



Design, Simulation and Estimation of battery SOC using Wireless Dynamic charging technique for Electric Vehicle Battery pack

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Abstract: Wireless power transmission (WPT) exploiting glamorous resonance is a technique that might liberate humans from the tyranny of cords. Various investigations are now being conducted for improving the efficiency of said technique. The idea is to extend the distance between the transmitter and the receiver while using less transmission power. This concept required the use of WPT's technology to charge battery of the electric car. This dissertation improved overall distance position between transmitter circuit and receiver circuits while also investigating the varied power positions at different distances between the transmitter and receiver.

In effort to reduce fuel consumption and pollution, the use of electric vehicles (EV) rather than combustion engine cars is rapidly expanding. The most pressing worry of heat unit users is being handled by themselves through various pricing methods. The layout of charging infrastructure may be the most important difficulty in the adoption of heat units. The wireless charging system (WCS) is a popular opportunity in the expanding heat unit industry. This research develops a WCS for charging electric automobiles using inductively linked power transfer technology. In MATLAB/SIMULINK, a simulation system is created, and the simulation results are used in order to validate the system's performance.

Index Terms - MATLAB, Simulink, Electric Vehicle, Battery, SOC, Wireless Technology.

I. INTRODUCTION

Wireless technology is fetching extra widespread as a battery charging mechanism for electric vehicles (EVs). The proposed wireless EV battery charging methodology is based on a magnetic coupling based Inductive Power Transfer (IPT) in order to pass on energy to two coil. One of these coils are having linkage to the electrical grid and the other coupled with the rechargeable battery. Technology based on IPT gives advantages in terms of safety and comfort. Because there is no draw-in operation with IPT, electrocution from power lines is avoided, and the battery charging operation may begin immediately.

Based on the condition of the EV, we have two categories of IPT for wireless charging: stationary referred as static IPT, means the vehicle is stable or immobile and nothing is inside it. Dynamic or quasi-dynamic IPT, when the vehicle is in operation. Because a cable connection would be impossible during the stir, wireless power transmission is clearly the only solution for dynamic charging. Despite the undeniable benefits of Inductive Power Transfer, researchers must address many difficulties in order to make this technology really appealing for EV demand [9] [19].

When compared to a traditional line-based system, the IPT system is fundamentally less successful in terms of power transmission efficacy. Indeed, there is a necessary minimum leakage glamorous field owing to the glamorous coupling between the coils, resulting in an energy loss. Similarly, various technical elements must be considered in the practical performance of an IPT system. For example, in order to achieve maximum coupling, the misalignment between the coils must be as little as feasible. In terms of safety, while the IPT reduces the risk of electrocution, some caution is required when working in a glamorous area. Aside from design concerns, other key considerations should be taken, such as pricing, infrastructure consequences, standards, and customer event.

Inductive coupling is also found suitable for the power flow from a Grid to wheel and wheel to grid. Based on the recent trends of active consumption in a smart grid based electric energy distribution. The customer is a good candidate to become an energy patron. Wireless power transmission can support V2G and therefore be a Bi-Directional Inductive Power Transfer (BDIPT)[18].

The majority functions of wireless charging batteries are need to be explored to meet the changing scenarios of EV charging. A broad domain knowledge on IPT arrangements need to be verified and explored with a focus on the electrical and glamorous design. Following that, the IPT applied to EVs is tossed about in terms of broad overview and concerns on flashy couplers, design techniques. Control tactics and safety problems are implemented.

For a cordless electric car battery charging, IPT system is suggested. The linked coils and the power electronics system are designed with special attention. A 48 V Lithium battery is used, with electrical output ranging from 100 W to 250 W. The simulations were done out using the MATLAB platform. Similar issues such as bifurcation and skin impact are also addressed. A typical Bi-Directional Inductive Power Transfer (BDIPT) system is thoroughly evaluated in terms of power transfer and effectiveness as a function of certain control parameters, and an effectiveness optimization technique is presented in addition to the system design. Electronic simulations are used to validate the fine analyses [14].

