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Design & Construction of Electro-Magnetic Induction based Roads (EMIR)

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Abstract**: *Middle-east and especially UAE promotes the use of Electric Vehicles to bring down the carbon emission. Cost of Electric Vehicles (EVs) can be brought down by reducing the cost of its battery. Dynamic charging allows smaller and lighter batteries to be used due to frequent charging, using the charging infrastructure embedded under the roads. Hence this reduces the battery cost and improves the battery life. Reduction in battery cost will bring down the cost of EVs and thus will encourage large population to move toward EVs. This paper presents the design & construction of a prototype EMIR to facilitate dynamic charging of EVs. Aim of this project is to construct 32 feet long and 3 feet wide prototype road with Induction charging facility. Four primary coils with the dimension 164cm x 31 cm with 3 turns and an inductance of 29.1µH are uniformly spaced on the road. Secondary coil of 40 cm x 31 cm with 6 turns with an inductance of 20 µH is attached onto the lower side of the chassis of the EV.***

Index Terms**: Dynamic Charing, Electric Vehicles, Zero Voltage Switching, Wireless Power Transfer, Electro-Magnetic Induction.**

I. INTRODUCTION

EVs are being looked to as the future of transportation, with the objective of reducing the emissions caused by fuel driven vehicles [1]. EVs gained popularity due to concerns about environment pollution with green house gases and a desire to move toward the greener energy. Concerning the wireless charging process, several different techniques have been present and currently are under investigation. Two categories of wireless charging process are static charging & dynamic charging [2]. Static charging, when the EVs are stopped and parked. Static charging solutions are of two types depends on the charging time. Long duration of static charging time, typically several hours when EVs are parked in a charging station. The second solution is fast static charging solution when EVs are stopped for few minutes at a Traffic signal. Dynamic wireless charging of EVs, which can be used to supply the motors and charge the battery while moving. Inductive power transfer is the most promising technology for dynamic wireless charging of EVs [3]. There are two distinctive designs for primary magnetic couplers in dynamic charging, including distributed elongate track and pads array. To track the couplers, continuous power can be transferred wirelessly from a long primary track to the receiver when the EV is running along the track [4]. Numerous studies have reported that one of the benefits of dynamic charging is that it allows smaller and lighter batteries to be used, due to frequent charging using the charging infrastructure embedded under roads [5]. Electric vehicles are also considered as a solution for the environmental problem [6]. By installing number of inductive power tracks, size of the battery can be reduced which reduces the cost of the EVs.

II. PREVIOUS WORK

Several ways of charging EVs have been discussed in the literature. Some belong to the category of dynamic charging and some of them belong to static charging category. In Kalyani Ghate and etal.[7], simple prototype depicting the wireless power transfer has been demonstrated. It also uses solar energy to energize the primary coils. System generates high frequency required for induction using microcontroller 89C51 and drives the coil using H bridge driver. System generates very small amount of power. In Shubhangi Das and etal [8], various methods of Wireless Power Transfer (WPT) have been discussed. It also elaborates on Roadway powered EVs and Online EVs. Paper also compares different types of WPTs considering following criteria:

- Strengths
- Weaknesses
- Applications

In Faiza Komal and etal [9], uses Resonant Inductive Power Transfer to transfer wireless power from primary to secondary. System uses series-series compensation topology and claimed to obtain an efficiency of 85%. Paper also discusses about mid-range stationary wireless power transfer. System is simulated using MATLAB. In B.Padmavathi [10],Prototype implements an Electric Vehicle using an Adaptive Robot. It uses autonomous charging system, which is capable of finding the transmitter coil. System has been simulated using CCS Compiler. In Katsuhiro Hata and etal [11], Dynamic wireless power transfer system is discussed. This paper focusses on a control method to estimate the road side voltage using vehicle-side information. Paper claims that it will avoid the use of regulation. It used a source frequency of 99.8KHZ and a DC-DC converter was set for 10KHz. In Chirag Panchal and etal [12], available wireless power transfer technologies for EVs are elaborated. Paper also reviewed “vehicle-to-grid” and “In-wheel” wireless charging systems. Paper also discusses about health and safety standards linked to charging of EVs.

