An approach of dynamic wireless charging structure for an electric vehicle based on mutual inductance calculation

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ABSTRACT

A number of reasons, including the ongoing decline in photovoltaic (PV) module prices, the quick rise in electric vehicles (EV) sales, and worries about greenhouse gas emissions, have contributed to the increasing integration of PV with EV charging systems. This electric vehicle can be charged through dynamic wireless charging system while moving on separate charging lane, it will be eliminating the need to stop an hour for the sake of charging in parking stations. By this we can save time while travelling a long distance. Through a mobile app, these lanes can be found and followed. People also can pay through the same app when they are travel in particular lane. According to user needs, additional lanes may be added to highways or existing lanes may be widened to minimize traffic. It might be environmentally benign because a charge controller powers the battery using the solar system. By calculating an exact mutual inductance, we can automate the charging current. A solar panel, battery, transformer, AC to DC converter, regulatory circuits, copper coils are all used in the system. Also, we used here Arduino mega 2560 controller, GSM 900, and LCD display to develop the system. We can measure the state and consumption of the electricity utilization by employing voltage and current sensors.

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1. INTRODUCTION

The excellent innovation of the present and the future is the electric vehicle. It is very much useful and alternate solution for internal combustion (IC) engine-based vehicle [1]–[5]. Renewable energy is power derived from resources that can be renewed organically throughout time in the human species. Sunlight, wind, water flowing, and geothermal heat are examples of renewable resources, whilst the majority are sustainable, some are not [6], [7]. Fossil fuels, on the other hand, are being consumed much faster than they are being replaced. Unlike conventional energy sources, which are largely confined to a small number of nations, renewable energy sources and major prospects for energy efficiency are widespread around the globe [8]. Significant improvements in energy security and the economy would come from the quick adoption of renewable energy, energy efficiency, and technology sources of energy diversity. Power from the sun and wind is now considerably more affordable. Our reliance on fossil fuels can be significantly reduced by utilizing solar energy in conjunction with electric vehicles or EV charging. Electric vehicles must be fuel by sustainable sources of energy because there are many different types of electricity [9]–[14]. We anticipate that almost everyone who owns a solar energy system will build a solar charging station in the future years as electric cars become incredibly popular. Solar power is regarded as an alternative source for this use due to the scarcity of fossil fuels and the ongoing decline in the price of photovoltaic (PV) modules [15]. It is anticipated that in order to oversee the charging stations for a significant number of EVs, a more advanced energy management system would be needed. Preventing grid outages is the primary concern when multiple electric vehicles are connected to the system at the same time for brief intervals of time. Simultaneously, it is critical to optimize EV charging according to PV power availability, current electricity demand, and pricing structures [16].

Another potential topic to look into is the integration of different energy sources (apart from PV), such as fuel cells, wind turbines, and stand-by batteries, with the smart grid [17], [18]. Additionally, both in terms of labor and fuel costs, photovoltaic systems are almost maintenance-free. The actual charging hardware, which consists of a maximum power point tracking or MPPT DC-DC converter, a bi-directional DC charger, and a bi-directional converter, is then developed or evaluated. The DC-to-DC converter is depicted in Figure 1 and is used to create effective charging through a solar-powered charging system [19]–[21].