inductive coupling results are offered in place of planned and constructed inductive coils. The design refers with respect to the air gap available with the coils and designed with measures to fit within the limits of an automotive wheel. A discussion of these choices using the COMSOL Metaphysics program leads to the characterization of the best outcome in terms of efficacy and acceptance thresholds of deviations or misalignments. The comparison is conducted with an exact model of the entire system, including switching losses inside the electronic elements. The proposed wireless charging technology will support in accessing the vehicle from multiple point of location on other side this technology has a vast business opportunity at locations like Hospitals, industries, overcrowded roads, educational institutions etc. [2][10]

A. Wired Charging Station

An EV charging station is a set of equipments which connects an electric vehicle (EV) to a power input in order to recharge EV. Some charging stations may provide advanced features such as, network access, E-billing with smart metering, and many more features.

The Charging mechanisms or facilities are also refereed as electric vehicle energy outfit (EVSE), which are distributed in public parking areas or malls or nearby hotel or motels. These stations include customized connections that meet a range of electric charging connector standards. EVSE freight costs range from yearly or monthly flat fees to per-kWh to hourly rates. Charging stations may be provided with almost free of cost or on subsidize cost with government involvement to promote EVs [23][8].

The categories of EVSE provide different charging options. Position 1 charging equipments deploy a 120 volt (V), AC input and a devoted circuit, which may support for an hour charging coverage of approximately 5 miles. Position 2 stations will be charged by a 240V, AC draw and carry home charging or public charging setup. For every hour of charging, position 2 stations provide 10 to 20 long hauls of range. The most prevalent are position 2 guns, which charge at nearly the same pace as a home system.

DC fast guns are another name for position 3 guns. Level 3 draws 480V direct electricity. They bypass the on-board bowl and deliver DC power to the battery through a devoted charging port. DC Fast guns can provide up to 40 longer trips of range for every 10 swirls of charging, however they are not compatible with all automobiles. Conversely, certain proprietary charging stations, such as the Tesla Supercharger, are built for substantially faster charging [20][27].

B. Wireless charging System

The wireless assumptions underlying an ever-expanding system of battery charging in a variety of operations. When using the power string is unpleasant or unfeasible, the elimination of cables is recommended. Wireless battery charging may be used in a variety of operations, ranging from huge demand-based systems like locomotives of rail transport to a less power scenarios like electric handheld gadgets, mobile phones, laptops, televisions, electric bikes, and many more.

The typical range for the amount of power consumption may in terms of few mili watt to few watts depending upon the device capacity and the end application [7].

II. LITERATURE SURVEY

A number of renewable sources may be used to generate electrical energy. The comparison of an electric vehicle with the fossil fuel driven vehicle gives clear benefit of zero emission with efficient energy management. That's the reason we need to upgrade and offer facilities to increase energy structure optimization, as EVs are the attractive and effective mode of commutation. But due to the expensive infrastructure, and range anxiety of electric vehicle battery packs, and social acceptance putting restrictions on the growth of EVs further. As compared to the conventional charging system, there is no one on one relationship between the source and the device under charging during the wireless way of power conduction charging sequence, this ensures WPT a viable alternative energy supplement proposition.

Static WP and dynamic WP are the two types of WPT technology used in EVs. DWPT charging is based on SWPT charging and may commendably reduce the bulk of the car battery pack, extend the travelling range, and provide better and improved the charging Mechanisms [5][24]

It was observed in the literature (14) that the energy or power transfer may be regulated by modifying either the phase-shift position or conducting (DC) - connection voltage. As a result, DC- link voltage and change in phase- angle together results in a control system to increase system effectiveness, dynamic sensitivity, and to lengthen the reliable electricity range. The research of operations and systems for wireless charging EVs is a multifaceted exploration domain whose success is contingent on integrated sweats. There is little doubt that program at the university on operations and systems views is vital, particularly at this stage of

technology development. WPT tech, a significant enabler of wireless charging Automobiles, has been spontaneously perfecting. [14][31]

As aforementioned, numerous compensated WPT systems have already been granted access. Changing at an unprecedented the technology has flourished to this point, thorough investigations of its operations and system counteraccusations for inductive recharging EVs are demanded. There are several reasons why such a soliloquy is desirable.