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In Soham Chatterjee and etal [13], Comparison study among various coil structures such as Circular, Rectangular & Double coils have been made. Author claims that double coils can achieve 1.5 times the coupling of a circular coil. Paper also discusses on the effect of changing coil parameters. In Jasprit S Gill and etal [14], Infrastructure cost related to inductively coupled power transfer for EVs is discussed. Paper focusses on overcoming the constraints of limited range of EVs and cost of Energy Storage System. Paper gives a thorough analysis of the cost associated with the implementation of a dynamic Inductively Coupled Power Transfer infrastructure. In Francesco Deflorioa and etal [15], traffic and electric performance of “Wireless Charge While Driving” is analysed for two types vehicles such as light van and car. Meso scopic traffic simulator has been developed to study the traffic behaviour.

III. PROPOSED EMIR

Functional block diagram of Solar Powered Electro-Magnetic Induction based Roads is shown in Fig 1. It consists of following sections:

A. *Solar Powered Source:*

Power required for Wireless Power Transfer is derived from the battery being charged by Solar Energy. This project uses 24V, 300W Solar Panel.

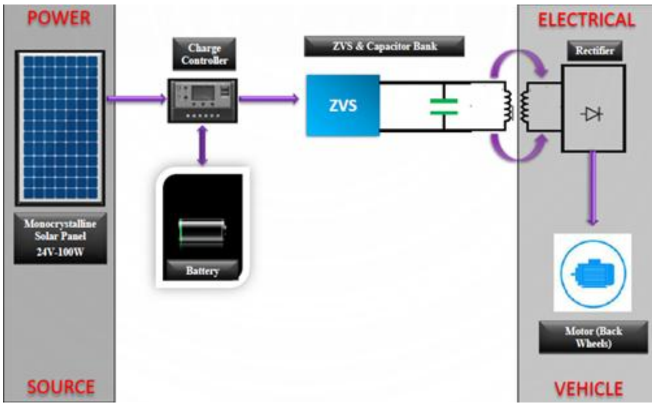

Fig 1: Block diagram of Solar Powered EMIR

B. *Wireless Power Transfer*

This section plays an important role in this project, Purpose of wireless power transfer circuit is to drive the primary coils which are laid out on the road. Fig 2 shows the pad array type primary coils. Voltage at the primary coil gets transferred to secondary coils due to Induction. Proposed WPT system operates at a frequency of 12KHz. Resonance is achieved by Zero Voltage Switching (ZVS) driver circuit. Primary LC tank circuit of ZVS decides the resonant frequency. Maximum power transfer takes place at resonance. This project aims at a spacing of 6cm between primary and secondary coils. After an exhaustive literature review, it has been decided to use coils made of Litz & USTC wires instead of conventional wires for primary & secondary. Litz & USTC cables eliminate the skin effect which is high in conventional single stranded cables. USPI-Z cables with 250 strands and 6mm outer diameters are used in this project. Secondary coils are placed at the bottom of the EVs. Induced AC voltage at the secondary is rectified to DC using high-frequency bridge rectifiers with filters. Rectified DC is fed to EV battery for charging.

85% power transfer efficiency is achieved at 12KHz with an optimal design of primary & secondary coils.

C. *Construction of Road for WPT:*

Fig 2 shows the construction of EMIR for wireless transfer of power from primary coil (On the road) to the secondary coil (In the EV). In this work, it has been decided to construct a road of 32 feet long and 3 feet wide. Different topologies of primary coils such as rectangular & ellipse shaped pancake coils are being tested. Both primary & secondary coils have been tuned to same frequency to enhance the highest coupling coefficient.

