JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

A REVIEW ON DYNAMIC WIRELESS POWER TRANSFER FOR ELECTRIC VEHICLES

Ayush Kumar
Electrical Engineering Department,
NIT Jamshedpur, Jharkhand, India
Email: ak403499@gmail.com

Abstract : With the increasing population, there needs to be an alternative to internal combustion (IC) engine vehicles, and Electric vehicles (EVs) has become an ideal alternative to IC vehicles. EVs encourage the people for adoption due to their user-friendly environment, reduces green emission & hike of petroleum. However, some challenges obstruct EVs' adoption, like low range long charging time. This paper presents the different wireless power transfer (WPT) charging techniques for EVs, comparative analysis of different core types & mono compensation topologies for suppression of the power losses and increasing the efficiency of WPT charging system. Here, single-coil tracking system & segmented coil tracking system for dynamic wireless charging technique, misalignment effect of transmitter and receiver coils are also reviewed..

Keywords—Wireless power transfer, Electric Vehicles, Resonant inductive power transfer, transmitter, receiver, Dynamic wireless power transmitter, inverter

I. INTRODUCTION:

Petroleum products and combustible fuel gas are being used in transportation sectors on a regular basis, and the growing population has caused a spike in vehicle usage. The demand for clean and green sources of energy has been sparked more by a limited quantity of fuels in the environment, exponential growth in the value of fuels, and the emission of toxic gases via IC-based vehicles [1]. Because of the alternative of combustion IC, EVs became more and more popular everywhere within the world. EVs will reduce environmental pollution and CO2 emissions and achieve high energy efficiency. Moreover, the event and improvement of key technologies concerning batteries and charging infrastructure, and electric motors and control increase EV attractiveness [2-4]. WPT dates back over two centuries ago. In 1899, Nikola Tesla conducted experiments on electricity transmission without wires in the USA. In 2007, 60W of power was wirelessly transferred over a 2-meter distance by researchers at MIT [5]. The most significant advantage of WPT over wired is eliminating cable and infrastructure and providing mobility within transmission range. It should also eliminate power plug compatibility issues [6,7]. On the other hand, older electric vehicle charging methods consume longer for charging [8]. WPT promises to significantly extend the Electrical Vehicles (EVs) mileage, decrease battery size and value, and improve the power density [9,10]. EVs mainly accommodate an electrical motor, a rechargeable battery, a charging setup & an electrical power control unit.

II. WIRELESS POWER TRANSFER

This charging system doesn't require any physical connection between the charging source & the EV's battery. A pair of the coil (transmitter coil & receiver coil) within the WPT system are magnetically coupled. In WPT charging method doesn't require any charging cables sockets. The medium of transferring power from transmitter to receiver coil is air. The WPT is represented in Fig.1 as a simple structure. The primary coil serves as a transmitting pad underground, while the secondary coil serves as receiving pad. Without any contact between the two pads, electrical power is transmitted from the pad near the floor to one placed on the vehicle's chassis.

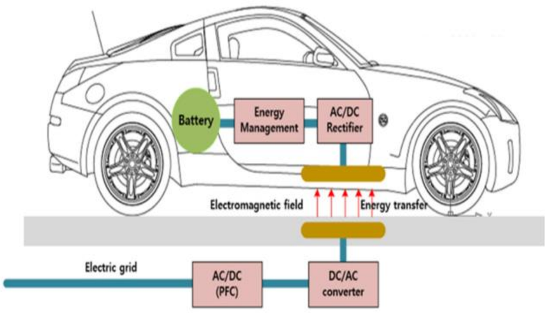

Figure 1: A simple structure of WPT[11]

III. Different techniques for WPT for EVs charging

The few methods of wireless charging are given as:

- *Capacitive wireless power transfer (CWPT)*
- *Resonant inductive power transfer (RIPT)*
- *Microwave Power Transfer Technique (MPT)*

Induction power transfer is predicated on Faraday's law of magnetic induction & was first reported by Tesla in 1914. In the IPT technique, A couple of inductors are mounted wirelessly in a common magnetic field. This type of charging system has two sections-

- Charging station
- Vehicle charging system.

