Advancements in Contactless Battery Charging for Electric Vehicles Integrated with PV Systems

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Abstract

This abstract outlines a novel approach to utilizing wireless power transfer (WPT) technology for electric vehicle (EV) applications, specifically focusing on harnessing power from a photovoltaic (PV) array. The system proposed employs a Series-Series compensated network to efficiently extract power from the PV array and recharge the EV battery. Recognizing the significance of resonance in power transfer efficiency, the paper conducts a frequency analysis of the compensator to account for reactive components. MATLAB Simulink software is utilized for simulation, presenting results that validate the proposed system's efficacy. Notably, the system demonstrates adaptability to diverse climatic conditions and potential for enhancement through closed-loop controllers.

Keywords: *PV array, H-bridge inverter, Rectifier, wireless power transfer, series-series compensation, photovoltaic, Battery, Transmitter, Receiver.*

I.Introduction:

Wireless power transfer (WPT) technology has emerged as a promising solution to address the charging challenges faced by electric vehicles (EVs). By simply parking the vehicle at a charging station, WPT eliminates the need for physical connectors. Its adoption in EVs has seen significant growth in recent years. WPT involves the use of an inductor and a considerable air gap between transmitting and receiving components. These inductor windings are typically linked to a magnetic core, enabling efficient power transfer through tight coupling. However, without a shared magnetic core, the efficiency of power transfer diminishes.

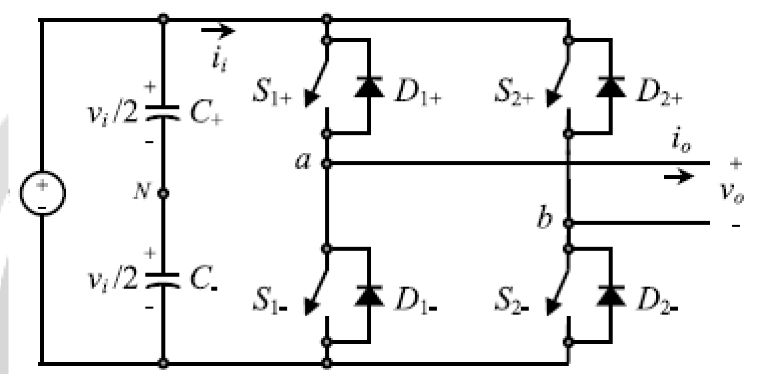
To mitigate this efficiency loss, maintaining inductors at resonance frequency is key. This is achieved by adding capacitors on both ends of the inductor, allowing for resonance to be achieved through various reactive components. A frequency analysis of a Series-series compensator is conducted to pinpoint the optimal frequency for wireless power transfer.

Moreover, integrating photovoltaic (PV) arrays offers an eco-friendly alternative for EV charging. By harnessing solar energy, PV cells can directly replenish the vehicle's battery. Leveraging solar energy as the primary power source for WPT systems is feasible by converting the electricity generated by PV arrays into high-frequency AC voltage through power conversion devices. This enables seamless power transfer to the battery charging circuit.

II.**Full-Bridge VSI:**

The power topology of a full-bridge VSI. This inverter is similar to the half-bridge inverter; however, a second leg provides the neutral point to the load. As expected, both switches S1. and S1ÿ (or S2. and S2ÿ) cannot be on simultaneously because a short circuit across the dc link voltage source vi would be produced. There are four defined and one undefined

The undefined condition should be avoided so as to be always capable of defining the ac output voltage. In order to avoid the short circuit across the dc bus and the undefined ac output voltage condition, the modulating technique should ensure that either the top or the bottom switch of each leg is on at any instant. It can be observed that the ac output voltage can take values up to the dc link value vi , which is twice that obtained with half-bridge VSI topologies. Several modulating techniques have been developed that are applicable to full-bridge VSIs. Among them are the PWM (bipolar and unipolar) techniques.



PWM Technique:

States 1 and 2 (Table 14.2) are used to generate the ac output voltage in this approach. Thus, the ac output voltage waveform features only two values, which are vi and ÿvi. To generate the states, a carrier-based technique can be used a sine half-bridge configurations where only one sinusoidal modulating signal has been used. It should be noted that the on state in switch S. in the half-bridge corresponds to both switches S1. and S2ÿ being in the on state in the full-bridge configuration.