Fig 2: Picture showing EMIR

A.Primary Circuit (Transmitter Circuit) Primary circuit consists of two units, namely, high frequency inverters and Primary or Transmitter side resonant circuit with parallel combination of Inductance (L) & Capacitance (C). As mentioned in section 1, high frequency inverter is designed to generate 12 KHz AC with an average voltage of 24V. Input DC voltage is derived from 24V, 80AH solar gel battery, which in-turn charged by 24V, 300W solar panels. Charging current is regulated by charge controller circuit. In this project, 40A charge controller has been used. Various types of high-frequency inverters have been tested. H-bridge inverters with a frequency of 100KHz have been tested at the initial stage. They dd not perform well because of transient effect. Hence it has been decided to choose Zero Voltage Switching (ZVS) circuits which is also named as Mazilli oscillator. ZVS circuits have given very good efficiency when compared to other high frequency inverter circuits. Fig 3 shows the ZVS module and Metallized Polyester Capacitor (MKS) bank. MKS capacitors are recommended for high switching applications. Capacitor bank and primary coil shown in Fig 4 make a parallel resonant circuit which is tuned to 12 KHz.

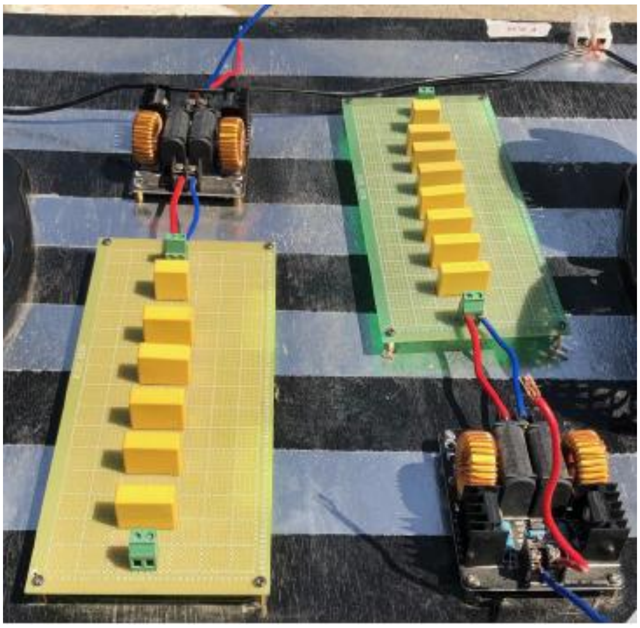

Fig 3: High-frequency inverter with MKS capacitor bank

Fig 4: Picture of array of primary coils

Fig 4 shows a 300mm wide & 1640 mm long, 3 turn rectangular coil which has been designed for the primary side for transmitting power. In this project, four primary coils of above dimension have been used. Fig 4 also shows primary coils set up on the road. Inductance of primary rectangular coil can be calculated using formula in eq (1):

$$L = \frac{\mu_0}{\pi} n^2 (\mathrm{w}. \ln\frac{l}{r} + l. ln\frac{w}{r}) \qquad (1)$$

Where l,w, r, and n are length, width, radius of the wire and ‘n’ indicates the number of turns which is 3 in this case.

Litz wire with 6mm radius has been used for constructing primary & secondary coils. Inductance of the transmitter coil is estimated at 29.1µH. LCR meter has been used to test the inductance of the coils at different frequencies.

B. Secondary Circuit (Receiver Circuit)

Secondary circuit consists of two parts, namely, secondary coil or receiver coil and high frequency rectifier unit. Fig 5 shows the secondary coil or receiver coil with an ellipse shape having length 400mm and width 310mm with 6 turns. Self-inductance of the coil has been estimated at 20µH.

Coil shown in Fig 5 performed well compared to circular coil with 6 turns and 150mm radius. Eq (2) shows the self-inductance formula for secondary coil. In eq(2), R indicates the mean radius of minor and major axis of the coil as it is having a shape of an ellipse. Parameters r and n have the same meaning as that of eq (1). It has been observed that coupling coefficient increases at higher frequencies.

$$L = \mu_0 . R . n^2 . \left(ln\frac{8R}{r} - 2\right) \qquad (2)$$

As in the case of primary circuit, secondary parallel resonant circuit formed by secondary coil shown in Fig 4 & capacitor bank shown in Fig 5. Both primary & secondary circuits are tuned to resonant frequency mentioned above to achieve high coupling coefficient. As mentioned earlier, since wireless transfer takes place at higher frequency, Metallized capacitors are well suited for such applications.