The charging station is connected to the utility power grid in Figure 2. On this charging station side, the AC supply is rectified to the DC supply and then the DC Power is inverted to AC power with increased frequency, suited for WPT [12]. Through the electromagnetic induction principle, primary & secondary coils are coupled & the alternate AC supply induced in the secondary side is rectified into DC supply, which is used to charge the electric vehicle's battery. It works on an identical frequency both on sides & usable in high-frequency WPT applications.

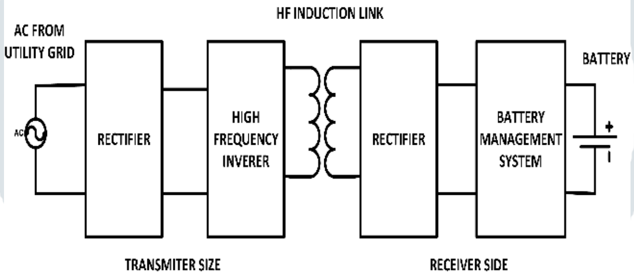

Figure 2: Block diagram of IPT

A. Capacitive Wireless Power Transfer (CWPT)

In this type of WPT technique, The linked capacitor is utilized to transmit energy between the transmitter and receiver pads. The advantage of CWPT is that it avoids the interference eddy current & electromagnetic interference that present in the magnetic-based WPT technique[13]. The AC feed from the utility system is then transformed to DC, which is then transformed to high-frequency AC by an inverter (see Fig. 3). Then the AC power is transferred from the transmitter capacitive pad to the receiver capacitive pad. The transmitter capacitive pad is buried within the ground & the receiver capacitive pad is placed within the bottom of the vehicles via the rectifier circuit; the transferred AC power is converted to DC power, which is suitable for charging an electric vehicle's battery system. The CPT system's power transfer capability is dependent on the gap between the transmitter pad and the receiver pad. It is used for stationary wireless EVs charging, but dynamic applications will be difficult to implement [14].

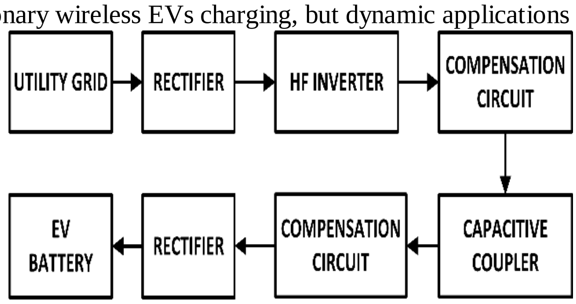

Figure 3: Block diagram of CWPT

B. Resonant Inductive Power Transfer (RIPT)

This method is the advanced version of traditional IPT. The inductively coupled wireless power transmission method is the most widely used technique [15]. The only difference between the conventional inductive power transfer & the RIPT system is that the RIPT system has the additional compensation circuit in both the primary & secondary sides of the charging system, as shown in Fig. 4. The advantage of the compensation circuit is that it compensates the leakage magnetic field [16] & maximizes the load power transfer with high efficiency.