Nottingham, United Kingdom, has initiated an inductive charging experiment for electric cars. In this case in point, ten taxis were outfitted with inductive charging technology, whom they exploited to recharge their batteries while awaiting for their next fare during certain ranks. This is a reoccurring subject when addressing cordless EV charging - a little-and-often method rather than the faster but less frequent utilization of swift plug-in chargers. In considerations of installing such a charger in the home, a US company called Plug less Power is working on its third-generation electromagnetic EV charger, which will be available in 2027. Manhattan in the New York city, has also planning or OLEV technology for bus service transit using SWC, QWC & DWC power transmitting techniques. These vehicles would be called as online vehicles which will get recharged while running onto road [5][17][32].

These would be intended to work with a 240V US domestic output, fit to existing automobiles, and the manufacturer says current can be transferred via an air gap of up to 12 inches, facilitating wireless charging of higher vehicles such as SUVs and trucks. Fewer plugs Power claims its next third-generation wireless charger will costing \$3,500 including installation, and that is also developing chargers for the European market. So, as reviewed till now few of the innovators have succeeded by implementing this technique using the method of resonant inductive power transmission according to the power demands of application [3][16][25]

III. METHODOLOGY

Inductive charging for auto motorists is possible thanks to Inferential Power Transfer. From comfort and protection view point, the stoner must never be concerned roughly management of electrical wiring, there by dodging the danger of electrocution, and might position the vehicle so that the charging operation can actually start automatically. As advised by, the coils are commonly installed in the prescribed sequence: the one related to the matrix is placed on the facing area, whereas the other is coupled to the battery is placed at the nethermost of the vehicle frame. In most cases, the minimum power position for recharging an electric vehicle is 3 kW.

Since EV firms are losing interest in this novel charging technology, many exemplifications of commercialized wireless charging stations for electrical vehicles might be handed out. Many leading companies like Ford, Toyota, and Nissan are among the businesses interested in the inductive based charging stations and allied system providers. Amongst the creative agencies who plays role in wireless charging organizations for EVs, are Evatran and Halo IPT. They are the pioneers in providing and enhancing inductive charging machinery. Evatran established the inductive charging machinery and technology resulting in Power without a plug.

Qualcomm has obtained one of IPT's renderings of the inductive bowl. The advent of rapid charging likely makes IPT more intuitive to EVs. The inductive link amongst the electrical network and the HEVs or EVs may also be used to generate a back power outflow from the vehicle towards the grid. According to the V2G concept, energy may stream from the grid towards a rechargeable battery pack and rear to the grid by operating adjustable power electronics converters. V2G is a commonly acknowledged conception that refers to the most recent concept of active usage in a smart electrical system. The minute a bulk of energy is stored in one stage of the grid, electricity can flow to another stage, transporting energy. **Figure 1** gives the pictorial view of a typical IPT system.

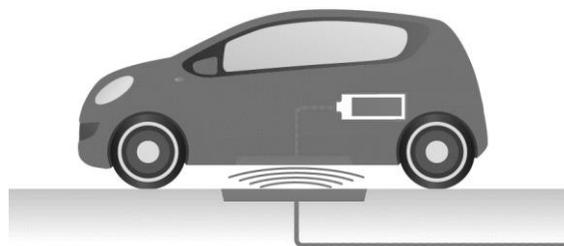


Fig -1: IPT Methodology

IV. IPT SYSTEM DESIGN

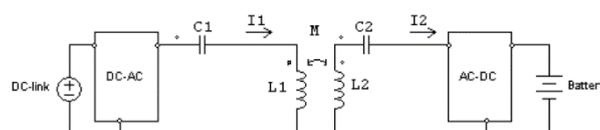


Fig -2: Basic Functional Circuit Diagram

Inductive energy transmission happens among two magnetized connected coils. **Figure 2** represents the basic functional circuit diagram for an IPT system design. Their inductances can be L_1 and L_2 respectively, and their collective mutual inductance is M . The primary and secondary coils are represented by L_1 and L_2 , respectively. The input side or primary part of coil is powered by a DC voltage source, while the supplementary DC voltage source represents the to-be-charged battery. Because

energy is delivered in alternating current between the coupled coils, two intermediary stages are necessary, one on the main side and one on the secondary coil or winding side. As these coils are tightly coupled, we need a responsive network to improve power transmission effectiveness and get the best ($\cos \phi$) power factor while the arrangement is in its resonance condition. A compensating circuit is a reactive network that be made of two capacitors, individual placed on either side. The **Figure 3** shows the primary circuit at grid and in that one can add the compensating capacitance C1 and C2 in series with both the coils, one on primary and other at secondary side.

