are the results of this more efficient power source. By doing so, we can ensure that all electrical regulations are satisfied and that equipment around are safer.

4. RESULTS

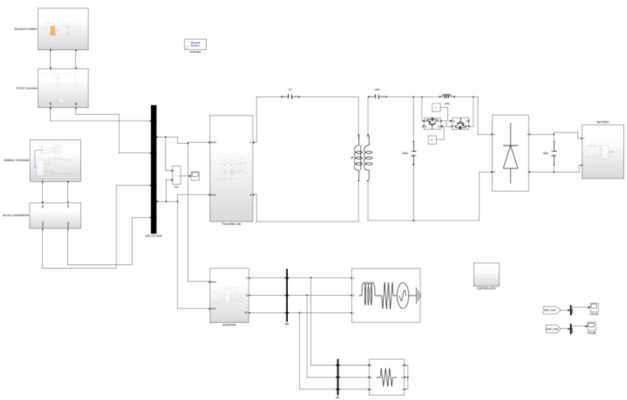

Fig1. Simulink diagram of PV integrated wireless charging system.

The maximum allowable current across the circuit is 3.3 kW and 85 kHz. We examine a range of load resistance values, from 25% to 100%, to illustrate the operation of the constant current mode. It quantifies the current and voltage at the source. You will require resistance levels of125%,150%,175%, and 200% to display this in CV mode. The research confirms that the load current remains constant at 8.85 A even when the load voltage increases when CC mode is turned on. Even if the discharge current decreases in CV mode, the load voltage remains constant at 350 V. As the load resistance is varied, the current and voltage are

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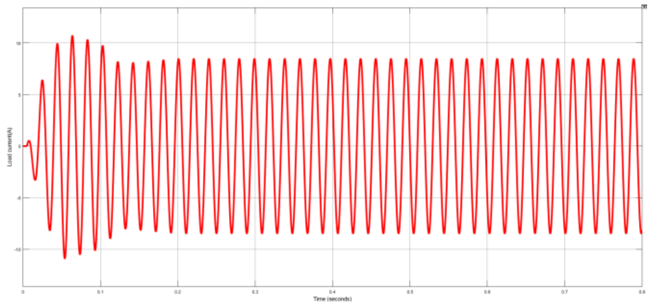
depicted in Figures 2 and 4, respectively. The load side voltage increases as the CC mode equivalent resistance approaches the rated resistance level. Even while the load current remains constant, Figures 2(b), (d), and (f) demonstrate that the load voltage fluctuates. The load current increases in tandem with the load resistance value when CV mode is turned on, and decreases as the load resistance value decreases. There is no relationship between the resistance value and the voltage at the load. Figures 3 and 5 display the whole-load RL's THD% voltage and current.



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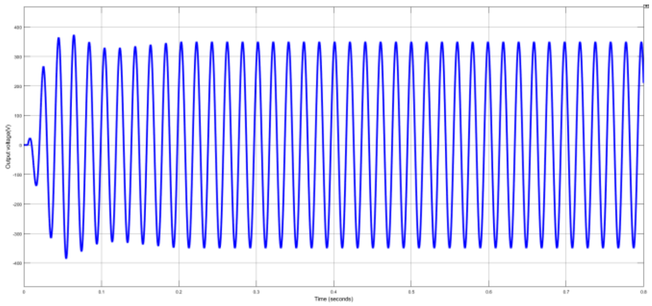

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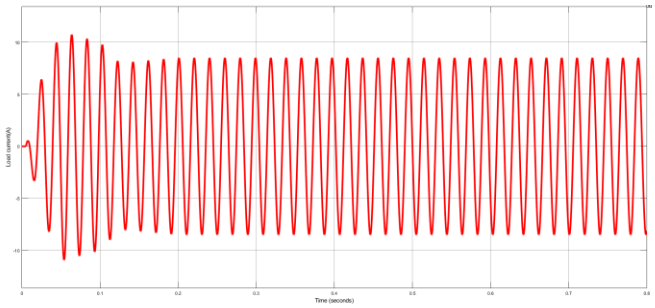