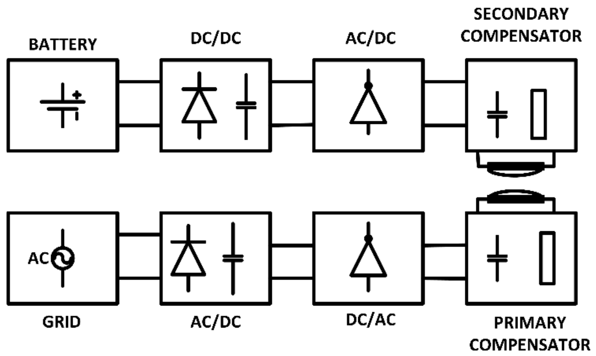

Figure 4: Block diagram of the RIPT system

C. Microwave Power transfer Technique (MPT)

Microwave Power Transfer (MPT) is a far-field WPT technique working with microwaves [17]. First, the supplied AC from the utility is converted into a high voltage DC supply in the MPT system. Then it is generated into microwaves via a high-frequency microwave generator, i.e. magnetron. Fig. 5 shows that these high-frequency microwaves are transmitted via the antenna. Then, transmitted microwaves are received & converted through the rectenna into DC before being fed back into the DC-DC converter to be converted to the desired dc voltage level to charge the EV battery [18]. Fig.6 compares different WPT techniques.

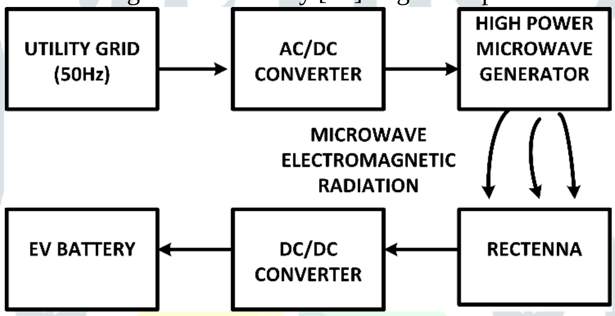

Figure 5 : Block diagram of microwave power transfer system

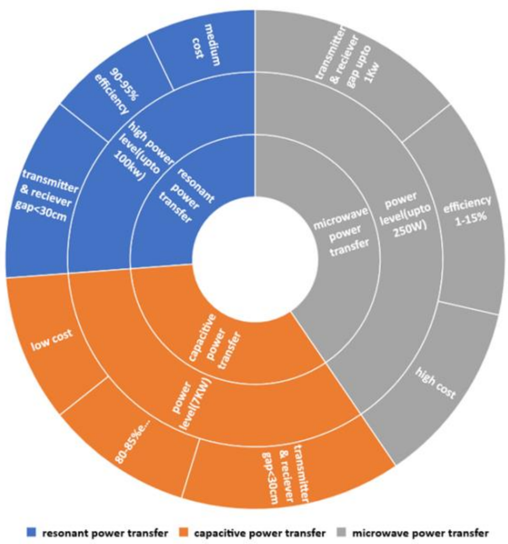

Figure 6 : Comparison of different WPT techniques

IV. COMPESATION TOPOLOGIES

The pads are loosely coupled with large leakage inductance in a WPT system. Mono-resonant Compensation network contains a capacitor inside the transmitter & a capacitor on the receiver side in different asynchronous (series) and parallel configurations [19]. The aim of the transmitter-side compensator is to reduce the phase mismatch between the voltage & current and reduce the source's reactive power [20,21]. The aim of a receiver-side compensator is to improve the load power transfer and efficiency [22]. The main purpose of the compensation circuit is to reduce the power loss caused by a considerable air gap between the transmitting & receiving coils in the WPT [16].

There are 4types of mono-resonant compensation topologies for compensation purposes are as below:-

Series-Parallel(S-P)

Series-Series(S-S)

Parallel-Parallel(P-P)

Parallel-Series

From Fig.7, L_1 and L_2 are the transmitter and receiver inductance respectively and M is the coupled inductor's mutual inductance. The compensating capacitors $C_1$and C_2 are linked to the transmitter side and receiver side coils, respectively. The PS and PP compensated WPT system provide a safe environment since it is impossible to transfer enough power when the source and receiver are misaligned, between the transmitter and the receiver and it is also protected from the power losses by the transmitter coil does not operate without receiver coil[23]. A voltage source converter could be directly coupled to the coil if the transmitter side is series compensated. If the transmitter side is parallel compensated, an extra inductor is frequently installed to convert the converter to a current source [24].