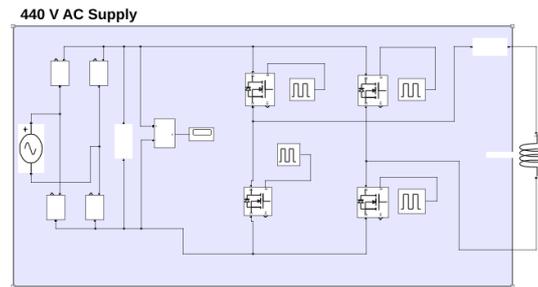


Fig -3: Primary Circuit at Grid

As the alternating current nature of the inductive connection seen between coils, the voltages induced in both the coils will be obviously alternating in nature. The power source is the off course electrical grid, prime energy input and the driven element or the load will be the battery under charging. There is need for 2 power converters one will be on the main winding end and other will be at secondary winding end. At the main winding side, a matching stage or twin is usually coupled, which get up from the cascade of an AC-DC a rectifier stage and a DC-AC the inverter

The secondary side AC-DC stage is required. **Figure 4** represents a typical rectifier circuit commonly used. At the load or secondary stage, rectification AC-DC stage is essential to charge the DC battery. AC to DC conversion stage is very common, the stalwarts working in this domain often focuses on the stage between the main and secondary side DC output. Several clarifications for the primary DC-AC rectification phase and the secondary inverter AC-DC phase are being explored and scrutinized. To connect the secondary AC side to the DC battery on the secondary side, two substitutions have been suggested: putting a rectifier plus a DC-DC converter a chopper stage or an active rectifier AC-DC conversion stage.

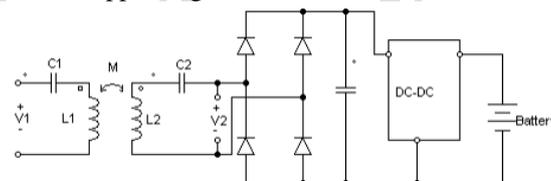


Fig -4: Passive Rectifier

A Bridge of four diodes simply rectifies the alternating current signal produced by the mutually connected coils. But while charging the rechargeable battery, the output DC voltage need to control. While accomplishing this, need to regulate the flux, a in between chopper stage DC-DC conversion is required between the battery and passive rectifier stage. By adopting an active AC-DC stage, the drawback of requiring another stage is avoided. Efficiency and controllability is questionable by using a standard passive rectifier in the AC-DC step. Use of MOSFETs with ultra-low resistance is favorable to improve efficiency.

In respect of maneuverability, an active stage enables direct control of the battery charging current, eliminating the need for an extra DC-DC converter chopper to supply the battery. By altering the phase change between the signals conveyed to the MOSFETs, the amount of electricity flowing to the battery capacity will be well be organized and controlled[11].

A meticulous battery approach is commonly bound to augment battery use. For Li-ion battery packs a concise dynamic model, including thermal effects, nonlinear equilibrium potentials, its thermal expansion and response to transient energy requirements, is presented. The notion, which has been validated through studies, is useful for improving battery runtime.

By creating a dynamic model of a lithium-ion battery, with specific emphasis on nonlinear capacity effects. For the battery charging mechanism to function properly, a precise understanding of the battery's current SOC is essential. For estimating SOC which refers to the nonlinearities between the state of charge and the corresponding open-circuit power output of the battery. **Figure 5** refers to a representative Li-ion battery cell charge profile. Charging modalities are classified into two types: continuous current and constant voltage. The current is maintained constant at a predetermined but it is observed that the value of the voltage rises to a extreme value during the constant current operating mode; after that, the voltage is remains stable at the peak value while the current declines down to minima.

