Wireless charging systems for electric vehicles

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ABSTRACT

Electric vehicles require fast, economical and reliable charging systems for efficient performance. Wireless charging systems remove the hassle to plug in the device to be charged when compared with the conventional wired charging systems. Moreover, wireless charging is considered to be environment and user friendly as the wires and mechanical connectors and related infrastructure are not required. This paper reviews the methods and techniques used for wireless charging in electric vehicles. First, the general techniques for wireless power transfer are described and explained. Capacitive power transfer and inductive power transfer which are the two main types of wireless charging are compared and contrasted. Next wireless charging systems for electric vehicles are classified and discussed in depth. Both the stationary and the dynamic wireless charging systems are discussed and reviewed. In addition, a typical model and design parameters of a dynamic charging system, which is a wireless charging system for moving vehicles, are examined. Control system functions of a wireless charging system of an electric vehicle are important for an effective and efficient performance. These are also discussed in the context of better efficiency of power transfer and improved communication between the transmitter and the receiver side of a vehicle charging system. Battery is an important part of an EV as different parameters of a charging system depend upon the battery characteristics. Therefore, different battery types are compared and battery models are reviewed. Findings of this state of the art review are discussed and recommendations for future research are also provided.

1. Introduction

Transmission of power without wires for supplying power to electrical devices and equipment, and for charging has been contemplated since the times of Tesla. However, this was not possible at that time because associated enabling technologies were not available. A breakthrough to this end was achieved in 2007 when researchers lit up a bulb from a wireless power source at a distance of two metres [1]. Much advancement in this field has been made since this major success [2, 3]. Electric vehicle (EV) charging is one of the many other areas where the option of wireless power transfer (WPT) has good potential and is being actively explored due to its many advantages [4, 5].

The traditional wired or plug-in charging systems are also called conductive charging systems. There are a few problems associated with these wired charging systems. For example, they require heavy charging wires and connectors. Furthermore, the charger should be manually connected to the electrical supply and the device to be charged [6]. The wired charging system is also not user and environment friendly [7]. If there is a short circuit or breakdown of the insulation of the charging wire due to reasons, such as high temperature, friction with the ground or the charging device itself, then this can cause an electric shock which can be fatal [8]. To reduce the charging time, and hence potential hazards associated with it, a large number of batteries can be used or the drained batteries can be swapped with the charged batteries when needed [9]. For example, if a vehicle can run a certain distance in a single charge with a given number of batteries, then the travel range can be increased by using a higher number of batteries. Alternatively, the vehicle batteries can be swapped with the charged batteries at charging stations during travel. However, the batteries have their own set of problems [10]. The batteries have heavy weight and a high initial cost but short life. Due to their weight, it may not be possible to carry a large number of batteries beyond a certain number. Future innovation in the energy storage devices may help overcome these problems. However, another possible method to overcome the problems associated with the batteries is the WPT [11]. For example, heavy and large size batteries can be avoided and the initial cost can be reduced by using the dynamic wireless power charging system [12]. Furthermore, the WPT method is convenient and user friendly as it removes the hassle of wires and connectors associated with the manual plugged in charging systems [13, 14].

WPT and its practical implementations are being widely investigated due to their potential use in a variety of industrial and engineering applications. Some of the applications where WPT can be used include EVs, electronic gadgets [15, 16], industrial plants [17], underwater vehicles [18], lighting [19], implanted medical devices [20], solar powered satellites [21], unmanned aerial vehicles (UAV) [22] and smart grids [23]. The WPT has also been investigated for long distance power transmission in the grid [24, 25]. A grid connected wireless power transmission system has been deployed as well, and is being tested [26].