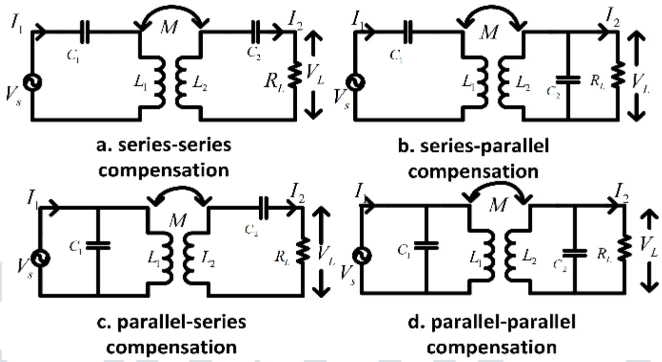

Figure7: Compensation topologies

Table I represent the capacitor values & efficiency for different mono-resonant compensation topologies. With the help of Table I, the value of transmitter side capacitance and receiver side capacitance can be calculated, which makes the WPT system highly efficient.

TABLE I. COMPARISON OF COMPENSATION PARAMETER

S.no.	Topology	Value of C_1	Value of C_2	Efficiency
1.	SS	$\frac{1}{L_1\omega}$	$\frac{1}{L_2\omega}$	$\eta \cong \frac{R_L}{R_1+R_L}$
2.	SP	$\frac{L_2^2C_2}{L_1L_2-M^2}$	$\frac{1}{L_2\omega}$	$\eta \cong \frac{R_L}{R_2+R_L+\frac{R_1L_2^2}{M^2}}$
3.	PP	$\frac{L_2^2C_2}{\frac{M^4R_L^2C_2}{L_2}(L_1L_2-M^2)}$	$\frac{1}{L_2\omega}$	$\eta \cong \frac{R_L}{R_2+R_L+\frac{R_1L_2^2}{M^2}}$
4.	PS	$\frac{L_2C_2}{L_1+\frac{M^4}{L_1L_2C_2R_L^2}}$	$\frac{1}{L_2\omega}$	$\eta \cong \frac{R_L}{R_1+R_L}$

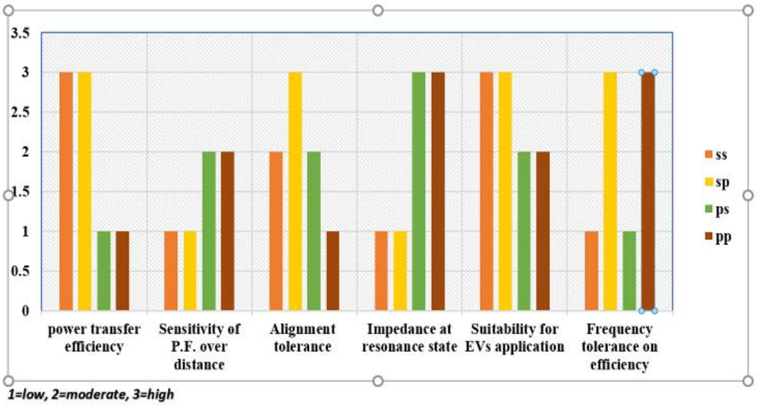

Figure 8 : Advantages and features of different mono-resonant compensation topologies

V. CORE TYPES FOR WPT SYSTEM

Basically, 2 kinds of core used for the fabrication of coupled inductors are given below-

Ferrite core- In the starting, ferrite core was available in E type core, U type core that and the pot is examined and positioned that they're improper for WPT due to their heavy nature. In modern times, various kinds of cores used for efficient power transfer in WPT techniques are shown below.

Single side circular core- The biggest advantage of this kind of core is that it offers low leakage inductance for WPT. Still, they're unable to transfer a decent output while taking the coupling between two coils and in mismatching conditions. [25].

Double D Quadrature – It eliminates the restrictions that occur with the aid of using the circular type core. The magnetization field induced by double D quadrature type core was two times of the standard E type, U type core[26].