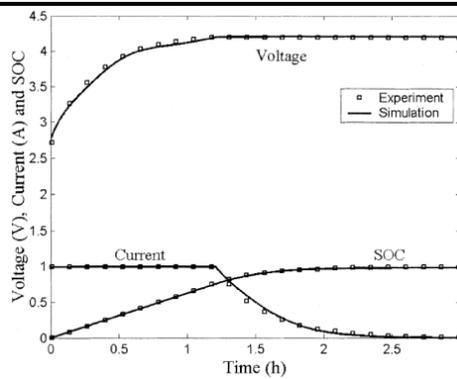


Fig - 5: Charging Characteristics of Lithium Ion Cell

The said WPT system maybe transmits beyond band or excessive EM emissions. To analyze the further risk for the emitted emissions as well as non-directional emissions. The ultimate conclusion was made that the emission can cause certain impact on the surrounding but can be taken care by controlling the direction of emissions [4]

A. Phase shift Control Strategy

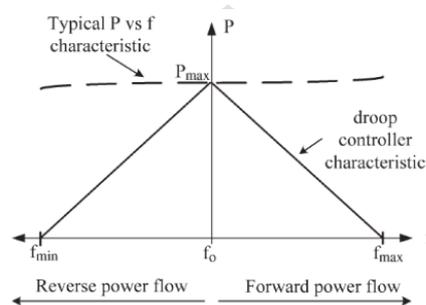


Fig - 6: Frequency Characteristics of power flow

IPT systems, which are intended for EV charging and for bi-directional conduction grids, the phase shift controller is a common control strategy. Control parameters relating to phase angles are used to regulate the amount and direction of power flow in phase shift control. **Figure 6** refers to a standard graph of power flow and frequency relationship. **Figure 7** represents the block diagram for the phase shift control strategy commonly adopted. At 90° , the phase difference between the fundamental harmonics of the main and secondary voltages is maintained. To attain the highest possible power factor and efficiency. The power flow direction varies depending on whether the phase angle is $+90^\circ$ or -90° , showing that electricity flows from the battery to the grid and Vis a versa. By changing the phase angle between each power converter's legs, the load flow amount is adjusted[21]

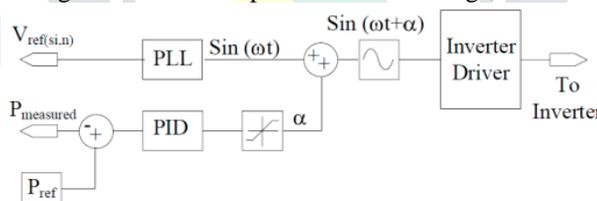


Fig - 7: Phase Shift Control Strategy

The magnitude and phase control is done to IPT system that lacks a compensation network in the secondary side, making secondary side detuning unlikely. Method of phase change control administrates the power flow to the battery of an EV concept that is charged with IPT. BDIPT is conflicting with the proposed topology. Compare to a single-side control the dual-side control enhances efficiency and component stress, exclusively in various load changing circumstances.

For operating frequency, soft or hard-switching action, power component technology, magnetic design considerations and performance for varied air gaps, precise concerns are need to be followed. The highest efficiency of the segment from the DC source to the battery is observed to be 95.8 percent with a minimum air pocket of 10 cm. To avoid the necessity for a communication link amongst both the power transmitter and the electricity receiver a control based purely on information is offered

B. Coil Shape and Design

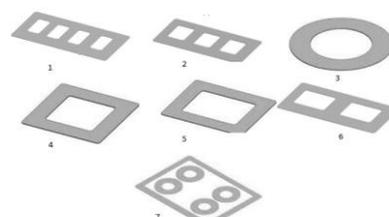


Fig - 8: Coil Shapes

The transmission and reception pads in wireless charging technologies are made up of many component layers to maximize power transmission efficacy and decrease electromagnetic snooping while remaining cost effective. A coil, insulating material (aluminum or ferrite plate), with insulation and reinforcing layers comprise the wireless transformer pads.