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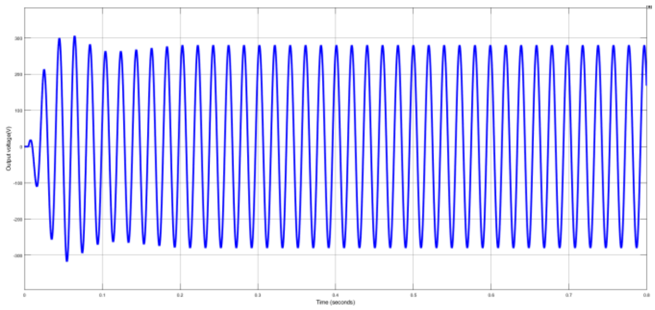

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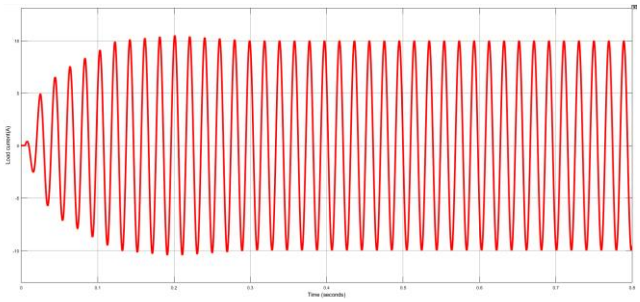

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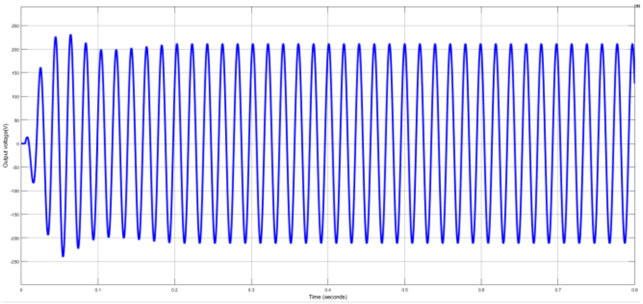

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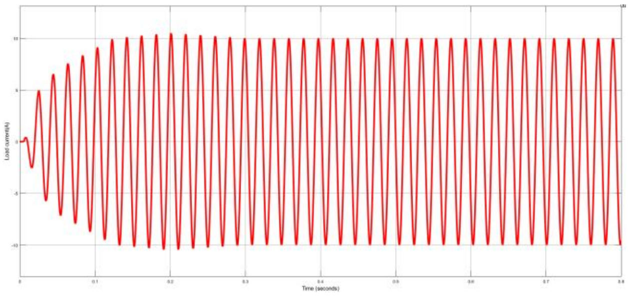

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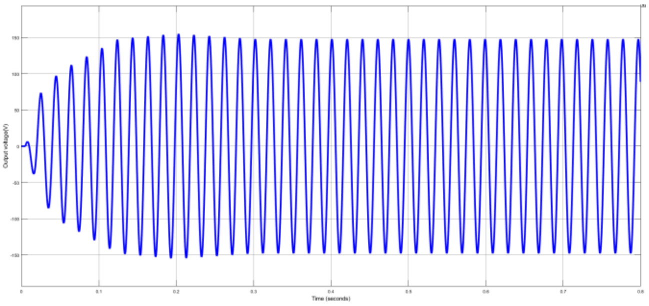

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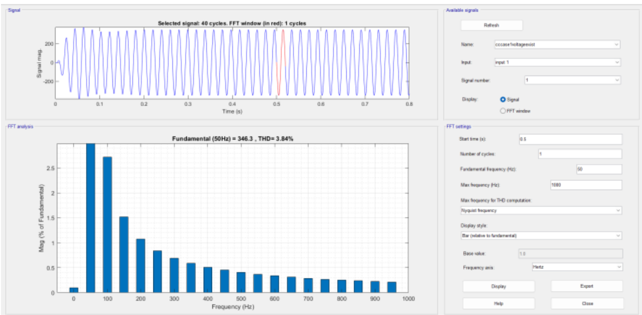
Fig 2 CC mode of operation measured load voltage and current (a) IL at 100% RL (b) VL at 100% RL (c) IL at 75% RL (d) VL at 75% RL (e) IL at 50% RL (f) VL at 50% RL (g) IL at 25% RL (h) VL at 25% RL .