Rectangular H-Shaped Core- This kind of core has lightweight as compared to the circular core, and Double D Quadrature, and also the efficiency is additionally high in misalignment conditions between the transmitter & receiver coils[27][28].

Tripolar Pad (TPP)- On this form of core type, the transmitter coil of the IPT system included three windings wounded individually and overlapped partially on one another, which does operate at various frequencies and various power transfer capacities and energized by more than one power sources. This kind of coil structure improves coil efficiency while operating in misalignment conditions.

Air type- On this form of core, there is no solid core is inside the coil. For the making of coils, conducting wires are wrapped on non-magnetic fabric like- plastic or ceramic [29]. The air-based core WPT system divided into various coils contains like-two, three, four & multiple numbers of coils systems [30]. With increasing the no. of coils, the gap between the transmitter coil & receiver coil decreases, therefore efficiency is to be increased. The U shape air core is the advanced innovation over the three coil WPT system & it increases the efficiency times to the two coils WPT system [31].

VI. DYNAMIC WPT FOR EVS

In plug-in charging of EVs or the static wireless charging of EVs must have sufficient charge beginning to the travel. This results in the massive capacity of charging storage packs required, which affords uninterrupted power to the EVs that make the EVs costly. At present, fast chargers are available in the market, but that is costly. So the problem of the cost of charging, range issue, and time taking problem for charging to EVs can be reduced by the Dynamic WPT charging technique[32].In the Dynamic WPT, the transmitter is on the surface of the road & the receiver is mounted underneath the vehicles. The dynamic power supply system is mainly specified as a centralized and individual power frequency scheme. In the centralized power supply scheme, a long coil (5-10 meters) is installed on the surface of the road, and in the individual or segmented power supply scheme, small size of many transmitter coils are connected in series and mounted underneath the road surface [33].

Dynamic WPT track can be built in2 types-
A. Single coil track
B. Segmented coil track [34].

Single Coil Track- In this type of track, only a single coil transmitter is used for the WPT. The structure of that system is very simple, but power losses in that type of tracking system are more as compared to segmented track. It occurs many disadvantages likes; the whole track is to be activated even track has low load, therefore power losses occur in that type of track. Due to any breakdown in this type of track system, the overall track system will be stopped. High exposure to electromagnetic fields is also the problem of that single coil track system[35].

Segmented Coil Track-To overcome the problem of the single-coil track, a segmented coil track structure is to be a good choice for a dynamic wireless charging system.[36]In this type of dynamic WPT system, many small transmitters are implemented one by one and make segmented coil-type tracking lines. This segmentation of coils can be energies by a single inverter or by the different individual inverters. Due to the small size of the individual coil, the power converter requirement is to be also small. The problem of power loss is also reduced due to different segments can be turned on or turned off with the help of sensors for different time periods[37].