For wireless chargeable EVs, cordless air-core transformer model is used to transport several watts to kilowatt hours of electricity from the generator to the reception sides. For variability of planar coil structures, including as spherical, quadrilateral, and fusion layouts, have been analyzed in wireless transducer designs to increase performance and resolve misalignment problems amongst the source and receiver pads. [12][19] The common types of wireless charging coils are the non-polarized pads (NPs) and polarized pads (PPs).

Mirrored pads are constructed from a variety of coils and sizes that create perpendicular and horizontal flux elements. Non-polarized pads, on the other hand, are formed from a single coil and generate only perpendicular (vertical) flux components. **Figure 8** shows the typical design and shapes followed in most of the typical wireless converters. NPPs come in a variety of coil forms, including circular, square, rectangular, and hexagonal. The circular coil is a well-known and often used structure in wireless converters because eddy current is maintained to a low in this design

By means of altering the inner diameter, the magnetic flux spreading may be improved. The magnetic field hemisphere takes on a spike profile, for lower center diameters, which can benefit to rise the coupling coefficient. Aggregating or increasing the focal point diameter can support to expand the magnetic flux scattering regions while stabilizing amplitude, which can resolve the misalignment problems. The minute the offset gap amongst adjacent windings extents 40%, the receiver power is reduced to the absolute minimum. **Figure 9** shows the circular shape coil referred for the analysis and simulation. Rectangular shaped coils are perfect for array placement because to their neatly matched sides. Nevertheless, they upturn inductance as of high corner edges produce eddy current that boosts impedance and causes hot spots [28][13]

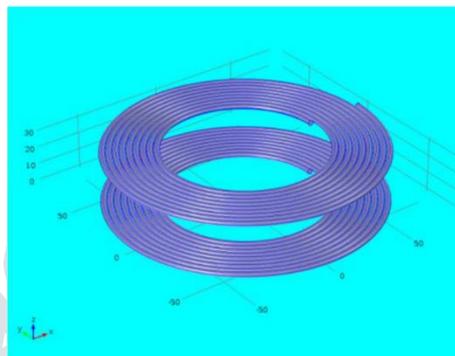


Fig - 9: Flat Circular coils (Scale 3.3:1)

Table – 1: Characteristics of proposed structure

Material	Value
ρ_{Cu}	$1.68 \times 10^{-8} \Omega.m$
μ_r, Cu	~ 1
Wire geometry	Value
d	5 mm
l	11.48 M
Coil geometry	value
d_{out}	50
N	30
Maximum Air Gap	20 Cm

The simulation file, displayed in vertical section view in Figure 10, fully demonstrates the complexity associated with the item's axisymmetric design. The colors indicate various magnetic field values produced by the coils. During a post-processing step, the simulator calculated the magnetic characteristics of the coupled coils. Magneto static simulations were performed on the premise that magnetic properties are not affected by frequency range of 200 kHz which is studied, because 200 kHz is the maximum value of the IPT structure frequency that has been verified and analyzed.

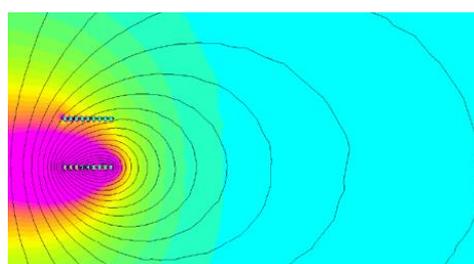


Fig - 10: Magnetic flux density simulation results

According to the **Figure 10**, the magnetic field was formed by pushing 80 A current into the upper coil. The flux of this magnetism via the top of the same coil was assessed to obtain the main self-inductance L1, and indeed the secondary self-inductance L2 is assumed to be the identical because coils are alike.[5][15][6] The inductance L is the average value of the self-inductances. The mutual inductance M was calculated using the **equation 1** as magnetic flux of the field above the face of the

bottommost coil. The electrical model parameters of the structure of the magnetic coupling, as obtained by Finite element analysis with a 20 cm air cavity. k is the electromagnetic structure's coupling coefficient. The following equation describes the link between mutual and self-inductances:

$$M = k [\sqrt{(L1 * L2)}] \dots\dots\dots (1)$$

V. MATLAB SIMULATION & RESULTS

The simulation was performed in MATLAB/Simulink using the conditions listed in **Table 2**. Table 2 displays the subsystems followed by the output power, current and voltage, and lacking such buck converter plus load at C2 capacitor. **Figure 11** gives the typical block diagram proposed to undergo the analysis and simulation.

