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Original Article

Wireless Charging Systems for Hybrid Electric Vehicles

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Abstract *- The essential aspect of society is energy conservation, and since cars play a significant role in daily life, preserving energy while simultaneously reducing pollution from fossil fuels in the automotive industry is a difficult task in the modern world. Therefore, the most important factors are cars that use less energy and produce less pollution. An Electric Vehicle (EV) system was suggested to solve this problem. The conservation of energy is the most necessary part of society. As the automobile is an important part of society in day-to-day life, the conservation of energy and an increase in pollution due to the use of fossil fuels in the automobile sector is a challenging job in today's life. Thus, energy-saving and pollution-free automobiles became the most significant considerations. An Electric Vehicle (EV) system was proposed to address this issue. This applies to various vehicles, such as buses and cars. However, the EV's battery can only go so far before needing to be charged again, which takes time. This paper will design a hybrid system and integrate a Wireless Charging System (WCS) for the battery in Electrical Vehicles (EVs) to address this problem. This improves electric vehicles' efficiency and range. During vehicle motion, the system uses a dynamo on the front wheels to produce electrical energy and a DC motor on the rear wheels for electric propulsion. A WCS with Inductive Power Transfer (IPT) is included to enhance usability further.*

Keywords *- Hybrid Electric Vehicle, Wireless Charging System, High-frequency circuit, Arduino UNO, Transformer and Dynamo motor.*

I. Introduction

Hybrid Electric Vehicles (HEVs) are the new players that have entered into the equation to address the very critical need worldwide for green and energy-saving transportation. Internal combustion engines plus electric propulsion in Hybrid Electric Vehicles offer better fuel economy and fewer pollutants, plus driving flexibility that is impossible with conventional vehicles. As more people buy EVs, wireless charging is getting more popular as a way to make charging easier [1,2].

Inductive Power Transfer (IPT) lets machines charge without wires, so they do not need touch links. They can sit on a Charging spot to charge their batteries. This technology could change how HEVs are charged, making it easier for drivers and allowing new charging setups like static charging [3-5].

A wireless power transfer system has a transmitter, a receiver, and a coil. It is meant to be a better way to transfer power than the current cable-based systems. It uses electromagnetic induction to send energy from the transmitter to the receiver. The source sends power to the transmitter, which makes an alternating electromagnetic field that the receiver coil picks up.

This enables battery charging while maintaining HEV mobility. The module is ideal for wireless applications because of its insulated construction, small size, and steady output [6, 7].

This paper aims to implement a prototype of a hybrid vehicle with a WCS. By integrating this technology, this module's objective is to overcome the limitations of current EVs, particularly the need for frequent and time-consuming battery charging.

To sum up, WCT has the potential to improve the usability and appeal of HEVs greatly. This innovation could hasten the transition to more sustainable transportation systems, especially in urban settings and smart cities, by making charging solutions simpler and more adaptable. However, the widespread adoption of wireless charging for HEVs is linked to ongoing research and cost-related challenges [8–10].

This paper addresses the following goals: 1) To create a completely electric hybrid car system that achieves zero emissions without using an internal combustion engine. 2) To incorporate WCT to facilitate easy, contactless energy transfer for vehicle battery charging. 3) To use static wireless charging capabilities to improve charging convenience and efficiency.

4) To lessen dependence on conventional plug-in infrastructure by offering a different charging option that is simple to use and deploy.

2. Approach

A multidisciplinary approach combining elements of electrical engineering, materials science, economics, and urban infrastructure planning is needed to research and develop Wireless Charging Technology (WCT) for Hybrid Electric Vehicles (HEVs). The following are the steps:

2.1. Main Power Source (Side of the charging station)

Typically, the primary power source is AC from a separate power plant or the grid. Before it can be sent, this power must be ready and conditioned.

2.2. Transformer Step-Down

The high voltage of the AC power is reduced to a lower, safer level for wireless transmission by the main supply step-down transformer. This procedure ensures that the vehicle receives power that is both secure and helpful.

2.3. Converting Low Frequency to High Frequency

The low-frequency 50/60 Hz signal is converted to a high-frequency signal after the voltage is first reduced. This is due to the fact that electromagnetic induction functions best at high frequencies for wireless power transfer.