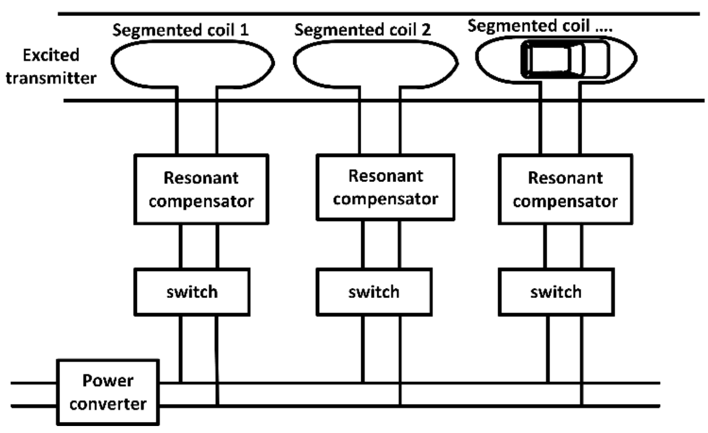

Figure 9 : Segmented coil track WPT

EFFECT OF MISALIGNMENT & EVS SPEED IN THE DYNAMIC WPT SYSTEM

The WPT through the magnetic coupling technique always operates at the resonant frequency with high efficiency, at that time, the value of the coupling coefficient is to be good[38]. Due to the driver's faults, a Tyre's pressure of EVs, the weight of passengers inside the EVs introduce the misalignment condition between the transmitter & receiver of the WPT charging system[39]. The EVs will be in dynamic condition, hence the amount of time that the transmitter & receiver coils will be interacting is significantly less as compared in stationary; this leads to the necessity of high-power device and also forces the system to have high alignment forbearance to make the system highly efficient with the increase in misalignment. The power transfer reduces and gradationally it increases the power transfer from the transmitter coil to the receiver coil in the WPT system, with transmitter and receiver coils apart from each other, the AC-DC converter's transmitter-side voltage, system operating frequency, and coupling coefficient reform, influencing the performance of the system [40]. Due to misalignment, transmitter side parallel combination of compensation circuits are ineffective for delivering rated demand, and transmitter side series combination of compensation circuit presents unsafe behaviour for source[41]. The scholars were prompted to create innovative compensation modules with high efficiency by the margins of traditional compensation designs used in RIPT-based WPT systems [42].

CONCLUSION

This paper presented an overview of the dynamic WPT techniques for EVs. Various types of WPT techniques and discussion of compensation topologies are added for the making high efficiency to WPT system. The mono-compensation topologies are not sufficient for dynamic WPT with High-efficient, so in the future, the researcher has to work ahead with overall mono-compensation topologies and Series-Parallel-Series (SPS) and Parallel-Parallel-Series (PPS) compensation topology and find highly efficient topology. Various types of coils and cores are briefly illustrated. On the basis of WPT charging techniques and after the analysis of the effect of EVs speed and alignment of the transmitter coil & receiver coil, the power transfer efficiency could be made better for the implementation of the dynamic WPT charging technique.

.

REFERENCES

[1] R. Bhatti, Z. Salam, M. J. B. A. Aziz and K. P. Yee, "A critical review of electric vehicle charging using solar photovoltaic," *International Journal of Energy Research,* vol. 40, no. 4, pp. 438-461, 2015.

[2] J. C. G. Palencia, V. T. Nguyen, M. Araki and S. Shiga, "The Role of Powertrain Electrification in Achieving Deep Decarbonization in Road Freight Transport," *energies,* vol. 13, no. 10, 2020

[3] X. Sun, Z. Li, X. Wang and C. Li, "Technology Development of Electric Vehicles: A Review," *Energies,* vol. 13, no. 1, 2020.

[4] M. D. Santis, S. Agnelli, F. Patane, O. Giannini and G. Bella, "Experimental Study for the Assessment of the Measurement Uncertainty Associated with Electric Powertrain Efficiency Using the Back-to-Back Direct Method," *Energies,* vol. 11, no. 12, p. 3536, 2018.

[5] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher and M. Soljacic, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," *science,* vol. 317, no. 5834, pp. 83-86, 2007.

[6] J. Pannier, D. Hendrickx, F. Petre and T. Nobels, "WIRELESS POWER TRANSFER FOR INDUSTRIAL APPLICATIONS THROUGH STRONGLY COUPLED MAGNETIC RESONANCES," 2019.

[7] C. Qiu, K. T. Chau, C. Liu and C. C. Chan, "Overview of wireless power transfer for electric vehicle charging," in *World Electric Vehicle Symposium and Exhibition (EVS27),* 2013.

[8] M. Kavitha, P. B. Bobba and D. Prasad, "Comprehensive Mathematical Modelling and Experimental Analysis of a Wireless Power Transfer System for Neighborhood Electric Vehicles," in *IEEE International WIE Conference on Electrical and Computer Engineering,* Dhaka,Banladesh, december 2015.