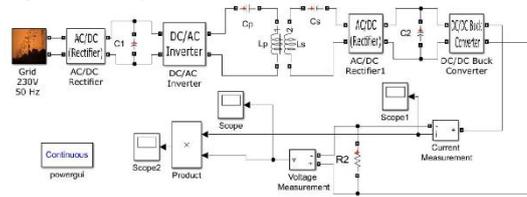


Fig - 11: Basic MATLAB Block Diagram

Figure 12 is circuit which is on the vehicle side and **Figure 13** refers to the battery pack under simulation. Once resistors are connected across the C2 capacitor, the yield is assessed over again. To end with, the buck converter remains linked across the C2 capacitor with resistors, and the output was monitored. The buck converter helps regulate the system's output, and the output may be adjusted by modifying the buck converter's switching frequency. The **Table 13** gives the details about the voltage levels with respect to the primary side and after conversion and at the battery pack side[30][18].

Table 2 – Proposed System parameters

Parameters	Design Value
Input Voltage	230 V
L_p	15 mH
L_s	15 mH
M	7.5 mH
C_p	4.691 mH
C_s	4.691 mH
C_1	1000 μ H
C_2	1000 μ H
k	0.5
D	25 cm
R_1	60 cm
R_2	30 cm

Table – 3: Voltages in the System

AC Supply Voltage	Value
V_{ac}	230V / 440V
DC Supply Voltage	Value
V_{dc}	48V
Battery Voltage	Value
V_{dc}	48V

The power efficiency is defined as: $\eta = [P_2 / P_1] \dots\dots\dots (2)$

Where P2 represents the output power whereas P1 refers to applied input power.

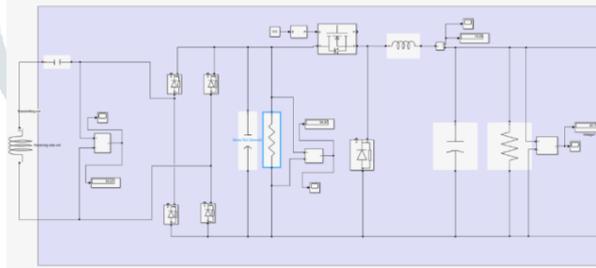


Fig - 12: Vehicle Side Circuit

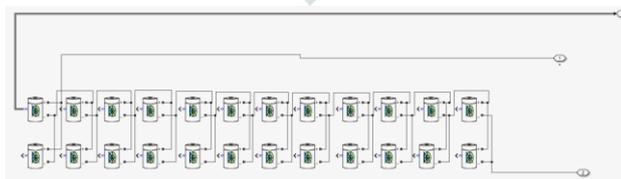


Fig - 13: Battery Pack under Simulation

The state of charge, or SOC,[26] of a battery is analogous to an instrument panel. Since the voltage level of a battery could remain approximately unchanged up to it is absolutely exhausted, a simple voltage test cannot disclose SOC. In some rechargeable batteries, electrolyte explicit gravity could be associated to voltage level, even if this is not quantifiable on regular battery pack cells and that is not associated to SOC throughout most lithium batteries.

Most SOC approaches use voltage, amperage, temperature, as well as further discharge and recharge process factors to sum up and about or down within such a pack's predefined capability. The multifaceted state of charge estimation algorithms takes into attention the Peukert's effect that links storage capacity to discharge rate. Figure 14 is a real-time SOC snapshot of a 48V 25Ah battery charging in a low load condition for 247.632 seconds. The typical observations and MATLAB simulation results are depicted in figures from 14 to 18.