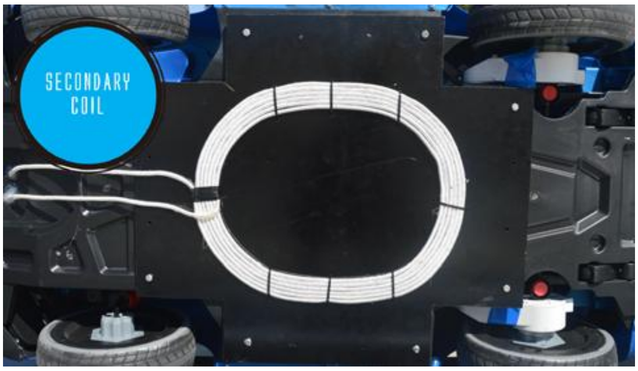

Fig 5: Picture of Secondary coil or Receiver coil

20V AC at 12KHz frequency is rectified by high frequency rectifier circuits. In this project, UF 4001 diodes have been used. Parallel combination of these diodes is used for high current applications.

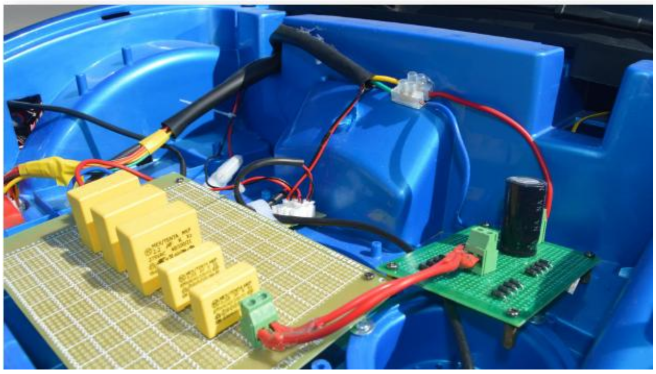

Fig 6: Secondary Capacitor bank & High Frequency Rectifier

Test1: Initial test has been carried out on H-bridge inverters using MOSFETs IRF 640. PWM Gate voltages with dead time are generated by using DDS Signal generator. Fig 6 shows the gate driving voltages. Dead time prevents both H-side and Low-side transistor to work at the same time which otherwise shorts the power terminals. As observed from the waveform, duty cycle of each waveform is around 40% with a dead time of 10%.

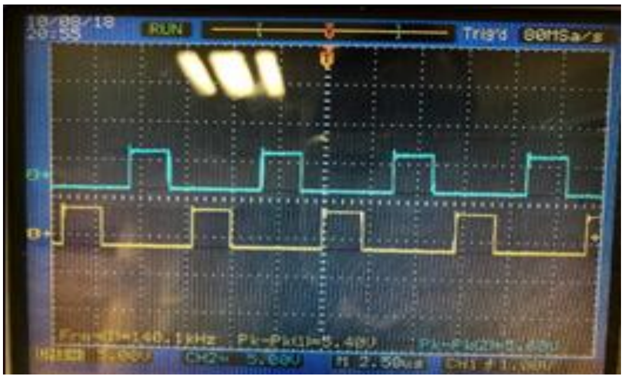

Fig 7: Gate voltages with dead time delay

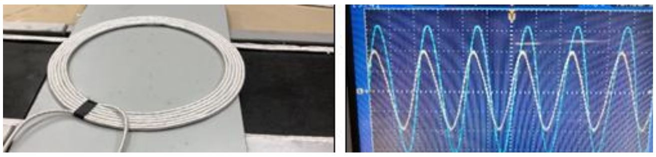

Fig 8: Testing of primary and secondary coils (a) & voltage outputs

Fig 7a shows the initial test stage where primary is a rectangular coil & secondary is circular. Fig 7b shows the primary side voltage and secondary side voltage at 12KHz. Zero Voltage Switching resonant circuits with parallel LC combination has been used in this case.