Similarly, Sÿ in the on state in the half-bridge corresponds to both switches S1ÿ andS2. being in the on state in the full-bridge configuration. This is called bipolar carrier-based SPWM. The ac output voltage waveform in a full-bridge VSI is basically a sinusoidal waveform that features a fundamental component of amplitude ^vo1that satisfies the expression

$$\hat{v}_{o1} = \hat{v}_{ab1} = v_i m_a$$

In the linear region of the modulating technique (ma _ 1),which is twice that obtained in the half-bridge VSI. Identical conclusions can be drawn for the frequencies and amplitudes of the harmonics in the ac output voltage and dc link current, and for operations at smaller and larger values of odd mf(including the over modulation region (ma > 1)), than in half bridge VSIs, but considering that the maximum ac output voltage is the dc link voltage vi . Thus, in the over modulation region the fundamental component of amplitude ^vo1 satisfies the expression

$$v_i < \hat{v}_{o1} = \hat{v}_{ab1} < \frac{4}{\pi} v_i$$

In contrast to the bipolar approach, the unipolar PWM technique uses the states 1, 2, 3, and to generate the ac output voltage. Thus, the ac output voltage waveform can instantaneously take one of three values, namely $v_i, -v_i,$ The signal vc is used to generate van, and $-v_c$ is used to generate vbN ; $v_{bN1} = -v_{aN1}$. .On the other hand, $v_{o1} = v_{aN1} - v_{bN1} = 2 \cdot v_{aN1};$ thus $\hat{v}_{o1} = 2 \cdot \hat{v}_{aN1} = m_a \cdot v_i.$ This is called unipolar carrier-basedPWM.

Identical conclusions can be drawn for the amplitude of the fundamental component and harmonics in the ac output voltage and dc link current, and for operations at smaller and larger values of mf , (including the over modulation region (ma > 1)), than in full-bridge VSIs modulated by the bipolar SPWM. However, because the phase voltages $(v_{aN} \text{ and } v_{bN})$ are identical but 180_ out of phase, the output voltage $(v_o = v_{ab} = v_{aN} - v_{bN})$ will not contain even harmonics. Thus, if mf is taken even, the harmonics in the ac output voltage appear at normalized odd frequencies fh centered around twice the normalized carrier frequency mf and its multiples. Specifically,

$$h = lm_f \pm k \qquad l = 2, 4, \ldots$$

where k . 1; 3; 5; . . . and the harmonics in the dc link current appear at normalized frequencies fp centered around twice the normalized carrier frequency mf and its multiples. Specifically,

$$p = lm_f \pm k \pm 1 \qquad l = 2, 4, \ldots$$

where k . 1; 3; 5; . . .. This feature is considered to be an advantage because it allows the use of smaller filtering components to obtain high-quality voltage and current waveforms while using the same switching frequency as in VSIs modulated by the bipolar approach.

RECTIFIER - AC DC CONVERTER

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

A device which performs the opposite function (converting DC to AC) is known as an inverter.

When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term*diode* and the term *rectifier* is merely one of usage, i.e., the term *rectifier* describes a *diode* that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper (I) oxide or selenium rectifier stacks were used.

Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector". Rectification may occasionally serve in roles other than to generate direct current per se. For example, in gas heating systems *flame rectification* is used to detect presence of flame. Two metal electrodes in the outer layer of the flame provide a current path, and rectification of an applied alternating voltage will happen in the plasma, but only while the flame is present to generate it.

III. **PV System Design:**

A photovoltaic (PV) array comprises interconnected PV cells that convert light energy into electricity. These solid-state devices harness photons to generate an electrical current, facilitating energy storage and flow. Typically assembled into modules, PV cells capture sunlight energy, collectively forming solar panels. This technology, known as photovoltaics, encompasses both practical applications and theoretical advancements.

PV systems offer several advantages:

1) Renewable Energy Source: Solar energy from PV panels replaces electricity generated by fossil fuels, reducing greenhouse gas emissions as adoption increases.

2) Reliability and Longevity: Industrially-matured PV panels offer durable, efficient energy production. Manufacturers provide warranties ensuring longevity and efficiency, with some panels lasting up to 25 years.

3) Autonomous Operation: PV panels operate quietly and autonomously, with minimal maintenance requirements. Some systems utilize adjustable mechanisms to track the sun, maintaining efficiency without disturbance.