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Abbreviations

AC	Alternating current
BPP	Bipolar pad
CC	Constant current
CP	Circular pad
CPT	Capacitive power transfer
CV	Constant voltage
DC	Direct current
DD	Double D
DWCS	Dynamic wireless charging system
DWPT	Dynamic wireless power transfer
EV	Electric vehicle
FOD	Foreign object detection
GHz	Giga Hertz
HTS	High temperature superconductors
IPT	Inductive power transfer
kW	Kilowatt
LCC	Inductor-capacitor-capacitor
LCLC	Inductor-capacitor-inductor-capacitor
LED	Light emitting diode
Li-ion	Lithium ion
LOD	Living object detection
LPF	Low pass filter
MOD	Metal object detection
NiCad	Nickel cadmium
NiMH	Nickel metal hydride
OLEV	Online electric vehicle
PFM	Pulse frequency modulation
PP	Parallel-parallel
PS	Parallel-series
PWM	Pulse width modulator
QDWCS	Quasi dynamic wireless charging system
QDWPT	Quasi dynamic wireless power transfer
RC	Resistor capacitor
RF	Radio frequency
Rx	Receiver
SAE	Society of automotive engineers
SoC	State of charge
SP	Series-parallel
SS	Series-series
SWCS	Stationary wireless charging system
SWPT	Stationary wireless power transfer
Tx	Transmitter
UAV	Unmanned aerial vehicle
USB	Universal serial bus
VCO	Voltage controlled oscillator
WPT	Wireless power transfer
ZCS	Zero current switching
ZPA	Zero phase angle
ZVS	Zero voltage switching

The reason behind the use of the WPT system in these applications is that it is safe, easier and flexible. By using this technique, the battery powered devices can be charged dynamically. This technique is also favourable during rainy weather as there are no wires involved and electric shock hazard is reduced. Additionally, it is adaptable, position free and enables mobility.

Wireless charging for EVs also uses the WPT and can be accomplished in three different ways i.e. static or stationary wireless charging system (SWCS), semi or quasi dynamic wireless charging system (QDWCS) and dynamic wireless charging system (DWCS) [27, 28]. In SWCS, the WPT is used for the charging of a stationary EV. The semi or QDWCS employs the WPT to charge an EV when a vehicle stops for a short duration during its travel. For example, an EV may stop at a traffic signal where WPT is used to charge the EV. Dynamic charging systems seek to charge an EV while it is in service and is moving.

In this work, we discuss and review the operating principles, technology, elements, methods, and various other aspects related to the EV wireless charging systems through a thorough study of the related research literature. Some of the main contributions of this work are listed below.

- A review of the related survey articles along with a tabular summary has been presented.
- The WPT methods are discussed in general before delving into the details of EV wireless charging systems and various techniques used for this purpose.
- SWCS and DWCS are reviewed and summaries of the developed systems have been presented.
- Design considerations of an IPT based DWCS along with a typical model have been reviewed.
- Wireless charging system communication and control with respect to system misalignment and power control have been discussed.

This state of the art article comprises ten sections. Section 1 gives a brief introduction to this research study and Section 2 presents a review summary and main contributions of the related survey articles that have been published. In Section 3, general techniques for the electric power transfer using wireless medium are discussed. In the ensuing

Section 4, the IPT and the CPT are reviewed and compared. Section 5 introduces the EV wireless charging. It discusses the WPT operating principles and reviews the charging process under different conditions. Section 6 furthers the subject under study and a review of charging techniques used in EVs is presented. CPT and IPT charging techniques and associated topics are reviewed in this section. In Section 7, wireless charging system control with respect to communication, efficient power transfer and misalignment is discussed. Section 8 discusses EV batteries as many parameters of a wireless charging system are determined by the batteries. The review findings and recommendations for future research are provided in Section 9. The article concludes with Section 10. The organisation and structure of this article is illustrated in Fig. 1.