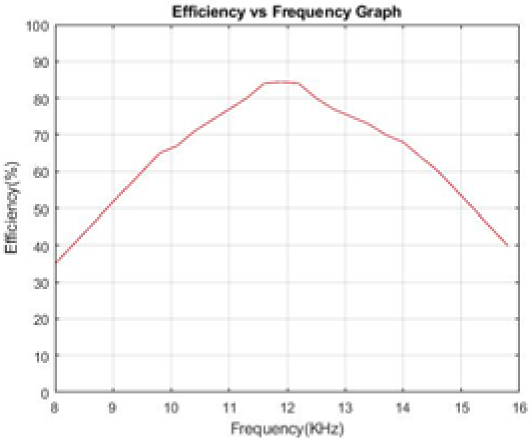

Fig 9: Efficiency vs Frequency graph

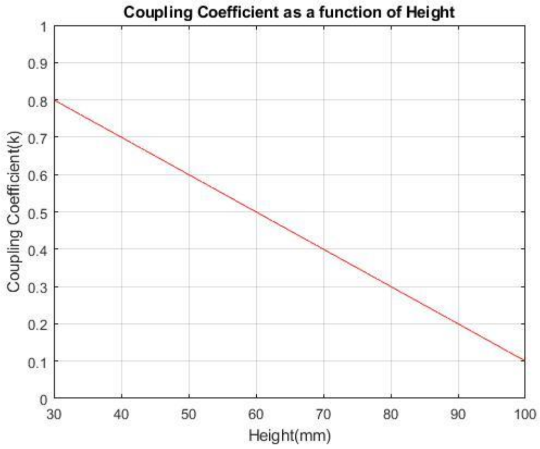

Fig 10: Coupling coefficient as a function of Height (mm)

Fig 8 shows the power transfer efficiency as a function of frequency in KHz. It is observed from the graph that; Maximum power transfer efficiency occurs at 12 KHz. On either side of frequency axis, efficiency drops considerably. Graph shows that 85% efficiency is achieved by optimally designing the primary and secondary coils. Fig 9 shows coupling coefficient as a function of spacing between primary coil and secondary coil recorded as height in milli meters (mm). Coupling coefficient of 0.8 is recorded at a lower height. As seen from the graph, coupling coefficient varies inversely proportional to the height.

IV. CONCLUSION

This paper presented the design & construction of electro-magnetic induction-based road for dynamic charging of electric vehicles. Dimension of the induction-based road is 10-meter-long and 3 feet wide. In this paper, four identical transmitter coils are embedded in the road for dynamic charging. Use of rectangular primary coils with a dimension of 164cm x 31cm and secondary coil with 40cm x 31cm with oval shape gave best results as observed from the graphs. Maximum efficiency of 85% has been recorded even when the vehicle is moving. Entire system has been made sustainable by powering the primary coils through solar energy. Future work will focus on increasing the coupling coefficient at a higher spacing between the primary and secondary coils. A study on compensation circuits to enhance the efficiency is also essential and will be investigated in the next phase of the work.

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AUTHORS PROFILE

Ramaprasad Poojary is working as an Associate Professor at Manipal Academy of Higher Education Dubai Campus in Dubai, UAE. He has about 20 years of Teaching & 6 years of research experience. He has pursued his B.E. in Electronics & Communication Engineering & M.Tech. in Digital Electronics & Communication from NMAMIT, Karnataka, India. He did Ph.D. in the area of Dental Image Registration from VTU, Karnataka, India. He has published many journals in the area of Image Processing. Presently he is mentoring undergraduate project on Electro-Magnetic Induction based Roads. He has worked on several university funded projects. He will be submitting a proposal for ANPR based funded project by Manipal Academy of Higher Education Dubai Campus.

Kimberly Crasto is presently an undergraduate student at Manipal Academy of Higher Education Dubai Campus in Dubai, UAE. She has won best paper award at the 4th Student Research Colloquium (AEIT-2019) held at Manipal Academy of Higher Education Dubai Campus during April 2019. Project on Electro-Magnetic Induction based Roads carried out by her team won first place in IEEE competition under Senior Design category held at Ras Al Khaima, UAE. This project also won First Place in Future Generation Competition held at Trade Center, Dubai during March 2019. Proposal on Electro-Magnetic Induction based Roads submitted her, received a grant of AED 25,000 from Expo-live, Dubai under University Innovation Programme.

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