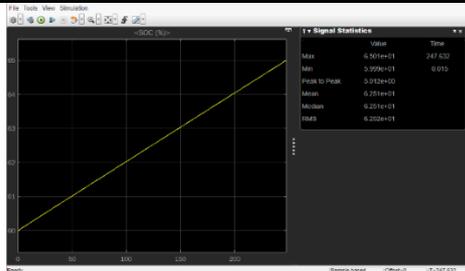


Fig - 14: Battery SOC

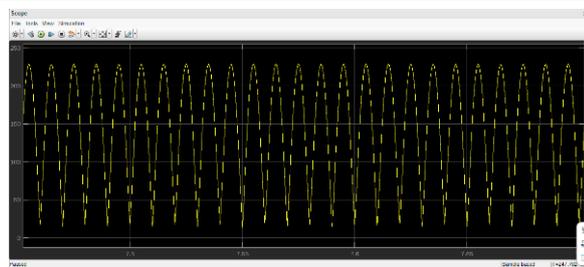


Fig - 15: Primary Input Voltage

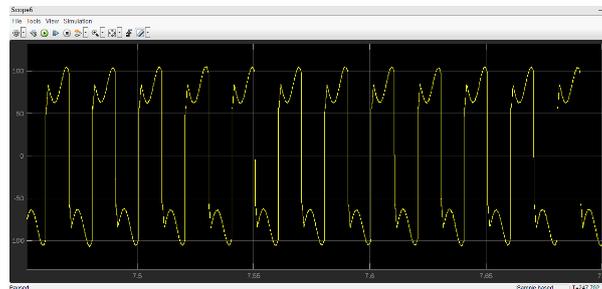


Fig - 16: Secondary Input Voltage

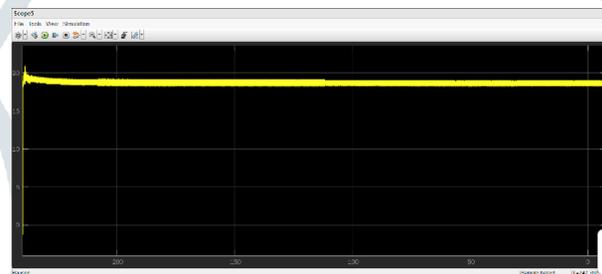


Fig - 17: Battery Charging Current

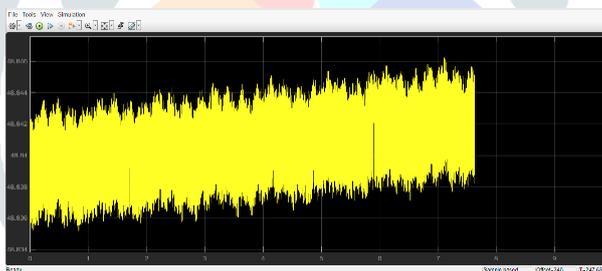


Fig - 18: Battery Voltage

VI. CONCLUSIONS

The hypothesis of wireless charging by inductive coupling, which was employed in this experiment. The efficiency is calculated here using the interspace between transmitting & receiving coils also the SOC. There is a link between power and distance. For power versus detachment separation, an exponential degradation has been discovered. Power transmission has begun to suffer as the interspace between transmitter and receiver coils grows. During mentioned experiment, we succeeded to charge a 48V DC battery completely wirelessly. Furthermore, it was discovered that unattractive matters covering between the two coils had no effect on IPT.

In the MATLAB/Simulink environment, a WCS with inductive coupling was constructed and simulated. The overall simulation approach for a WCS is given, and system response is achieved for loaded and unloaded conditions. The resultant waveforms are examined both conditions the load scenario and for the buck converter. The output observed across the condenser 2 (zero load) is substantially ranked greater than the yield in laden situation. The use of the buck converter results in smoother output waveforms, which is critical for battery charging. As a result, this innovation may be effectively applied in the automobile industry to charge car primary or secondary batteries as well as alternative equipment. As we all understand, no system is flawless in every way, and they all have certain limitations. Our suggested system has certain drawbacks, such as sluggish execution, another issue is that remote charging has not fully implemented because it can still be deliberate and fewer efficient than a cable recharger. Weather and other disturbances might cause problems between transmitting and receiving coils, as previously stated. There might be a lot more study done later on, such as improving battery charging efficiency by commissioning magnetic resonant coupler expending magneto plated wire and fetch down charging period by using fast charging methodology. Also, by reducing the size of both the coils, one can analyze how this Inductive system will be useful for real applications.

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