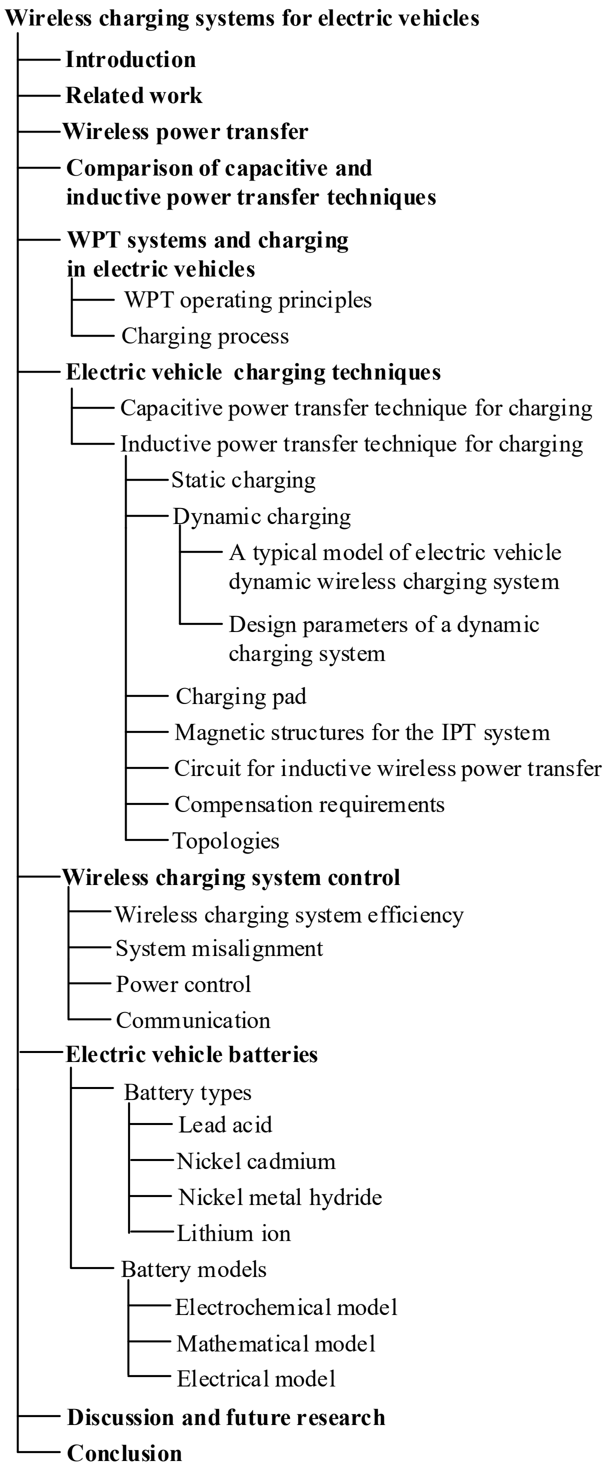


Fig. 1. Organisation and structure of the article.

2. Related work

In this section, we provide a review of the related work in chronological order of the year of publication.

Various aspects of wireless charging systems for EVs have been studied, reviewed and presented in the literature since this area of research gained focus a few years ago. A work in the early days of wireless charging for EVs [29] reviews different technological solutions. Feasibility of each possible solution is evaluated considering the limitations of the cost, available power electronics technology and consumer acceptance. Coupling theory is reviewed and its application for WPT using IPT is further discussed. However, this review is limited in nature, and many aspects, such as SWCS, DWCS, design considerations, control and communication are not discussed and analysed. Another relatively short review in [30] studies near field inductive power transfer (IPT) using strongly coupled magnetic resonance for wireless charging of EVs. The work also reviews multiple pickup control, misalignment tolerance, shielding methods and simultaneous power and data transmission. However, this work lacks a thorough analysis of the reviewed topics. Moreover, CPT and DWCS are also not reviewed. The authors of [31] review the technology companies that have developed the wireless charging solutions for EVs. In addition to this, the authors review the research laboratories and the universities that are working in this field and some of their proposed solutions. The automobile companies that are interested to deploy the wireless charging systems for EVs and their work are also discussed. The safety issues and regulations related to the wireless charging systems are described too. However, this review focuses only on the feasibility, penetration and adaptation of the EV wireless charging systems. Many technical details, such as, different types of charging techniques, and the IPT and the CPT are not reviewed. The work in [32] reviews and compares the IPT and the CPT for the WPT using analytical modelling and empirical data. The authors conclude that the IPT is preferable for the WPT if the gap is greater than 1 mm. The power densities of the CPT and the IPT couplers are nearly identical for air gaps in the range of 1 mm. However, the CPT may be preferred for the applications in which the gap is 1 mm or less due to the large size of coils used in the IPT. On the other hand, if the gap is larger than 1 mm, the IPT may be preferred due to its better and larger power transfer ability. This work compares only the IPT and the CPT for small gap charging applications, whereas other aspects of the EV wireless charging are not considered and analysed. The review articles discussed in this paragraph were published in the years 2014 to 2015. These are preliminary studies in which the basic methods and issues related to EV wireless charging systems are discussed.