2.4. Primary Coil (Charging Station Side)

High-frequency AC power is applied to the primary coil, creating a fluctuating electromagnetic field. The primary coil is typically located in the ground where the car is parked or near the charging station.

2.5. Secondary Coil (Car Side)

The secondary coil is typically located on the car side near the bottom. The parking lot is above a charging pad with a primary coil underneath. Electric current flows due to the primary coil's electromagnetic field and inductive coupling through the secondary coil.

2.6. Changing AC to DC

An AC to DC converter can turn alternating current into direct current. The vehicle's system requires a direct current to charge the battery.

2.7. Voltage Regulation

The system has a block for regulating voltage after converting AC to DC. This ensures the voltage level stays constant and is right for charging the battery.

2.8. Charging the Battery

The regulator sends DC power to the battery, which is stored for the vehicle's electric motor. The battery stores energy mostly to run the car's electric motor and other systems that help it work.

2.9. Load (The Car's Electrical System)

This secondary load gets power from the battery. It also has a dynamo motor that uses power from the battery to recharge it while the car is running.

Figure 1 illustrates the Hybrid Electric Vehicle's (HEV) system architecture with WCS. The HEV is powered by a dynamo motor and a battery. The WCS comprises a secondary coil on the car and a primary coil at the charging station.

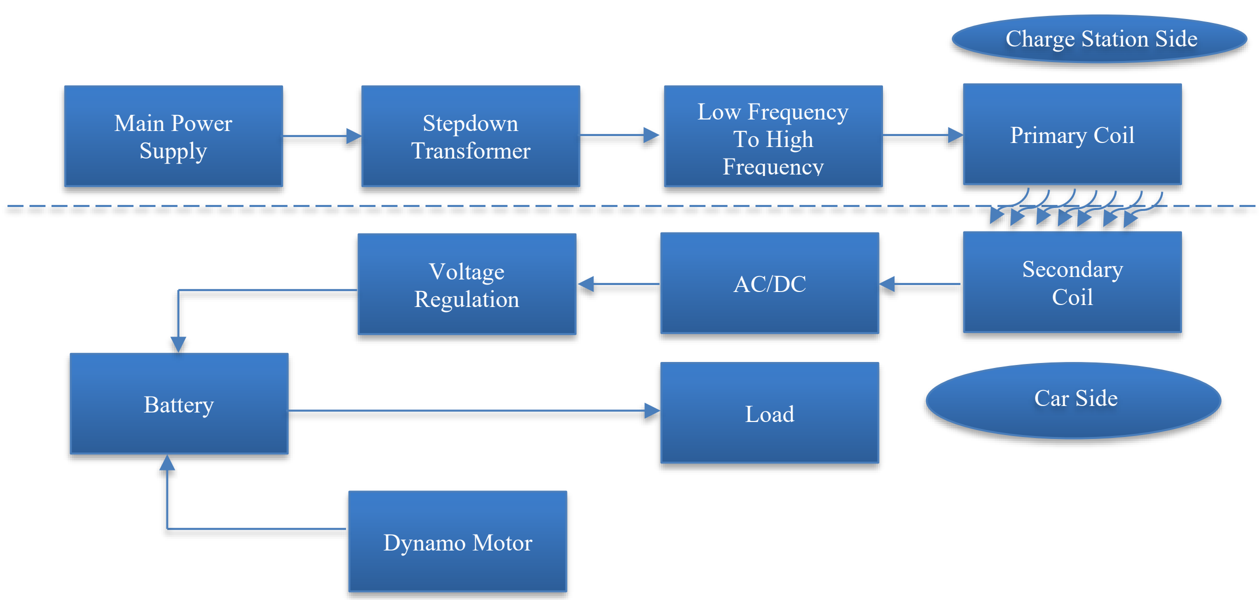

Fig. 1 Block diagram of WEVs charging system

3. Results and Discussion

This section demonstrates results in two sections: the wireless charging part shown in Figure 2 and the Hybrid Electric Vehicle shown in Figure 3. The wireless charging part consists of two sub-cases: the distance between the coils and the change in frequency.