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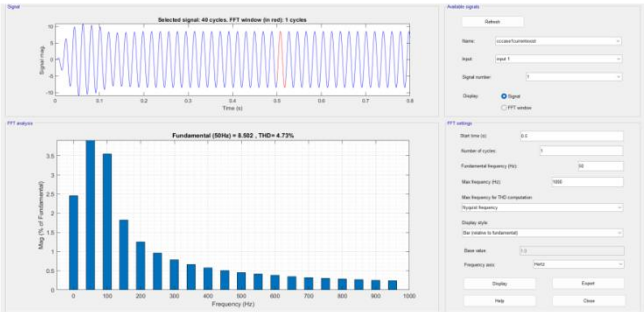

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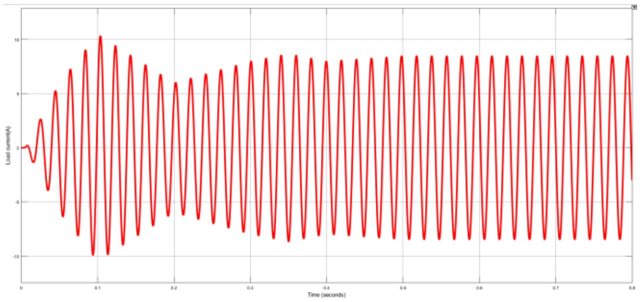
Fig 3 THD% of Load voltage and current



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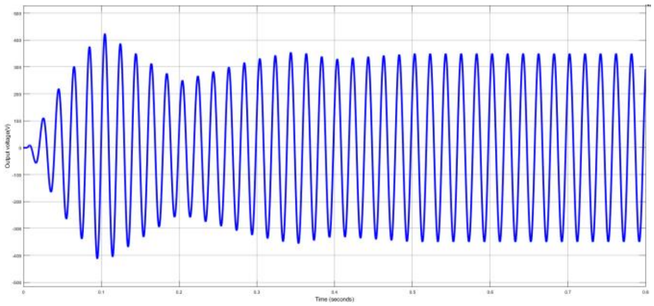

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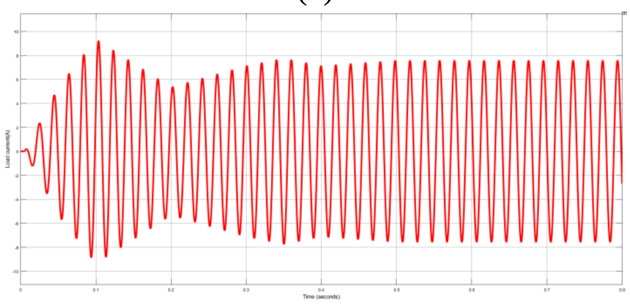

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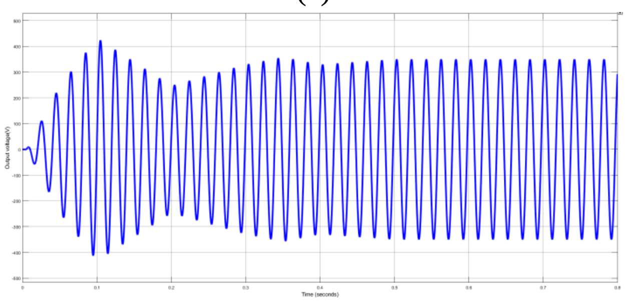

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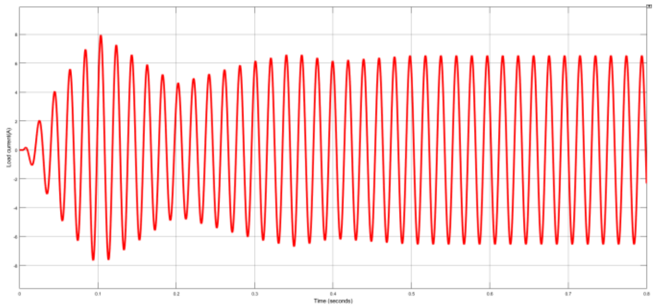

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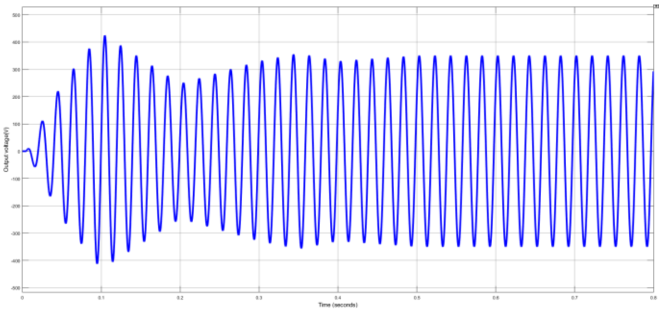