The WPT for EVs is reviewed in [33] from both technical and sustainability perspectives. The work focuses on the IPT for the WPT and briefly discusses the coil design for both the SWCS and the DWCS. Compensation topologies, control methods and power electronics converters for the WPT are also discussed. From the sustainability perspective, energy and environmental assessments are made, and economics, policy, health and safety issues are discussed and reviewed. In addition, prospects to enhance sustainable mobility are also described. This review is, however, limited in nature as many topics, such as, the charging process, the CPT, the design parameters, and the magnetic structures for the IPT are not discussed. The authors in [28] provide an in depth review of the wireless charging technologies for EVs. The work provides a comparison of the conductive and the wireless charging systems, which is followed by a detailed description of the stationary and the dynamic systems for wireless charging. Standards related to wireless charging are listed and reviewed. Issues related to sustainability, health, safety, economic analysis and social implications are also discussed in this work. Even though this work reviews and provides a good insight into many functions of EV wireless charging systems, it does not discuss the CPT, battery related issues, and control and communication aspects of these systems. Another work in [34] reviews the deployment, operations and commercialisation activities of the charging solutions. Assignment and allocation of charging infrastructure, driving range extension and cost and benefit analysis for wireless charging systems for EVs are also discussed. This review focuses on systems, operations and economics of the EV wireless charging systems and does not discuss technical details, such as, the IPT, the CPT, the compensation topologies and the magnetic structures. Wireless transformer structures with different ferrite shapes are reviewed in [35]. In addition, the SWCS and the DWCS are reviewed in the light of developments made by the industry, the universities and the research laboratories. However, this article does not discuss the charging process, communication and control related issues of the EV wireless charging systems. This paragraph has reviewed the articles published in the period from 2016 to 2018. The work during this period discusses economics and social implications of the wireless charging systems in addition to the technical aspects.

The work in [36] reviews various aspects of an inductive wireless charging solution in detail. Some of the key aspects of an EV charging system are reviewed, summarised and compared. A few of these include coil design, compensation topologies and communication between the ground and vehicle assembly. Particularly, the work investigates the use of superconducting material in the coil design and its potential impact on a wireless charging system is also discussed. In addition, standards, health and safety issues and costs related to EV wireless charging systems are discussed and reviewed. Even though this work is a detailed review, it does not cover some important topics related to an EV wireless charging system. For example, the battery related issues are not discussed. In addition, the IPT and the CPT are not compared in sufficient detail. In a relatively short review [37], wireless charging of EVs using the IPT with strongly coupled magnetic resonance is discussed. Various aspects of the IPT, such as, operating principles, compensation technologies, charging distance, power level and misalignment tolerance are also reviewed. However, this review is restricted only to the IPT and associated topics and many further details of the EV wireless charging are not discussed. Authors in [38] give a detailed review of wireless charging systems for high power transfer applications. Laboratory prototypes and commercial systems for high power wireless charging are discussed and reviewed with respect to compensation networks, magnetic pad designs, power electronics converters, and communication and control strategies. The work, however, is dedicated only to the high power wireless charging applications, and therefore does not discuss topics related to the common wireless charging systems, such as, the charging process, the CPT, and the battery related issues. Different technologies used for the WPT for the charging of EVs are discussed and reviewed in [39]. After describing various charging modes, this work proceeds to review the near field and the far field WPT for the charging of EVs. This review article focuses on different types of WPT methods and their performance comparison. It does not discuss some important topics, such as, design considerations, compensation networks, the charging pad, communication and control of an EV wireless charging system. The articles discussed in this paragraph were published in the period from 2019 to 2021. These articles present further advancements and detailed technical reviews of the EV wireless charging technology.