4) Low Operating Costs: PV panels require minimal maintenance and operating costs, with increased efficiency through regular cleaning.

However, PV panels also present challenges:

1) Low Efficiency: Compared to other renewable sources like wind turbines, PV systems exhibit efficiency levels ranging from 12% to 20%, limiting their effectiveness.

2) Conversion Costs: PV panels require DC-to-AC conversion for consumption, incurring expenses for electronic equipment and facing technological limitations. Implementation costs also rise with panel size.

3) Energy Storage Limitations: Solar energy cannot be stored for later use, affecting output during nighttime or adverse weather conditions. This variability impacts the financial performance of PV projects.

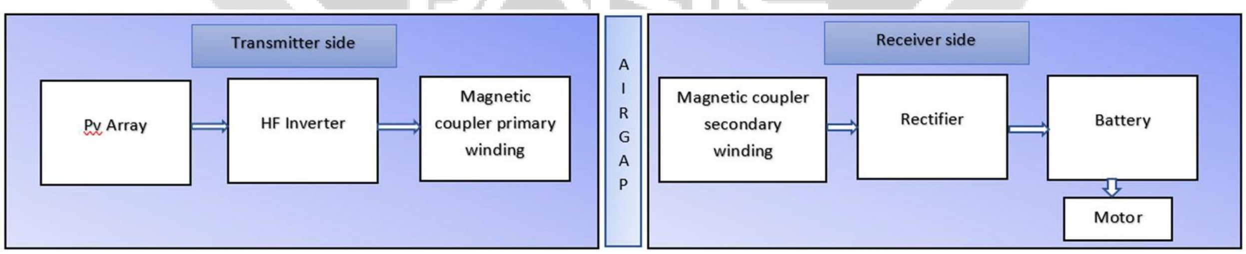


Fig. Test system representation

Induction Network:

When an electric circuit exhibits mutual inductance between its components, typically inductors and coils, it's considered coupled. The terms "inductor" and "coil" are sometimes used interchangeably, with a component acting as an inductor in the absence of other elements like resistors.
From the frequency analysis [6] there are 3 frequencies available as follows.

$\omega_{01}=1/\sqrt{(L_1C_1)}$
$\omega_{02}=\omega_{01}/\sqrt{(1-k)}$
$\omega_{03}=\omega_{01}/\sqrt{(1+k)}$

The compensation network, comprising various inductors and capacitors, gives rise to three distinct resonance frequencies. Existing literature indicates a preference for the self-inductance and capacitor frequency as the primary resonance frequency, while the others involve leakage inductance and capacitor frequencies. These three resonance frequencies are thoroughly investigated. The first pertains to self-inductance frequency, while the remaining two concern leakage inductance and voltage gain. It's noted that voltage gain may vary with the quality factor's alteration, but remains constant at 1 for the other two frequencies regardless of load variations.

These three resonance frequencies are thoroughly investigated. The first pertains to self-inductance frequency, while the remaining two concern leakage inductance and voltage gain. It's noted that voltage gain may vary with the quality factor's alteration, but remains constant at 1 for the other two frequencies regardless of load variations.
The determination of the third resonance frequencies relies on the coupling coefficient (k). In power electronic applications, ω02 is favored due to a consistent voltage gain of 1, while in other scenarios, ω03 is preferred. Series capacitors and inductor values are computed based on the first resonant frequency, ω01.
For enhancing power transfer efficiency in inverters, operating at the second resonance frequency proves beneficial. Table-1 Represents Coupled inductor parameters