[9] S. C. Moon, B. C. Kim, S. Y. Cho and C. H. Ahn, "Analysis and Design of a Wireless Power Transfer," *IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS,* vol. 61, no. 11, 2014.

[10] G. A. C. J. T. Boys, "Inductive Power Transfer," *IEEE,* vol. 101, no. 6, pp. 1276-1289, June 2013.

[11] Y. Choi, B. Kwak and M. Kim, "4kW magnetic resonance wireless power transfer system," in *2016 IEEE International Conference on Power System Technology (POWERCON),* Wollongong, NSW, Australia, 2016

[12] Z. Shuwei, J. Kejun and L. Deshun, "Passenger transport modal split based on budgets and implication for energy consumption: Approach and application in China," *Elsevier,* vol. 35, no. 9, pp. 4434-4443, 2207

[13] E. Abramov, J. . M. Alonso and M. M. Peretz, "Analysis and behavioural modelling of matching networks for resonant-operating capacitive wireless power transfer," *IET Power Electronics,* vol. 12, no. 10, pp. 2615-2625, 2019.

[14] J. Dai and D. C. Ludois, "Capacitive Power Transfer Through a Conformal Bumper for Electric Vehicle Charging," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 4, no. 3, pp. 1015-1025, sept.2016.

[15] S. Kim, "Adaptive cognitive radio energy-harvesting scheme using sequential game approach," *EURASIP Journal on Wireless Communications and Networking,* 2017.

[16] C. S. Wang, G. Covic and O. Stielau, "Power transfer capability and bifurcation phenomena of loosely coupled inductive power transfer systems," *IEEE Transactions on Industrial Electronics,* vol. 51, no. 1, pp. 148-157, feb 2004.

[17] J. W. Guo, L. Sun, X. J. Niu, J. W. Liu, X. Z. Zhang, W. H. Zhang, W. Lu, Z. Shen and L. X. l, "45 GHz microwave power transmission and coupling scheme study with superconducting ECR ion source at IMP," 2011.

[18] I. E. Huerta, D. F. Montana, P. H. Nava, A. G. Juarez, J. R. Asomoza and A. L. Cruz, "Transmission system for distribution of video over long-haul optical point-to-point links using a microwave photonic filter in the frequency range of 0.01–10 GHz," *Elsevier,* vol. 19, no. 6, pp. 665-670, 1970.

[19] S. A. Sabki and N. L. Tan, "Wireless power transfer for electric vehicle," in *2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014),* 2014.

[20] S. Li and M. C. Chunting, "Wireless Power Transfer for Electric Vehicle Applications," *IEEE JOURNAL OF EMERGING AND SELECTED TOIC IN POWER ELECTRONICS,* vol. 3, no. 1, MARCH 2015.

[21] M. Kline, B. B. Izyumin and S. Sanders, "Capacitive power transfer for contactless charging," in *2011 Twenty-Sixth Annual IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2011.

[22] Qiu, K. T. Chau, T. W. Ching and C. Liu, "Overview of wireless charging Technologies for Electric Vehicles," *Journal of Asian Electric Vehicles*, vol. 12, no. 1, pp. 1679-1685, 2014.

[23] K. A. Kalwar, S. Mekhilef, M. Seyedmahmoudian and B. Horan, "Coil Design for High Misalignment Tolerant Inductive Power Transfer System for EV Charging," *Energies*, vol. 9, no. 11, p. 937, 2016.

[24] C. S. Wang, O. H. Stielau and G. A. Covic, "Design considerations for a contactless electric vehicle battery charger," *IEEE Transactions on Industrial Electronics*, vol. 52, no. 5, pp. 1308-1314, oct. 2005.

[25] G. A. Covic and J. T. Boys, "Modern Trends in Inductive Power Transfer for Transportation Applications," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 1, no. 1, pp. 28-41, march 2013.