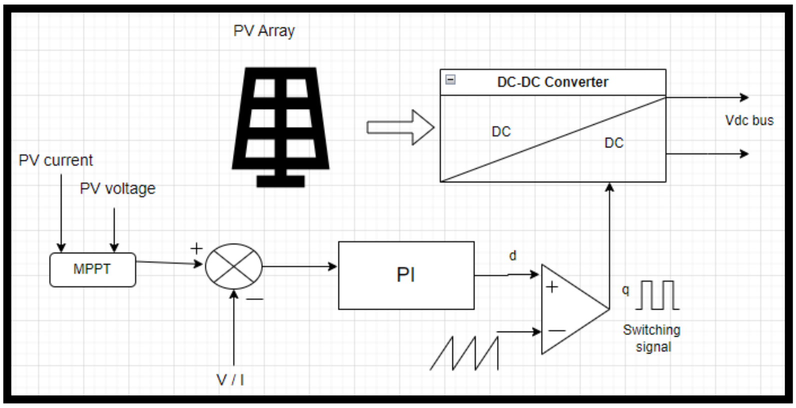


Figure 1. DC-DC converter with MPPT technology

In this proposed paper, only hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and fully battery electric vehicles (BEV) are considered electric vehicles (EV). In terms of charging, the PHEV and pure vary primarily in that the PHEV has plugs for external power charging while the HEV does not. The dynamics of the HEV's internal combustion engine recharges its battery [16]. Lead-acid batteries are the starting point of the evolution of electric vehicle propulsion, which also includes nickel and lithium batteries at the moment. Due to its poor temperature properties, limited capacity, low specific energy, chemical leakage, and lack of use in modern EVs, lead-acid batteries are no longer used. The following developments in the creation of dynamic EV charging platforms are notable. As a proof-of-concept, UC Berkeley tested a dynamic ClCh system for EV based on inductive power transfer (IPT) in the late 1970s [22]. They moved 60 kW of power along a 213 m long rail, 7.6 cm away from a passenger bus. Berkeley system has a 400 Hz operating frequency and only 60% efficiency due to limited semiconductor capabilities. Korea Advanced Institute of Science and Technology or KAIST on line electric vehicle (OLEV) is the first product on the market designed to support public transportation. It has dynamic wireless high-power charging of up to 180 kW for tramways and up to 100 kW for buses at a 20 cm spacing [23], [24]. Around the EV, less than 2.41 T magnetic field is produced. Technology used by OLEV. A charge of 60, 120, or 180 kW is wirelessly delivered by Conductix-Wampfler, a German company, depending on the EV (car or bus). The concept behind this dynamic charging module is similar to that of a construction kit.

In order to optimize the wireless power transfer (WPT) system, calculation of mutual inductance is a crucial design element. The mutual coupling between the two coils can be predicted by the model in a number of scenarios, such as lateral misalignment, angular misalignment, or both combined. This mode was compared to experimental results for various assembled coil misalignments as well as 3-D EM data [11], [25] Additionally, our approach proposes the creation of an adjustable receiver coil, which will precisely align to obtain a greater mutual inductance and hence improve charging efficiency.

In addition, nickel and, now mostly, lithium has taken their place. The best option is a lithium battery because it is more effective, has a higher power density, is portable, and weighs less [26]. Additionally, it has a wide working temperature range, a high cycle life, and a low self-discharge rate. The chemical components that make up lithium-based batteries are also very diverse. For instance, lithium ferro phosphate (LiFePO4) is easy to handle since it has extremely high thermal stability when the battery is completely charged. Here MPPT technique which is used to generate maximum power from the solar panel. It also created demand due to:

i) Lack of electricity in remote and rural locations for charging stations; ii) Vehicles can be wirelessly charged without using wires; iii) The vehicle charges as it is traveling, so there is no need to stop; iv) The charging system can be kept running with solar power; and v) No requirement for an external power source/grid. [27]–[29].

2. METHOD

Figure 2 shows the graphical representation of an electric vehicle charging system. In this we used solar panel to convert photovoltaic energy into electricity. To charge a vehicle's battery, this generated electricity through solar system can be routed into the regulator circuit and then through a transmitter/receiver coil. Transmitter which is mounted on a road and receiver coil which is located in a bottom of the car. The multiple transmitter coil placed on the equal distance of the road which is fed power from the solar system. So, the charging voltage may not be equal due to misalignment of coils which will create ununiform mutual inductance due to movement of a vehicle. This can be regulated through a bidirectional inverter.

Figure 3 shows the structure of dynamic wireless charging lane system which is implemented in highways. In normal static charging system, we can travel but we need to park the vehicle for charging batteries in particular parking spaces. It may take lot of time to get adequate charge. Also, we may not aware parking locations in all the places where we are travelling other than our native state. So, we need to search roam here and there when we want to charge our electric vehicle in other locations. But in our proposed method, we keep all the relevant data in particular website or mobile application. So, any people can search and use the particular road as mentioned in particular app. Hence, the people can charge their car batteries when they are travelling on road.