Table-1

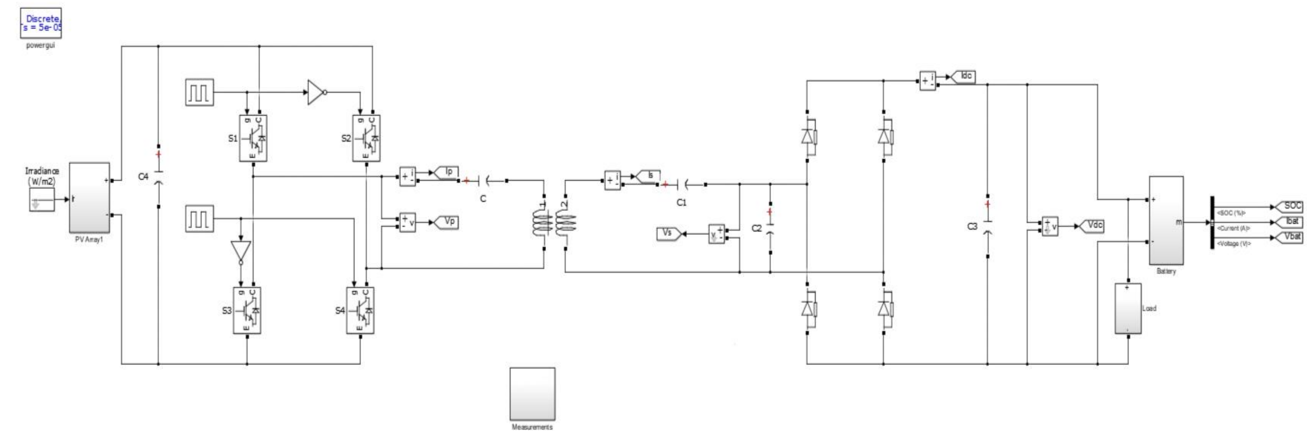
S.no	Name of the component	Value
1	Turns ratio	1:1
2	C1, C2	0.1uF
3	L1, L2	126.6uH
4	Mutual Inductance	25.3uH
5	Coupling Coefficient	0.2

IV.EV Model:

A battery comprises multiple cells that undergo chemical reactions to generate an electron flow, commonly known as electricity. Its fundamental components include an anode, a cathode, and an electrolyte. When connected to a circuit, the chemical interaction between the anode and cathode initiates electron movement, facilitating electrical flow. However, if materials in either component remain uninvolved in the reaction, the battery ceases to produce electricity. Batteries intended for single use are termed primary batteries, while those rechargeable are secondary batteries. For this project, a Lithium-Ion battery, widely utilized in electric vehicles (EVs), is employed.

In addition to the core components, supplementary elements like a filter and motor are incorporated. The filter ensures a smooth output without waveform disturbances, while the motor serves to validate the model's functionality in tandem with real-world EVs.

V.Simulation Diagram:



VI.Result Analysis:

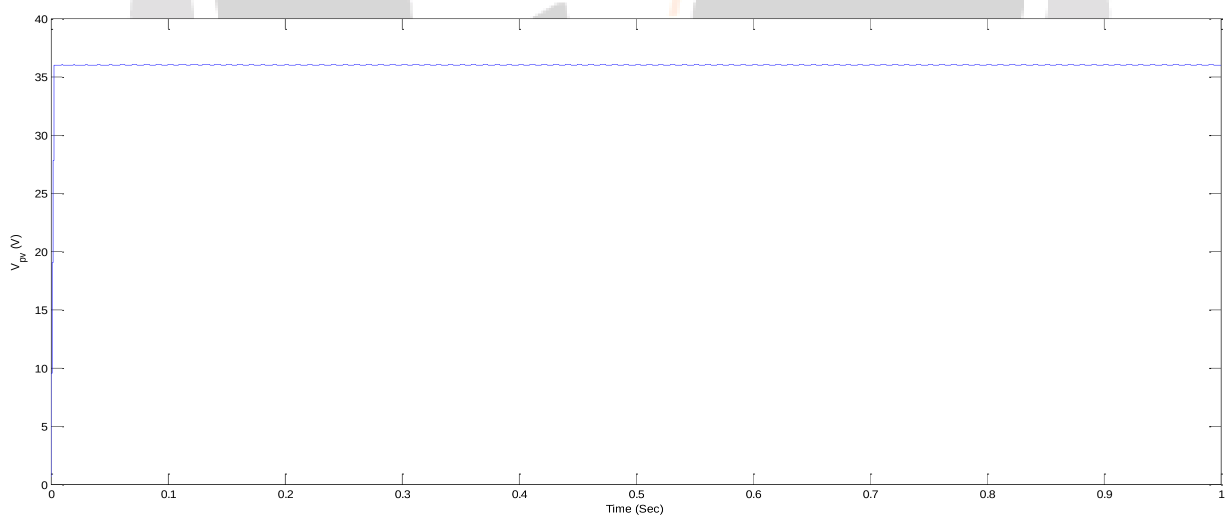


Fig. Voltage of a PV system

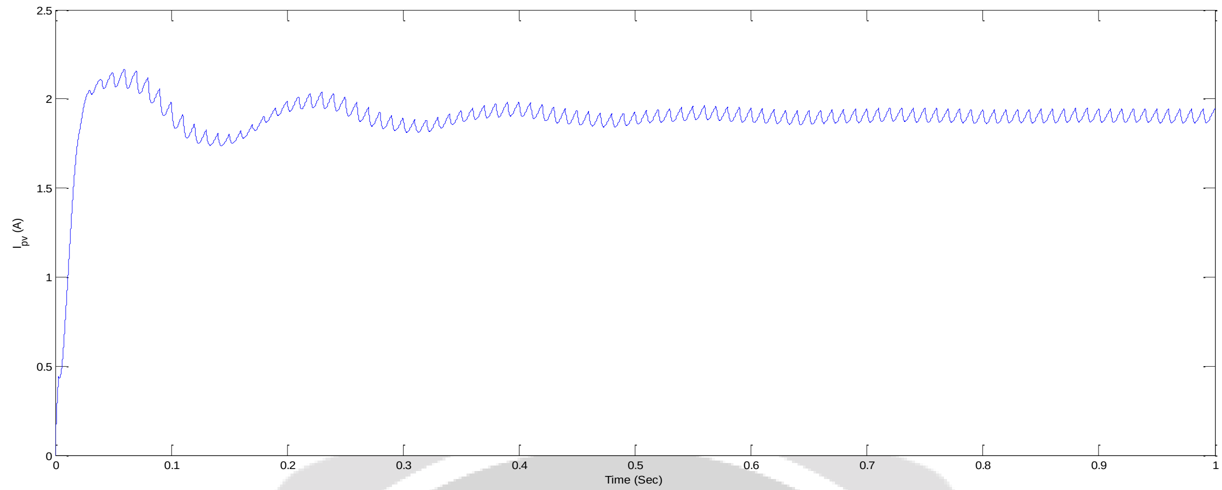


Fig. Current of PV System

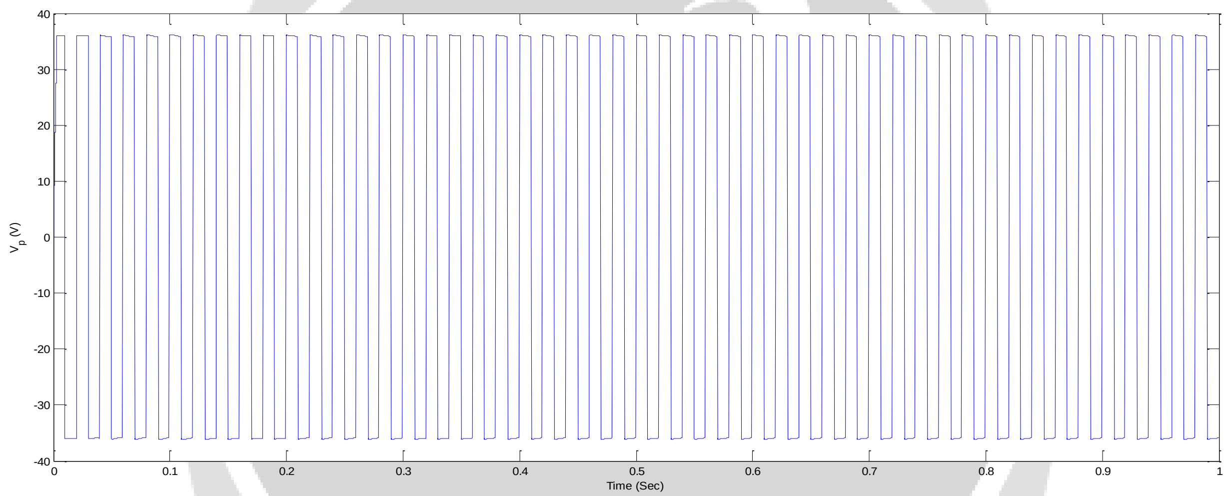


Fig. Primary Voltage of proposed system

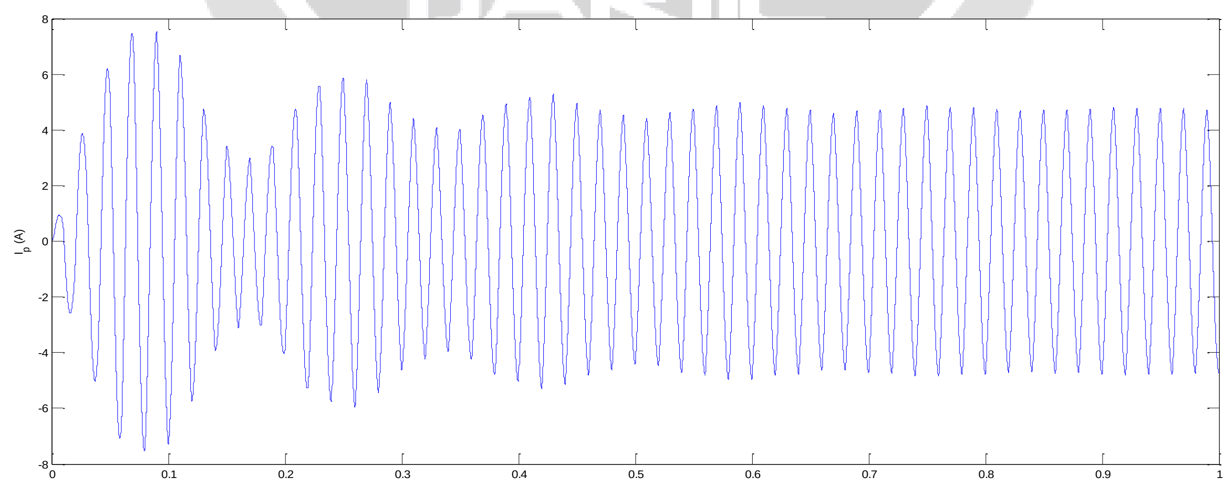


Fig. Primary Current of Proposed system