Our current work provides a review of the EV wireless charging systems with a unique perspective. The general WPT methods are described before discussing wireless charging in EVs. In addition, these wireless charging systems are discussed in the context of both SWCS and DWCS. Summaries of the stationary and the dynamic wireless charging systems with quantitative details are also provided. Furthermore, this work takes a wider view of wireless charging research. For example, different types of batteries and battery models are also discussed, as the batteries are significant when discussing a charging system. Another unique aspect of this study is the review of the related survey articles which is presented in this section, and is summarised in Table 1.

3. Wireless power transfer

In a WPT system, the electrical energy may be transferred from the source to the destination using near field and far field transmissions [40]. The medium used for far field WPT may be acoustic, microwave or optical. For the

Table 1
Summary of related review articles and their contributions.

Reference	Year	Title	Main contribution	No. of cited references in the paper
[29]	2014	Overview of wireless power transfer technologies for electric vehicle battery charging	Review of coupling theory and its use for the WPT.	40
[30]	2014	Overview of wireless charging technologies for electric vehicles	Studies EV wireless charging using IPT and strongly coupled magnetic resonance.	31
[31]	2014	Electric vehicle wireless charging technology: A state-of-the-art review of magnetic coupling systems	Companies, laboratories and universities developing wireless charging solutions are reviewed.	58
[32]	2015	A survey of wireless power transfer and a critical comparison of inductive and capacitive coupling for small gap applications	Analytical modelling and empirical data are used for the comparison of IPT and CPT for small gap (1 mm) applications.	101
[33]	2016	A review of wireless power transfer for electric vehicles: Prospects to enhance sustainable mobility	Coil design for both stationary and dynamic charging. Compensation topologies, converters and control methods. Sustainable mobility.	86
[28]	2018	A comprehensive review of wireless charging technologies for electric vehicles	Comparison of conductive and wireless charging. Static and dynamic charging systems. Wireless charging standards.	180
[34]	2018	Survey of the operation and system study on wireless charging electric vehicle systems	Development and commercialisation activities. Infrastructure issues, driving range extension and economic analysis.	127
[35]	2018	Review of static and dynamic wireless electric vehicle charging system	Transformer topologies, coil shapes. Stationary and dynamic charging.	118
[36]	2019	A critical review on wireless charging for electric vehicles	Coil design, compensation topologies, communication aspects. Use of superconducting material in coil design.	288
[37]	2019	Review of wireless power transfer (WPT) on electric vehicles (EVs) charging	IPT with strongly coupled magnetic resonance. Charging distance.	68
[38]	2020	Advances in high-power wireless charging systems: Overview and design considerations	High power wireless charging systems. Compensation networks, magnetic pads, communication and control.	274
[39]	2021	Wireless power transfer technologies applied to electric vehicles: A review	Charging modes of operation. Near field and far field wireless power transfer.	108
This	2022	Wireless charging systems for electric vehicles	Summary of review articles. WPT methods. Stationary and dynamic charging. IPT, CPT.	305

near field, capacitive or inductive coupling technique that is non radiative electric, magnetic or electromagnetic field is usually used.

Microwaves may be employed for transferring energy using frequencies in the range of 1 GHz to 1000 GHz [41]. In the optical method, power is transferred by a laser beam [42]. Both microwave and laser can be used for power transmission over long distances. However, both require a clear line of sight between the transmitter and the receiver. These are potentially harmful to humans and biological life also. Some work for EV charging using microwave [43, 44] and laser [45] has also been done. However, these are not being used commercially [46] as yet.

WPT using mutual coupling is an effective wireless charging technique [47]. In this method, the mutual coupling can be capacitive or inductive. Capacitive coupling employing capacitors forms the basis of the CPT, and the inductive coupling using inductors results in the IPT. CPT based wireless charging produces low power levels and the charging gap is also small when compared to the IPT based wireless charging [32]. Therefore, the IPT based wireless charging techniques are considered better and are being used for commercial deployment [48].