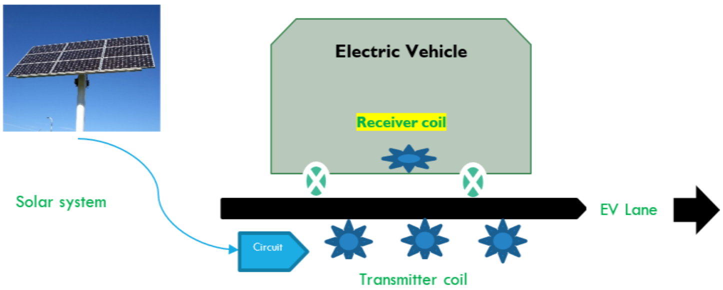


Figure 2. Graphical diagram of EV charging system

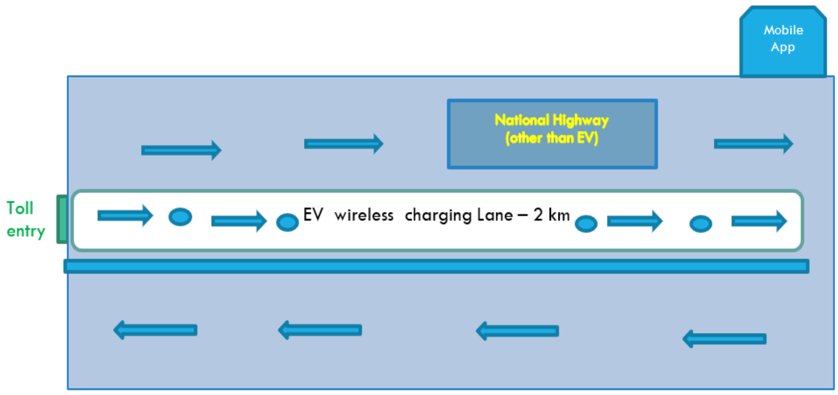


Figure 3. Overview of EV lane in highways

2.1. PV Standalone charging

The term "PV-standalone" describes EV charging done exclusively using PV, that is, without the need for grid connectivity. Compared to PV-grid charging options, this strategy is less common because of the variable solar irradiance. Typically, an intermediate storing battery bank is used to connect the PV to the EV for charging. Nonetheless, the PV array needs to be big enough to meet the number of cars that it is intended for in terms of charging [30]. To meet the charging objectives, there are two primary methods: (1) using an intermediary Energy storage unit (ESU), (2) direct Photovoltaic to EV connection, as illustrated in Figure 4. PV system's behavior under changing temperature (T) and irradiance (G) can be comprehended by looking at its power-voltage (P-V) and current-voltage (I-V) characteristics. Figures 4(a) and 4(b) illustrate the nonlinear I–V and P–V graphs that are produced by changes in G and T, respectively. A maximum power point (MPP) is the single operating point where power is at its highest at any given time. As G or T varies, the MPP fluctuates continually.

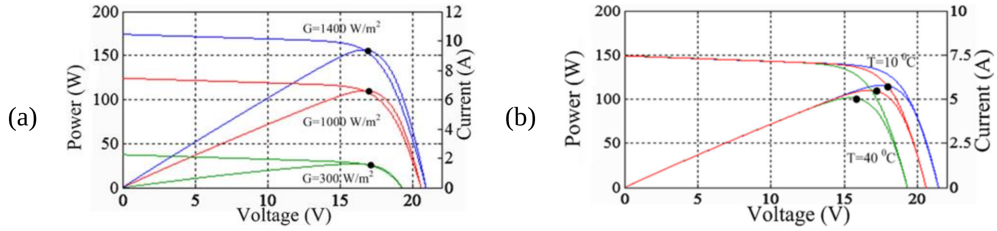


Figure 4. The behavior of a PV system under varying irradiance (G) and temperature (T): (a) the I–V and the P–V curves under varying G and (b) the I–V and the P–V curve under different T

2.2. Multilevel topology

Figure 5 shows the capacitor clamped three level PWM inverter and bidirectional isolated A.C to D.C converter. The multilevel topology is another kind of bidirectional inverter that is suitable for EV charging. These converters benefit from lower switching losses and lower voltage strains on the switches as a result of the decreased switching frequency. It also displays less harmonics and interference. Despite these advantages, multilayer inverters are physically more complicated, particularly when the voltage level exceeds a specific level.