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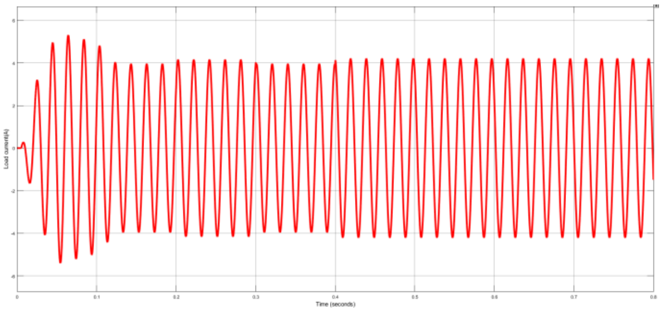

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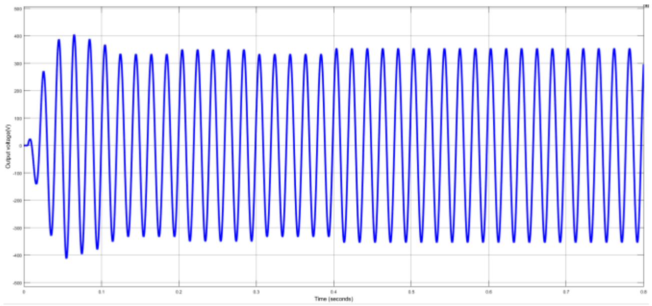
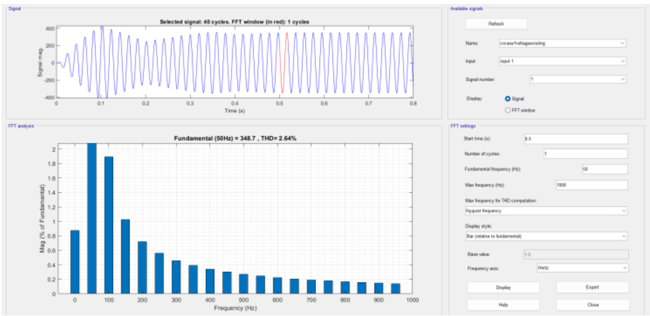


(h)

Fig 4 CV mode of operation measured load voltage and current (a) IL at 125% RL (b) VL at 125% RL (c) IL at 150% RL (d) VL at 150% RL (e) IL at 175% RL (f) VL at 175% RL (g) IL at 200% RL (h) VL at 200% RL



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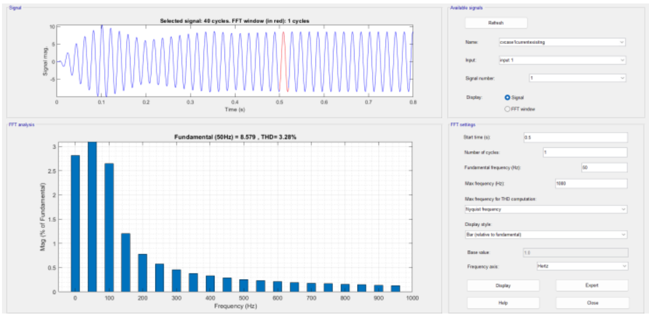

(b)

Fig 7.5 THD% of Load voltage and current

5. CONCLUSION

It's a huge step forward in developing greener transportation infrastructure to have solar-powered wireless charging systems for EVs that incorporate hybrid adjustment methods. In order to make charging simple, secure, and self-sufficient, these systems combine renewable solar energy sources with wireless power transfer (WPT) technology. Real hookups are unnecessary. You can obtain hybrid compensation topologies by combining series-parallel or LCL configurations. These have stabilized reactive power flow, reduced alignment sensitivity, and increased power transfer efficiency.

According to a new research, mixed compensation networks not only improve overall system efficiency to the tune of 90%+, but they also dependably function over a wide variety of irradiance, load, and coil alignment conditions. Voltage stability, EMI reduction, and system longevity are all improved via control approaches like as adaptive frequency modulation, fuzzy logic optimization, and MPPT-enabled DC conversion.

Smart cities, urban mobility, and outlying regions with spotty or nonexistent grid connections are further potential applications of these technologies. With capabilities like temperature adjustment, real-time energy monitoring, and AI-driven control optimization, these wireless charging solutions are more practical and adaptable.

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