3.1. Hardware Photo

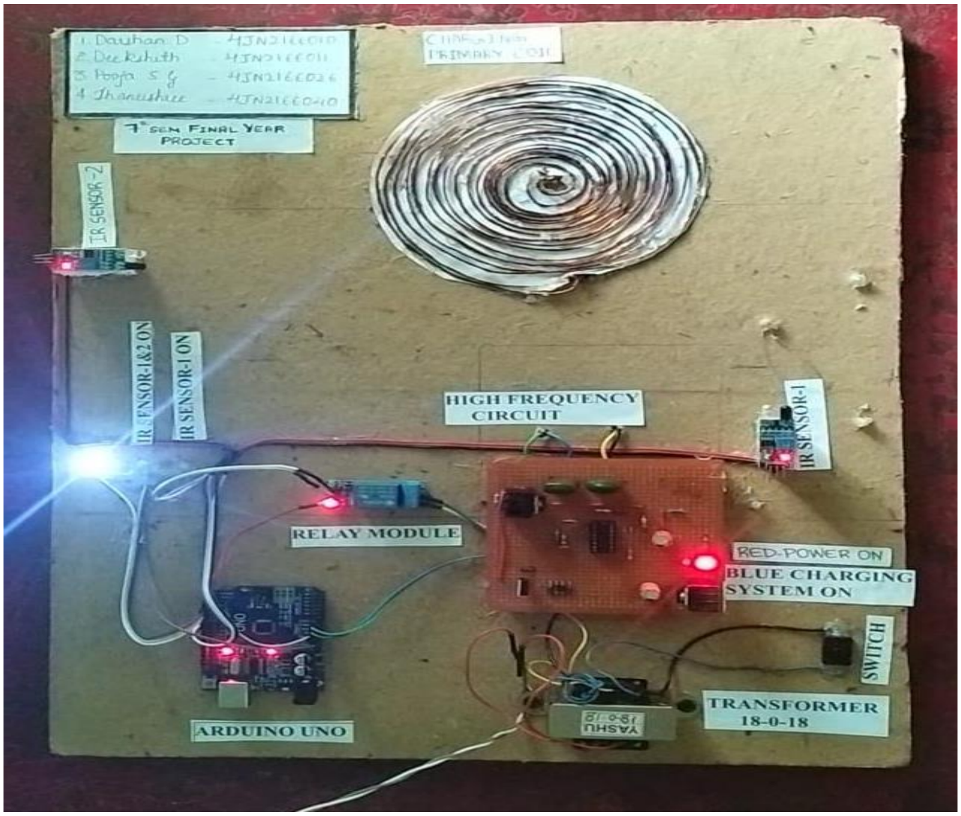

Fig. 2 Wireless charging system

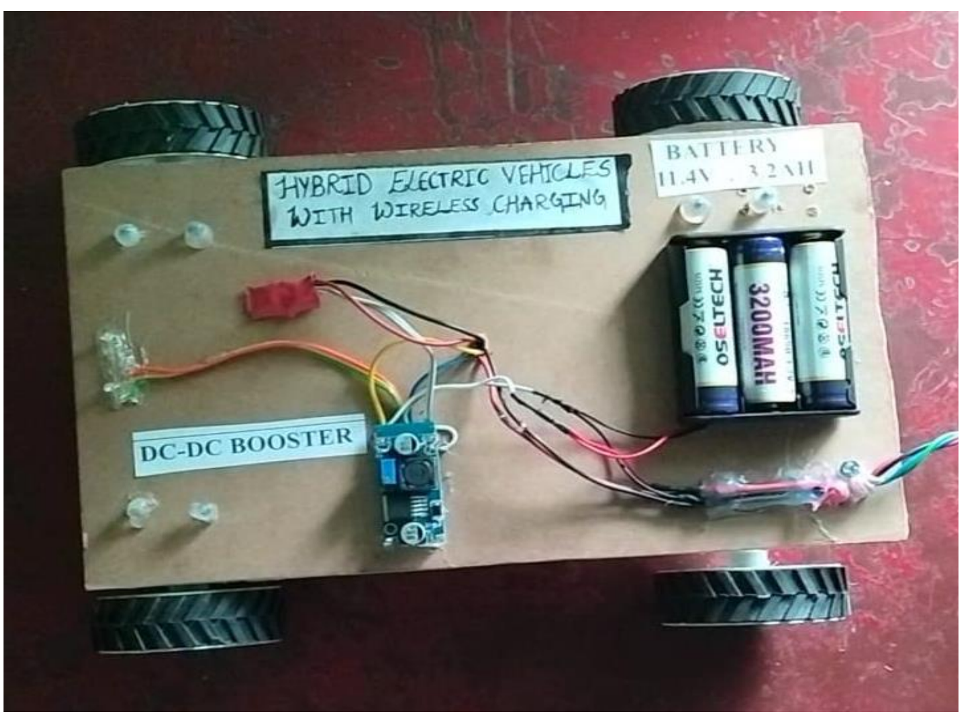

Fig. 3 Hybrid electric vehicle

3.2. Wireless Charging Part

3.2.1. Case-1: Distance between the Coils

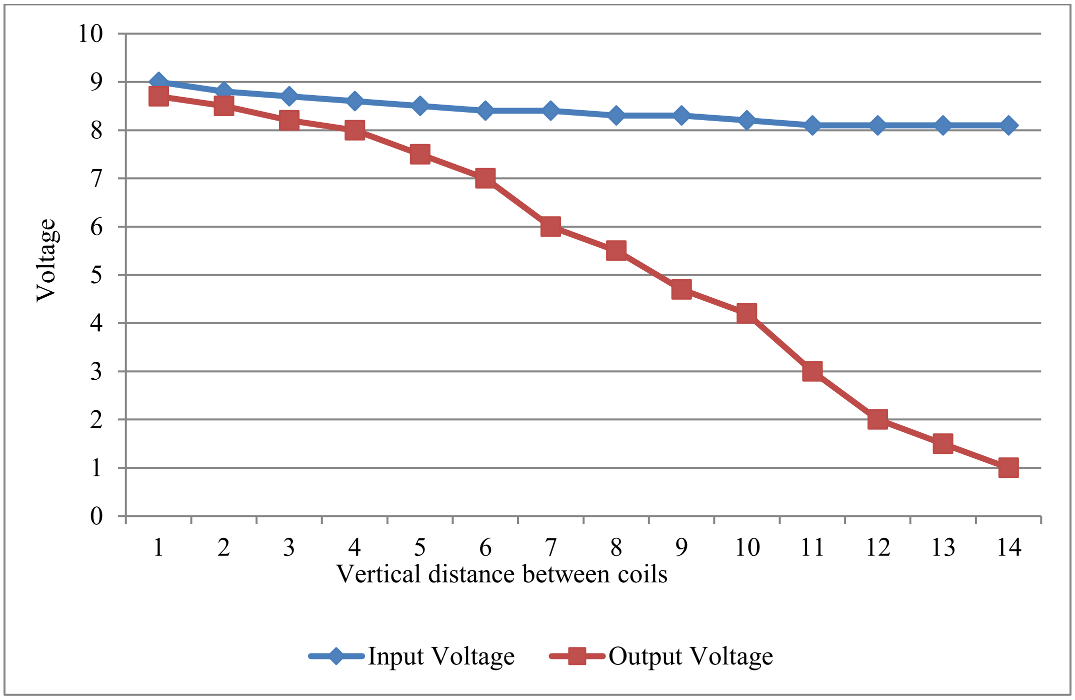

Fig. 4 Graphical representation of input and output voltages due to vertical distance between coils

Figure 4 illustrates the relationship between vertical distance between coils and voltage (input and output). Here is a detailed analysis:

3.3. Observations

3.3.1. Input Voltage (Purple Line)

- The input voltage remains relatively constant at approximately 8.8 – 9 V across all distances (1 cm to 14 cm).
- This stability implies that the power supply or input source is unaffected by the distance between the coils.

3.3.2. Output Voltage (Red Line)

- The output voltage decreases significantly as the distance between the coils increases.
- At 1 cm, the output voltage starts near 8.5 V, nearly matching the input voltage.

Case-2: Change in frequency

a) As the distance increases, the output voltage drops sharply. For example:

- ❑ At 7 cm, the output voltage is approximately 5 V.
- ❑ At 14 cm, the output voltage reduces to around 1 V.