From Figure 6, an electric vehicle is one that is propelled by one or more motors and is powered by electricity supplied by the battery. Also, the transmitter and receiver coils which are mounted on the road and car respectively. By placing a microcontroller and sensor, user can measure the electricity consumption from the charging lane which is again an important system to satisfy the customer. All these charging lane locations, charging values and vehicle information can be monitored through a mobile application. The language encompasses electric vehicles such cars, buses, trucks, trains, motorbikes, and bikes.

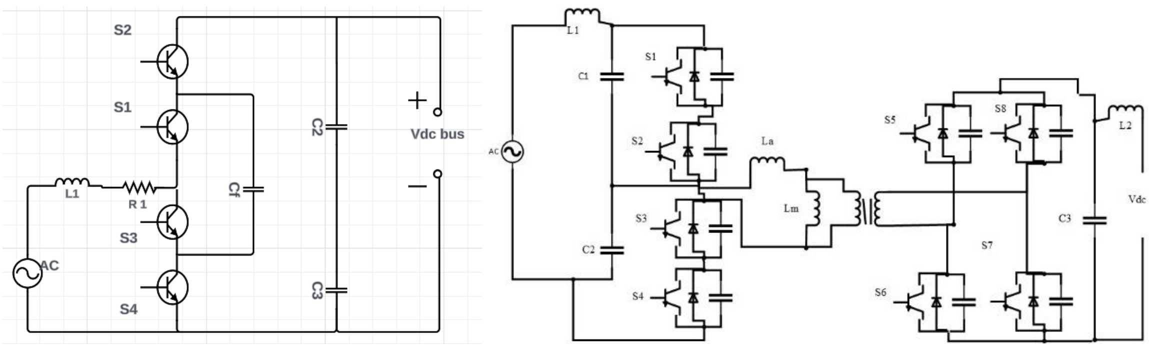


Figure 5. Bidirectional inverter circuit diagram

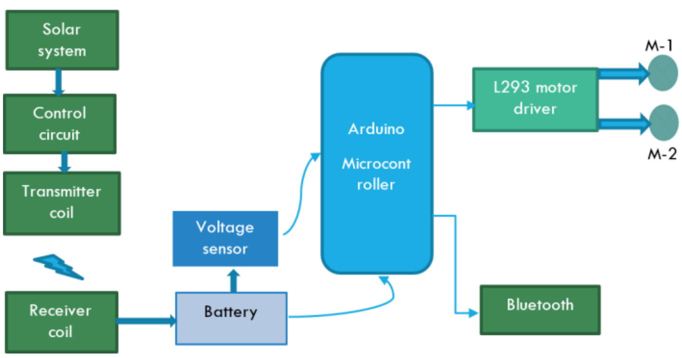


Figure 6. Block diagram

2.3. Mobile application

Through a smartphone application that is regularly updated by a toll gate system, users on the highways can quickly determine the location and current usage of the electric car charging lane (like Google Map, and Parivahan). To plan their route to that certain lane, the folks may find this to be quite helpful. Additionally, users of this program can log in and pay for the use of a specific lane to skip the queuing system, which will lessen traffic.

3. RESULTS AND DISCUSSION

3.1. Simulation results

The coil's self- and mutual-inductance values were calculated using the ANSYS-MAXWELL software. The complete system and its circuits were developed and simulated using the ANSYS and MATLAB-Simulink package. ANSYS MAXWELL is a program that solves electromagnetic fields for electric machines, transformers, wireless charging, permanent magnet latches, actuators, and other electric mechanical devices. It resolves magnetic and electric fields that are time-varying, frequency-domain, and static. Additionally, Maxwell provides specialized design interfaces for power converters and electric devices. The parameters of the simulation using ANSYS are shown in Table 1.

The material used for the windings is 24 SWG insulated copper wire. According to the vehicle's requirements, the transmitter and receiver coils should have 8.5 cm diameters. It may change based on the type of vehicle. With at least 30 mm of distance between the transmitter and reception coils, the coils are separated by an air-filled medium. The maximum current that can pass through the wire element is 2 A.