In an inductive coupling based WPT, the current is produced by means of mutual induction [49]. A pair of coils is used for the transfer of electrical power. One of the coils is the primary and may be considered as an antenna for the transmission of power. The other coil can be thought

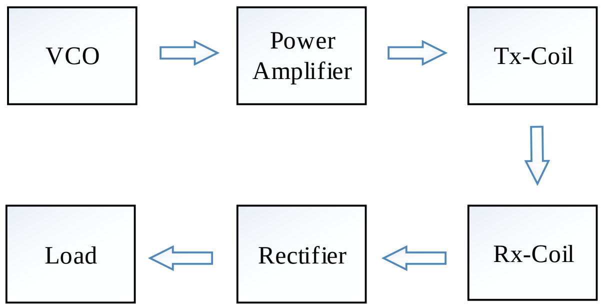


Fig. 2. Inductive coupling is employed for wireless power transfer over a short distance. Mutual induction between a pair of coils is used for the transmission of power. The primary coil acts as the transmitting antenna, whereas the secondary coil serves as the receiving antenna.

of as secondary serving as the receiving antenna. A time varying voltage applied to the transmitter side coil results in a magnetic field in the near field of that coil. Due to this magnetic flux, a voltage is induced in the receiver side coil that is present in the near field of the first coil. This is due to the mutual induction between the coils. The inductive coupling based WPT system may additionally be augmented by a magnetic resonance network between the primary and the secondary sides [50, 51]. At the resonance frequency, the coupling wave has its maximum, and therefore, it results in an efficient power transfer. Performance of the system may be affected by a number of parameters which include the operating frequency, resistance, turns of coils and the diameter of the coils [52]. So, these parameters should be considered and tuned while using this technique. The process of inductive coupling based WPT is illustrated with the help of Fig. 2.

In the IPT technique, the energy is transferred using flux that is produced by the transmitter [53]. If a large amount of flux is received by the receiver, then this means that the coupling between the coils is good. The distance between the coils has a direct impact on the system efficiency [54], as it limits the transmission of flux from the transmitter to the receiver [55, 56]. If the distance between the coils increases beyond a certain limit, the coupling decreases and consequently, the working efficiency of the power transmission reduces.

Of the three methods used for the WPT described in this section, only the mutual coupling is employed for the wireless charging of EVs at present [39], and will be the focus of discussion in the remainder of this article. A comparison of the aforementioned power transfer methods on the basis of cost, output power, distance and biological effects on humans is provided in Table 2 [56, 57].

4. Comparison of capacitive and inductive power transfer techniques

Both CPT and IPT, which are the two main techniques for the WPT, have pros and cons. An overview of the comparison between the CPT and the IPT techniques is provided in Table 3 [32, 58, 59]. Both these techniques are further discussed in this section.

While the CPT is suited only to low power systems, the IPT is considered to be appropriate for both high and low power applications [32, 60]. As an EV requires high power in the range of kWs for charging, the IPT may be preferred over CPT for EV charging applications [61]. IPT works on the same principle as that of a transformer. Without a physical connection, the energy is transferred between the coils. Therefore, mutual induction and coupling play an important role in an IPT system [62]. To achieve a good coefficient of coupling, the gap between the transmitting primary and receiving secondary coils should be appropriately adjusted.

In a regular transformer, efficient transmission of high power is not possible by utilising this approach alone. Therefore, a compensating circuit must be used that provides high voltages at the input and the output for the transmission of high power [63, 64]. Based on the combination of the capacitor and the coil in the compensating circuit, the IPT can be subdivided into different categories. The compensating capacitor can be either in parallel or in series with the coil. Therefore, four combinations are possible [65]. These combinations are,

- parallel-parallel (PP),
- parallel-series (PS),
- series-parallel (SP), and
- series-series (SS).

Simplicity is the key advantage of this approach. However, all these combinations do not support all the load conditions [66, 67]. Efficiency can be compromised by variations in the load [68]. Moreover, there should be an alignment between the coil and the capacitor so that the power level is maintained. To resolve this problem, different methods, such as, double sided LCC compensation method have been proposed [69, 70]. In the double sided LCC compensation method, one inductor and two capacitors are attached on both the sides. For both the input and the output, the resonant tank behaves as an energy source using this approach [71], and the current at the output is not affected by the load conditions. One of the problems associated with the IPT technology is related to the coefficient of coupling [49, 72]. When the coefficient of coupling is low, the reactive power is high, and the efficiency of power transmission is low [73]. Compensation tank helps improve the efficiency and reduces the reactive power [74]. As a result, the load and the coupling coefficient are invariant of the resonance frequency. This is one of the main advantages of the IPT technology.