Key Observations

- The output voltage and vertical distance have a definite inverse relationship.
- Energy transfer efficiency diminishes as the distance increases, possibly due to weaker magnetic coupling or energy losses.

Efficiency Consideration

- At smaller distances (1–3 cm), the output voltage closely matches the input voltage, indicating high efficiency.
- Beyond 5 cm, there is a noticeable efficiency loss, and at 14 cm, the output voltage is less than 15% of the input voltage.

Figure 5 shows the relationship between output voltage and output frequency at three different distances: 2 cm, 5 cm, and 9 cm.

Overall Trend

At all distances, the output voltage increases with frequency initially, reaches a peak, and then declines as the frequency rises.

Distance Effect

- At 2 cm (Red Line): The highest output voltage is observed. The voltage starts at approximately 5 V at 10 kHz, peaks around 9 V at about 60 kHz, and then gradually decreases to around 6 V at 120 kHz.
- At 5 cm (Blue Line): The voltage is lower than 2 cm but follows a similar pattern. It starts at around 4 V, peaks at 7 V near 60 kHz, and declines to about 4.5 V by 120 kHz.

- At 9 cm (Green Line): The voltage is the lowest. It starts at about 1 V, peaks around 4 V at 60 kHz, and decreases to around 2 V by 120 kHz.

Frequency Impact

- The peak voltage at all distances occurs around 60 kHz, indicating that this frequency might be optimal for maximum voltage output.
- Beyond 60 kHz, the voltage declines significantly, especially at longer distances.

Key Observations

- Output will be higher only at the particular frequency.
- The voltage drops sharply at greater distances, highlighting the attenuation effect with increasing separation.

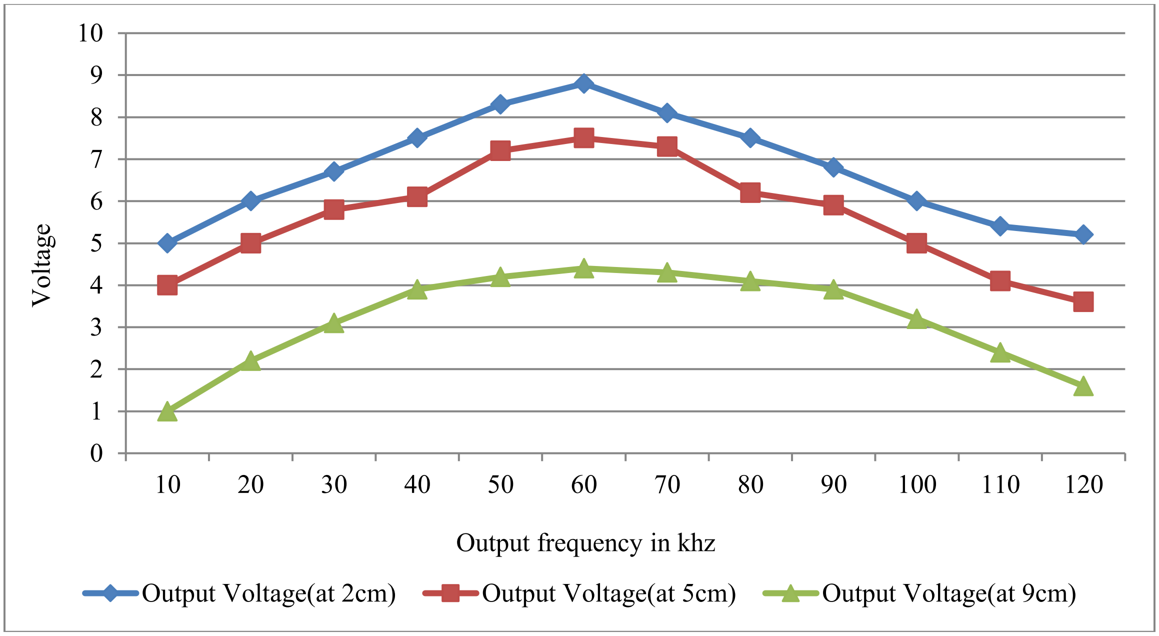

Fig. 5 Graphical representation of output voltage in different working frequencies at different distances

3.4. Important Points to be Noted are

- Frequency can be varied by adjusting the external timing components connected to the oscillator section of the chip, specifically the Resistor (R) and Capacitor (C) connected to the pins for frequency setting.