Here the value of inductance obtained is self-inductance 680.89 uH and the mutual inductance obtained is 150.60 uH for the distance of 30 mm. From Figure 7 we can analyze the simulation results coils which is placed around 30 mm separation. The parameter which are taken for obtaining these results are given in Table 2.

Figure 8 displays the boost converter out's output voltage waveform as acquired from Simulink. So, from this we can able to get some clarity about the results about the converter segment. The output waveform of an ultracapacitor when the load is connected directly is shown in Figure 9. The graph below displays the charged voltage as a function of time (time as the automobile moves away from the first coil) in seconds. The ultracapacitor will get a charge from solar system through transmitter and receiver coil and it will charge the vehicle batteries as simple and quick. The overall efficiency and power quality will be high by use of ultracapacitor technology.

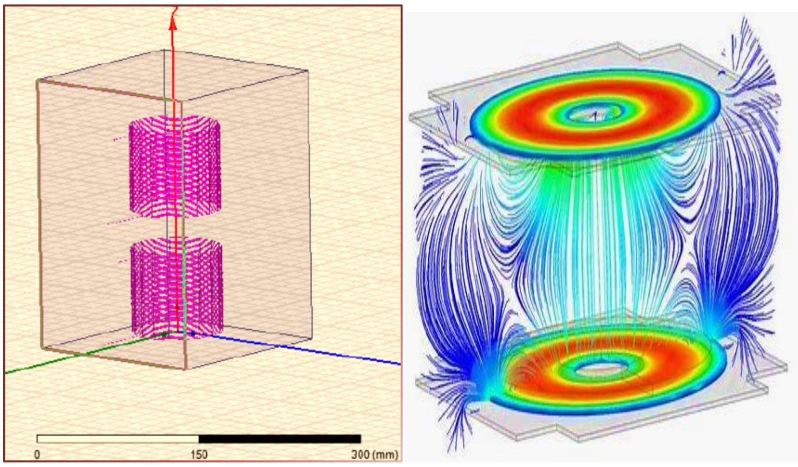


Figure 7. An ANSYS-MAXWELL simulation schematic diagram

Table 1. Input parameters - ANSYS

Parameter	Input
Wire material	Copper
Size	24 swg
Diameter	8.5 cm
No. OF TURNS	70
Medium	Air
Separation	30 mm
Excitation current	2 A

Table 2. Input parameters to SIMULINK

Parameter	Input	Parameter	Input
DC Source	18 volts	Coil self-inductance	680 uH
Inverter	Push-pull	Mutual inductance	150 uH
Parallel capacitor	1000 uF	Rectifier	Full bridge
Series resistance	2 ohm	Ultra capacitor	12 V, 20 F
Coupling capacitance	98 nF	Load	DC motor (6 V,1 W)