[26] G. A. J. Elliott, S. Raabe, G. Covic and J. T. Boys, "Multiphase Pickups for Large Lateral Tolerance Contactless Power-Transfer Systems," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 5, pp. 1590-1598, june 2010.

[27] M. Chigira, Y. Nagatsuka, Y. Kaneko, S. Abe, T. Yasuda and A. Suzuki, "Small-Size Light-Weight Transformer with New Core structure for Contactless Electric Vehicle Power transfer System," *IEEE Energy Conversion Congress and Exposition*, pp. 260-266, 2011.

[28] S. Li and C. Chris, "Wireless Power Transfer for Electric Vehicle Applications," *IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS*, vol. 3, no. 1, 2015.

[29] S. kim, G. A. Covic and J. T. Boys, "Tripolar Pad for Inductive Power Transfer Systems for EV Charging," *IEEE Transactions on Power Electronics*, vol. 32, no. 7, pp. 5045-5057, 2017.

[30] "Coils Used for Wireless Charging," Freescale Semiconductor,Inc., 2014.

[31] Z. H. Ye, Y. Sun, X. Dai, C. S. Tang, Z. H. Wang and Y. G. Su, "Energy Efficiency Analysis of U-Coil Wireless Power Transfer System," *IEEE Transactions on Power Electronics*, vol. 31, no. 7, pp. 4809-4817, july 2016.

[32] C. Mi, S. Y. Choi and C. Rim, "Modern Advances in Wireless Power Transfer Systems for Roadway Powered Electric Vehicles," *IEEE Transactions on Industrial Electronics*, vol. 63, no. 10, pp. 6533-6545, june 2016.

[33] Coca(Ed.), Wireless Power Transfer - Fundamentals and Technologies, E. Coca, Ed., Londan, United Kingdom: IntechOpen, 2016.

[34] Y. A., W. S, L. W and H. J, "Analysis of Battery Reduction for an Improved Opportunistic Wireless-Charged Electric Bus," *Energies*, vol. 12, no. 15, 2019.

[35] H. Wang and K. W. E. Cheng, "An Improved and Integrated Design of Segmented Dynamic," *energies*, vol. 14, no. 7, 2021.

[36] K. Song, c. Zhu, J. Jiang, c. Wang and . X. Huang, "Basic Concepts of Static/Dynamic Wireless Power Transfer for Electric Vehicles," *springer*, 2022.

[37] J. P. K. Sampath, D. M. Vilathgamuwa and A. Alphones, "Efficiency Enhancement for Dynamic Wireless Power Transfer System With Segmented Transmitter Array," *IEEE Transactions on Transportation Electrification*, vol. 2, no. 1, pp. 76-85, 2016.

[38] X. Liu and S. Y. Hui, "Optimal Design of a Hybrid Winding Structure for Planar Contactless Battery Charging Platform," *IEEE Transactions on Power Electronics*, vol. 23, no. 1, pp. 455-463, Jan.2008.

[39] K. Y. Kim, Y. H. Ryu, E. Park, . K. . S. Song and C. H. Ahn, "Analysis of misalignments in efficiency of mid-range magnetic resonance wireless power link," in *IEEE International Symposium on Antennas and Propagation*, 2012.

[40] R. Severns, E. Yeow, G. Woody, J. Hall and J. Hayes, "An ultra-compact transformer for a 100 W to 120 kW inductive coupler for electric vehicle," in *Proceedings of Applied Power Electronics Conference*, 1996.

[41] U. Madawala, D. Thrimawathana and N. Kularatna, "An ICPT-supercapacitor hybrid system for surge-free power transfer," in *Industrial Electronics,IEEE Transactions* , 2008.

[42] B. L. Cannon, J. F. Hoburg, D. D. Stancil and S. C. Goldstein, "Magnetic resonant coupling as a potential means for wireless power transfer to multiple," *IEEE Transactions on power Electronics*, vol. 24, no. 7, pp. 1819-1825, July 2009