Table 2
Comparison of WPT methods [56, 57].

Microwave	Laser	Mutual coupling
It is a costly method	It is also an expensive method	Relatively cheap as compared to the other methods
Used for long distance applications	Used for both long and short distance applications	Used for short distance applications
Harmful for human beings	This is also harmful for humans	Not harmful for humans
High output power	High output power	Low output power as compared to the other methods

Table 3
Comparison between inductive power transfer and capacitive power transfer [32, 58, 59].

Inductive power transfer (IPT)	Capacitive power transfer (CPT)
Used for both high and low power applications	Used for low power applications
Magnetic field is used for power transfer	Electric field is used for power transfer
High efficiency	Low efficiency
Compensation circuit consisting of inductor and capacitor is used	Compensation circuit consisting of inductor and capacitor is used
Can transfer power at large distance	Can transfer power at small distance
Installation of system is expensive	Relatively inexpensive installation

For an efficient transfer of electric energy from the primary to the secondary side coil in an IPT system, the frequency should be high [75, 76]. For this purpose, the low frequency AC current that is supplied by the grid is first converted into DC. After this, it is changed in high frequency current by using DC/AC converters [77]. Next, the power transfer takes place as a result of the magnetic induction. The voltage induced on the secondary side is then rectified and converted to DC, and is utilised by the EV battery [49]. To transfer high power and to achieve high efficiency, compensation capacitors are used on both sides [65]. Choice of the compensating elements is made by taking into consideration the mutual inductance and self inductance of the coil in case of static inductive charging [78]. The use of such compensating elements should be carefully evaluated in the dynamic inductive charging systems because the inductance value changes with respect to the motion of the EV [79].

Though the IPT has advantages for charging an EV, the CPT method is also being investigated for EV charging [80]. In addition to the consideration for EV charging, the CPT method is mostly used in low power applications, such as universal serial bus (USB), lamps and small robots [81]. The main limitation of the CPT method is that the transmitted power is low and the distance over which it can be transmitted is also small [47]. The CPT method can also be categorised based on the type of the compensation circuit used. For a series resonant circuit, a series inductor is used with the coupling capacitor. The capacitance is usually large as compared to the inductor [82]. Another method in CPT is the use of class E converter. However, its power and efficiency are limited due to the high frequency converters [83]. For the transmission of capacitive power, PWM converters are used. Other topologies are also possible, such as LCLC in which two inductors and two capacitors are used on both sides [84]. However, there is a loss of power due to a leakage electric field in case the air gap is large.

5. WPT systems and charging in electric vehicles

The WPT systems used for the wireless charging can be divided into the following three categories with respect to the state of motion of the EV,

(a) Stationary WPT (SWPT),
(b) Semi or quasi dynamic WPT (QDWPT),
(c) Dynamic WPT (DWPT).

With the SWPT, a stationary EV is charged using the WPT. When compared to the plug in wired charger, the SWPT is different only in the wireless transfer of energy [85]. The SWPT is efficient in urban areas where the stations may be installed for EV charging. In the SWPT system, two pads are used [86]. One is for receiving, installed on the vehicle and the other is for transmitting, installed on the charger [87, 88]. The QDWPT is used for short term charging, and that is why it may be installed at the bus and the taxi stands [89]. Temporary stops at traffic lights can also be used to energise EVs by this system [90]. In a DWPT system, the electrical energy is transmitted to an EV using a wireless medium while it is in motion [91]. There is no need to stop and wait for the charging of the vehicle.