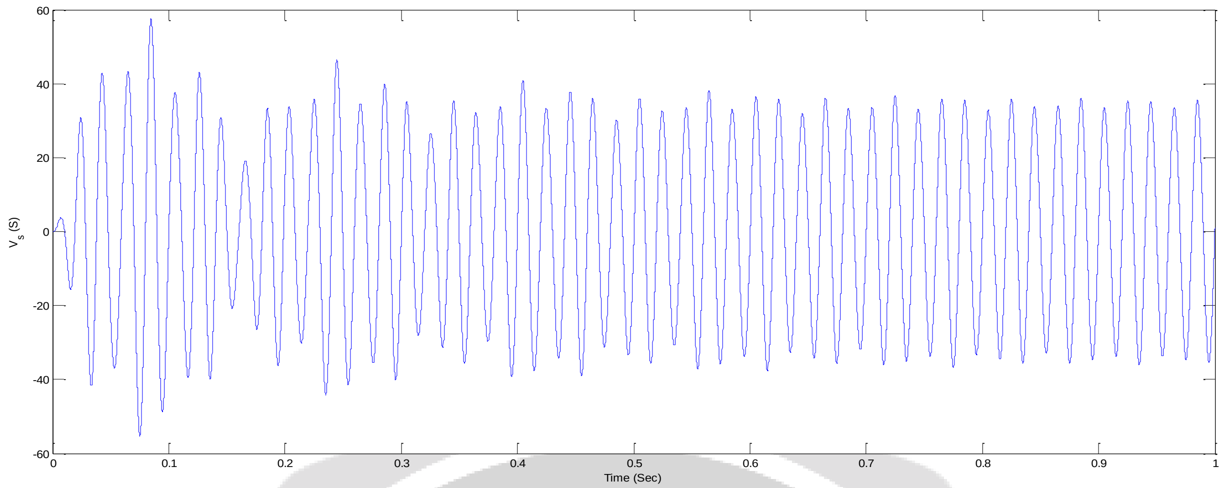


Fig. Secondary voltage of Proposed system

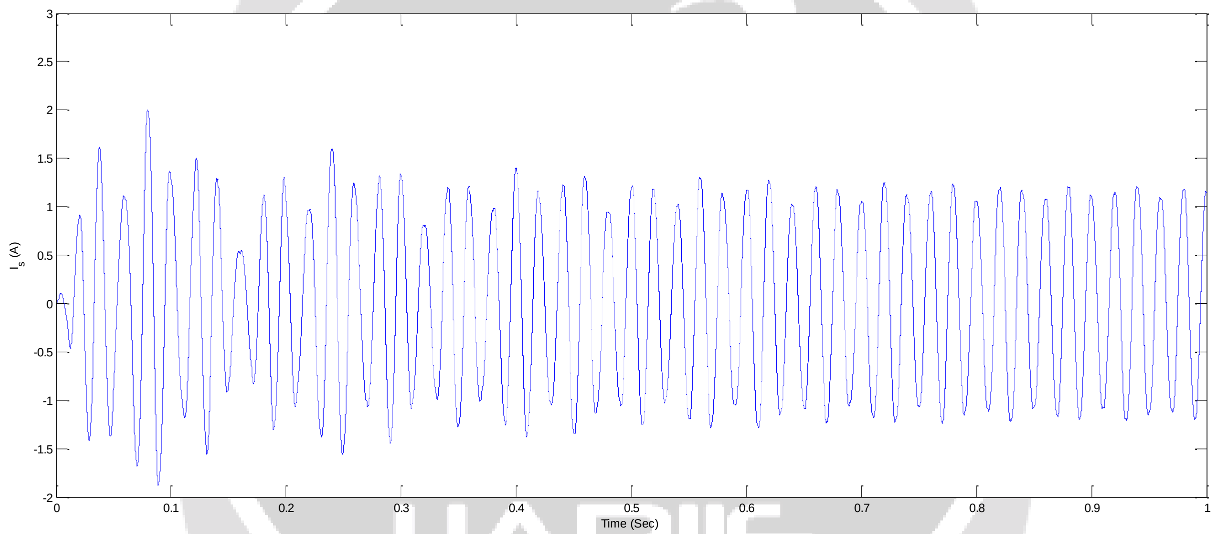


Fig. Secondary Current of Proposed system

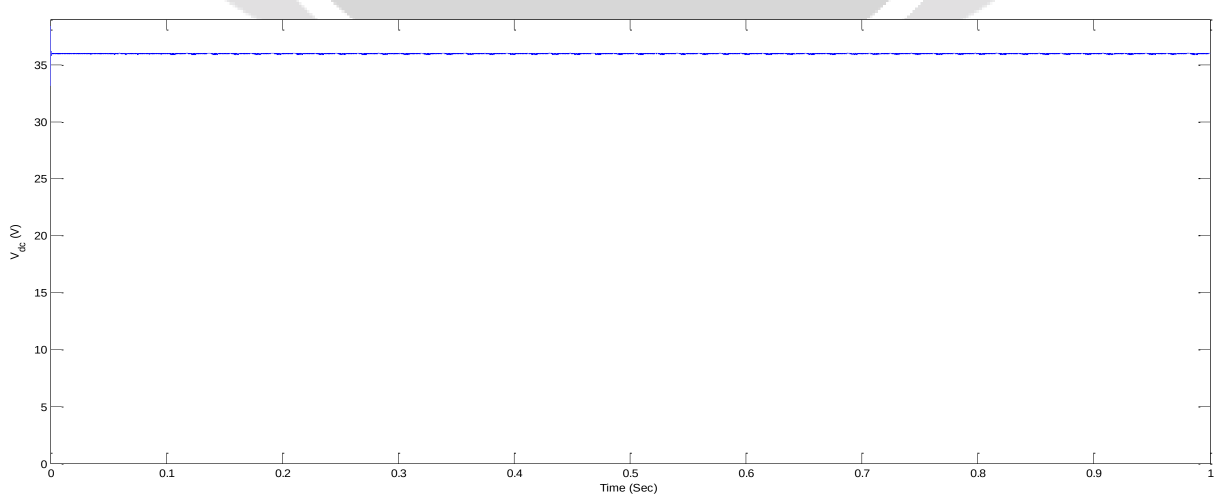


Fig. DC link Voltage

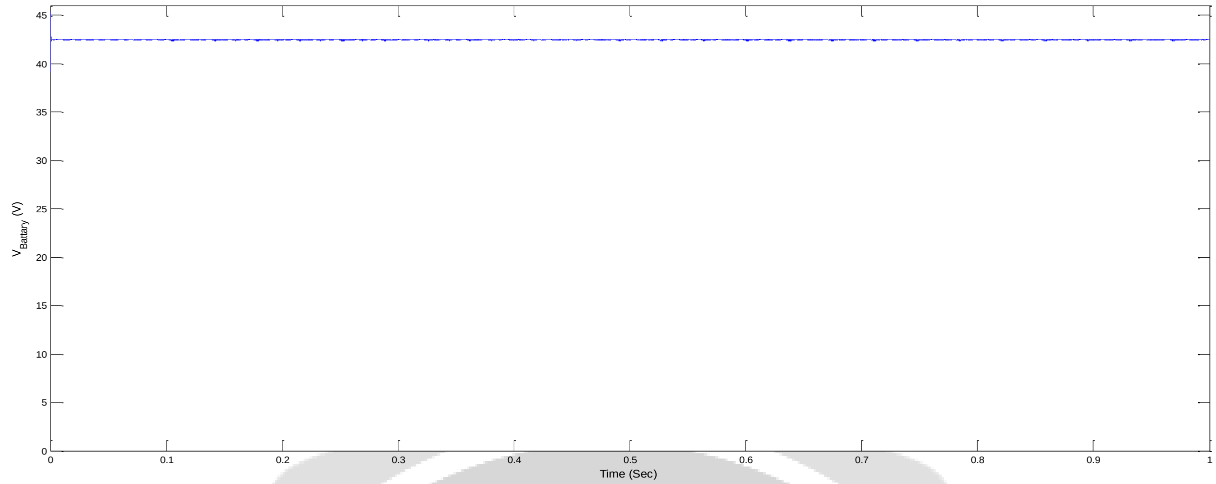


Fig. Voltage of Battery