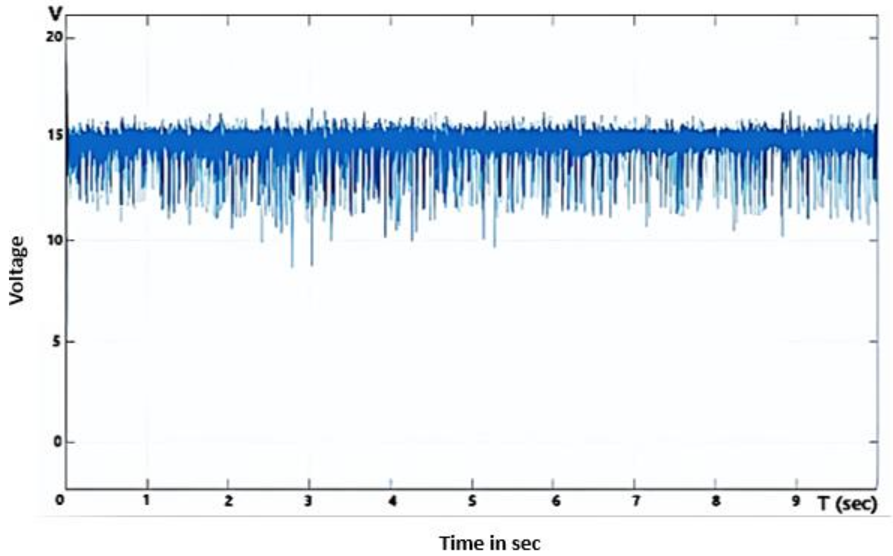


Figure 8. Output voltage waveform

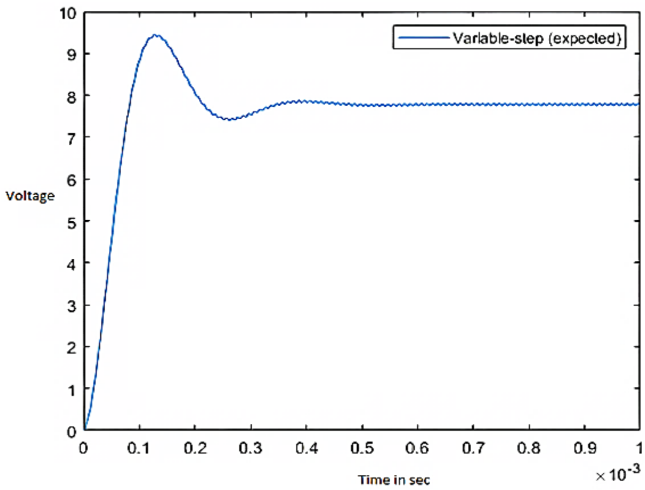


Figure 9. charging and discharging characteristics of ultracapacitor under load

3.2. Hardware results

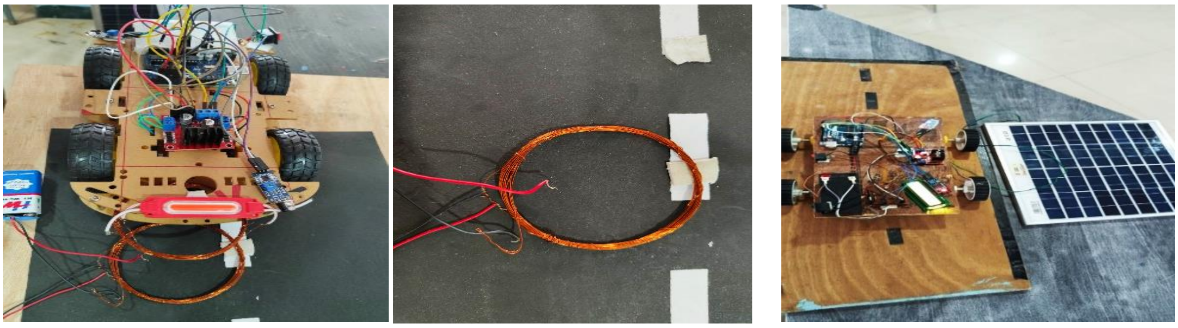
A prototype shows in Figure 10(a), created to compare hardware and simulation results. In this prototype model, power is transferred from a transmitter coil which is located on the road to a receiver coil inside a vehicle by the mutual inductance principle. Additionally, a converter circuit will give electricity to the car batteries via a number of transmitter coils that will use solar energy. Using a 12-volt DC motor, wheels, Arduino UNO, voltage sensor, LCD display, solar panel, battery, DC-AC converter, transmitter, and receiver coil, this miniature car is powered. Power generated by a solar panel using the photovoltaic effect will be sent back into the battery.

By using a bidirectional converter circuit, this saved DC power was transformed into AC power and then supplied to the transmitter coil. When the receiver coil is close to the transmitter coil, the mutual induction principle causes it to produce an emf. Depending on how far away the coil is, this generated emf may change. The distance can be adjusted through an adjustable projection system based on the road condition. The less distance will give better mutual inductance to produce efficient charging. In this prototype model, the generated emf is shown on an LCD screen and may be measured by a voltage sensor that connects to the Arduino controller. Through a regulating circuit, this created emf was supplied to the battery for charging purposes. As a result, the HC-05 Bluetooth module allows us to manage the vehicle through a battery. A Bluetooth connected app for smartphones can be used to measure the battery management system values and the entire charging and discharging of the battery. Through mobile application or website, users may access complete availability and traffic information about the many lanes that are available on the same roadways, helping to cut down on time wasted in queuing systems. Even users who pre-book a certain lane can pay with the same mobile app.