Key Pins for Frequency Setting

1. Pin 6 (RT): Timing resistor
2. Pin 5 (CT): Timing capacitor

By analyzing the above graph, several points are concluded:

In wireless charging, as the frequency increases, the efficiency generally peaks at a specific optimal frequency, then tends to decrease with further frequency increases, meaning that efficiency will initially rise with increasing frequency until reaching a maximum point, then decline as the frequency continues to climb.

The output frequency of the 3525A PMW controller IC depends on the timing resistor (RT) values and the timing capacitor (CT). The relationship is,

$$F = \frac{1.45}{[\, RT * CT \,]}$$

Minimizing both RT and CT frequency can be maximised. The data sheet for the three 5 to 5 a typically specifies a minimum value for RT that is two kilos home, and Connecticut is often around 100 picofarad.

$$F = \frac{1.45}{22000 * 1 * 10^{-6}}$$

$$= \ 65.91 \text{ kHz}$$

Figure 6 represents the higher frequency circuit consisting of a diode bridge, 3525A IC, IRF3205, and primary and secondary coil.

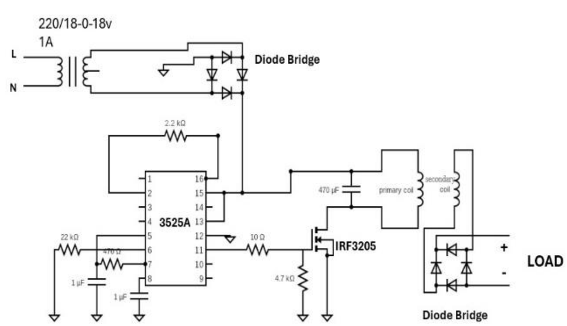

Fig. 6 Higher frequency circuit

3.4.1. Hybrid Electric Vehicle Charging Part

As per the working of this module, the following points are noted:

- A hybrid charging system means the battery charges while the vehicle is running by means of the regenerative system.
- Proper vehicle alignment with charging is essential for efficient wireless power transfer. For this purpose, two IR sensors are fitted on either side of the charging pad. This helps to detect proximity to the transmitting coil and confirm correct placement to ensure the receiving coil is aligned with the transmitting coil.
- The system allows wireless charging to begin when the vehicle is aligned. The IR sensors achieve this by detecting the vehicle, and then they send the signal to the relay, which turns on the frequency circuit to supply power to the transmitting coil.
- Here, the motor used for running the vehicle is 100 rpm; for regenerative purposes, it is 200 rpm, and both are 0.5 A.
- Suppose the vehicle motor of 12 V is running at 100rpm; then the speed of the regenerative motor is reduced by half, and thus, the voltage induced by it will also be half, that is, 6 V.
- As two regenerative motors are connected in series, the output voltage should be 12 V, and the current should be 0.5 A.

4. Observation and Calculation

As per our observation, the voltage induced is 9 V, and the current is 0.5 A. Output of buck booster= 11 V and 0.4 A = 4.4 W

From this, we can say that, suppose the vehicle is running, and then it consumes 0.3A+0.3A=0.6A of current in 12 V, which is 7.2 W power.

Energy consumed is given by,
Energy (Wh) = Power (W) x Time (hours)
If the vehicle runs for 1 minute (20 meters),
Energy = 7.2 x 0.016670 = 0.12 Wh
Equivalent battery capacity,

$$= \frac{energy}{voltage} = 32.43 \text{ mAh}$$

If a 7.2 W load runs for 1 minute, the battery capacity consumed is approximately 32.43 mAh.

If 4.4w of power is charging the battery by regeneration, then it charges a battery of approximately 19.8mAh in 1 minute (20 meters) by the above equation.