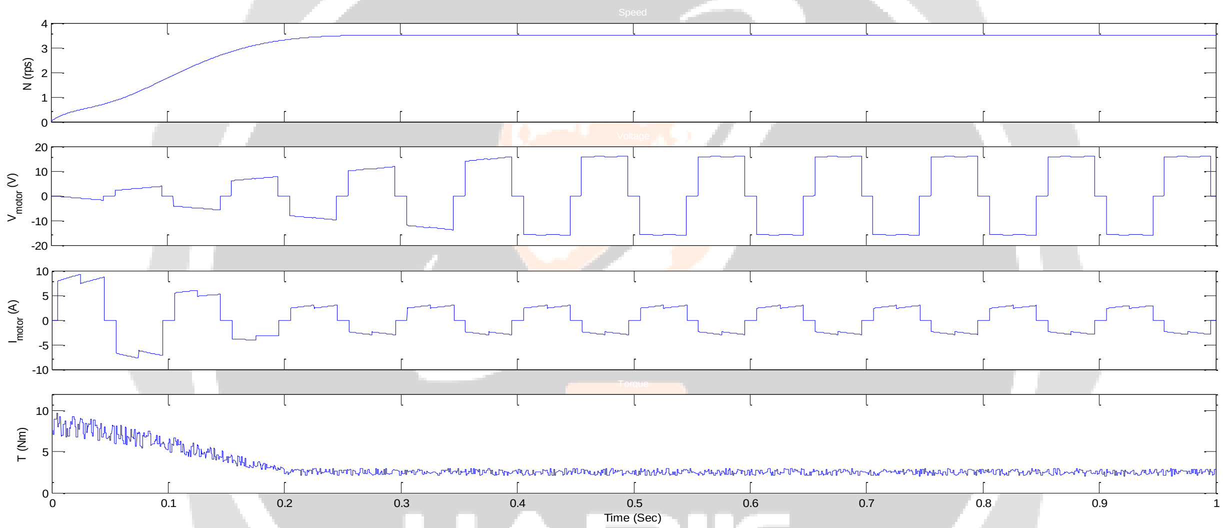


Fig. Motor Load Parameters

VII.Conclusion:

This paper introduces a proposed system for charging a battery from a photovoltaic (PV) array using wireless power transfer (WPT) mode. The system's feasibility is assessed through a comprehensive frequency analysis of its components and compensation network. A laboratory prototype is under development to validate the simulation results through experimental testing. Successful validation of both simulation and experimental results would confirm the viability of the proposed system for operational use.

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