The fundamental tenet of wireless power transfer is that when two items are magnetically resonant at a powerfully linked rule and have a similar resonant frequency, they tend to exchange energy while wasting relatively little energy to the extraneous off-resonant objects. The inductive energy that may be communicated from a transmitter coil to a receiver coil via an oscillating magnetic field is the fundamental component of wireless power transmission. The transmitter has custom-designed circuitry that transforms the DC current provided by a power source into high-frequency AC current. Also, 12 volts solar panel used here as a primary power source. Using a voltage and current sensor, the amount of electricity used for charging may be determined. This power may achieve from the solar system as illustrates in Figure 10(b). Here we used 12 volts, 20 watts solar system to generate power from the sun energy.

Table 3 provides values for a spacing of around 30 mm between the receiver coil and transmitter coils. Over this distance, we can collect output voltages of up to 8.2 volts, which we can then transform into 12 volts using a bidirectional converter. The output voltage will then be sent back to the battery for charging.

Table 4 provides values for a spacing of around 50 mm between the receiver coil and transmitter coils. We are able to obtain output voltages of up to 5.3 volts across this distance, which we can then convert to 6 volts using a bidirectional converter, further it can convert into 12 volts by use of multilevel topology and which will then send the output voltage back to the battery for charging. So, the increase of distance may reduce the performance of charging or reduce the efficiency of charging. The functionality of the converter can be changed with the help of an Arduino controller, and the battery will always reach the necessary voltage for charging. Additionally, a smartphone app can be used to monitor it.



(a) (b)

Figure 10. Electric vehicle with solar charging system: (a) transmitter and receiver coil-EV and (b) lane with solar system

Table 3. Output for 30 mm separation case-1 (30 mm separation)

Input	220 V, 50 Hz AC
Transformer output	18 V, 50 Hz AC
Inverter output	13.8 KV, 20 kHz, AC
Secondary coil output	8.2 V, 20 kHz, AC
Boost converter output	12 V, DC
Load current	99.4 mA

Table 4. Output for 50mm separation case-2 (50 mm separation)

Input	220 V, 50 Hz AC
Transformer output	18 V, 50 Hz AC
Inverter output	13.8 KV,20 kHz, AC
Secondary coil output	5.3 V, 20 kHz, AC
Boost converter output	6 V, DC
Load current	24.3 mA

3.3. Software details

Arduino integrated developed environment (IDE) software which is used here to code the Arduino UNO controller. This software is very much user friendly and easy to write or modify the code as per consumer requirements. Also, it is an open-source software, through this anyone easily can write the code at any time. User-friendly programming can be done by any person at any point of time due to its simple and easy understanding. The basic C skills enough to write the code in this advanced controller. Additionally, the ANSYS-MAXWELL program was used to determine the coil's self- and mutual inductance values. The ANSYS and MATLAB-Simulink package was used to create and simulate the entire system and its circuits. ANSYS MAXWELL is a program that solves electromagnetic fields for electric machines, transformers, wireless charging, permanent magnet latches, actuators, and other electric mechanical devices.

4. CONCLUSION

An analytical approach to figuring out the mutual inductance between two coils is put forth in the proposed study. The model is able to forecast mutual coupling between two coils in a variety of situations, including angular and lateral misalignment as well as a combination of the two. Additionally, it corrects when the vehicle contains adjustable setup receiver coil. The proposed proof of model for the EV charging system is created with a number of characteristics that provide the users with a number of advantages like Smart charging system that combines quick charging with a user-driven input method. By calculating exact mutual inductance, we can improve the charging performance of the vehicle which will increase the travelling time. Additionally, we can use a mobile app to find out how many charging lanes are available in a particular highway, whether a next charging lane is open to avoid queue system. Through this dynamic wireless charging approach, we can avoid parking our cars while they are charging, which will allow us to cover longer distances more quickly. It also gives access to a renewable energy source in the form of solar power.

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