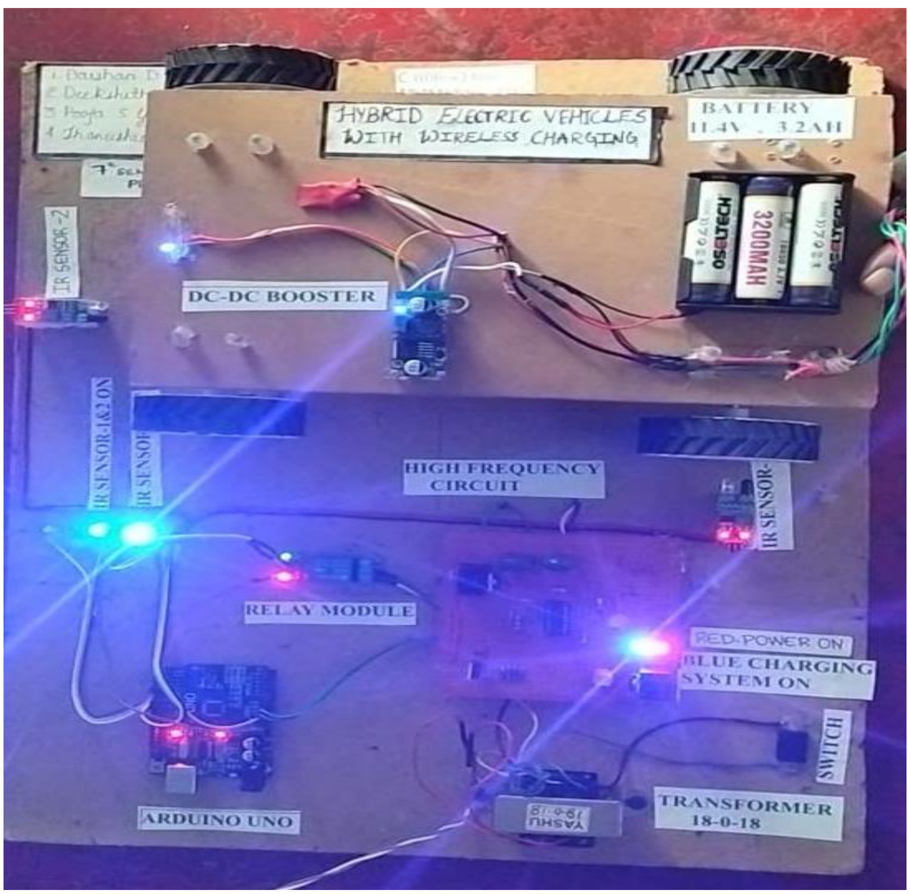

Fig. 7 Wireless Charging of HEV

5. Conclusion

With the implementation of wireless charging for HEV, the following specific conclusions are drawn,

5.1. Energy Consumption and Recovery

Over a distance of 20 meters, the hybrid electric vehicle consumes 32.43 mAh of energy. It manages to recuperate 19.8 mAh through its hybrid system, illustrating an effective energy recovery mechanism that contributes to extending its operational range.

5.2. Added Distance Range

The hybrid system utilizes regenerative braking to recharge the battery, which allows the vehicle to cover an additional 12 meters Past the standard distance.

5.3. Total Distance Possibility

Without the hybrid system, the vehicle can travel 1.8 km on a fully charged battery. With the hybrid system integrated, the distance observable is approximately 2.8 km (which includes 1.8 km of primary battery usage and 1.06 km from the hybrid system).

5.4. Input Voltage stability

The system input voltage (Vin) is held steady between 8.8 and 9 volts, which is a stable and reliable power supply system.

5.5. Output Voltage Dynamics

The output voltage (Vout) increases as the distance between the inductive charging coils increases, which is an inverse proportion. This shows that placing the coils closer to each other increases energy transfer efficiency.

5.6. Impact of Distance on Efficiency

Vertical distance between the charging coils within 1 to 3 centimetres achieves optimal efficiency. The distance beyond 5 centimetres significantly reduces efficiency, thus illustrating the relevance of short coil spacing in energetic transfer.

5.7. Frequency Optimization

The system's efficiency in energy transfers is greater with a higher frequency of the inductive charging system until hitting approximately 60 KHz. Any higher, the output voltage begins to drop, showing that about 60 KHz is the best efficient frequency.

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