Each of the SWPT, the QDWPT and the DWPT can be achieved by using either the IPT or the CPT [92]. Commercial scale deployments, at present, use the IPT due to its higher power transfer ability with a larger gap between

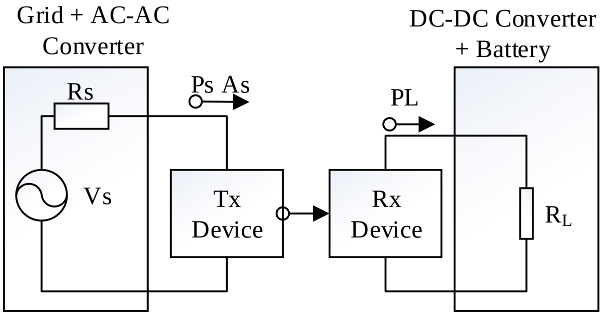


Fig. 3. A general depiction of a wireless charging system for an electric vehicle. There is an air gap between the transmitting and the receiving sides, and the power transfer between the two sides is due to the coupling between them.

the transmitter and the receiver when compared with the CPT [93]. However, the IPT implementations of the SWPT, the QDWPT and the DWPT involve large copper coils with ferrous cores which make the system bulky and heavy. On the other hand, CPT based prototypes and implementations [82, 94, 95, 96] use simpler structures involving plates and foils. The resulting charging system is not only lighter, but also cost effective. However, power transfer levels are lower and the air gap is also quite small. Due to the simplicity and cost effectiveness, research is underway [80, 97, 98] to overcome these shortcomings of the CPT based SWPT, QDWPT and DWPT charging systems.

5.1. WPT operating principles

The basic principle of operation of a WPT system for an EV is depicted in Fig. 3 [89, 99, 100]. Transmitter and receiver are the two basic modules of this system. The transmitting i.e. the primary, and the receiving i.e. the secondary coils are coupled and there is an air gap between these coils [99]. Power conversion circuit is installed on both sides. The primary coil is energised by the grid by using a diode rectifier that is connected in series with an inverter. The operational frequency of the inverter is high [101]. The inverter, the rectifier and the grid are used for setting up of the power supply to the primary coil [102]. This power supply is equivalent to that which is provided by a power source with a voltage V_s and an internal resistance R_s [99]. One of the main parameters for the energy transfer is the voltage provided by the power source or the generator. Therefore, selection of the generator is also important, which should provide a sinusoidal output.

The voltage induced by the secondary coil is fed to a rectifier circuit which is connected in series with a DC to DC converter [103, 104]. The output is provided to the battery charging circuit. The output voltage and the current can be adjusted according to the charging requirements of the battery [101]. The load R_L on the secondary side is connected by rectifier, chopper and battery [99]. Mutual inductance is affected by a variation in the air gap that exists between the two coils. If there is a large air gap between the coils, then a small mutual inductance will be produced and there would be a large leakage inductance [24]. Consequently, a large current is required to transfer a specific amount of power. Losses will be induced due to this large current. These losses will, in turn, affect the efficiency of the system. A compensating capacitor is used to alleviate this problem [105, 106]. By using this capacitor, there would be only resistive part in the topology. This results in the reduction of losses that are produced by the circulating current. As a result, the efficiency of the system is improved.

5.2. Charging process

The charging process of the EV batteries involves two modes. In one mode, the charging current is constant and the charging voltage is allowed to vary. It is referred to as the constant current (CC) charge. In the other mode, the charging voltage is kept fixed and the charging current is allowed to change. This is referred to as the constant voltage (CV) charge [107, 108]. At the start of the charging process of a drained battery, the CC mode is used. The charging current is usually kept at almost 10% of the battery rating. As soon as the battery SoC reaches near its rated capacity, say 80%, the CV mode is then used for charging the battery. This ensures a smooth charging process without overheating and damaging the battery, though it may require a longer period of time to charge [109]. If the CV mode is used to charge a drained battery at the beginning, then a heavy charging current may result which may overheat or damage the battery. Therefore, the CV mode is usually not used when a battery is charged to less than 80% of its full capacity. Similarly, if the CC mode is used to charge a battery near the rated capacity, then it may result in overcharging the battery, which may also overheat or damage it [107]. The fluctuation of the current and the voltage decreases the battery life. If the load varies during the charging process of the batteries, thereby resulting in a change of its SoC, then the CC and the CV modes can be used as needed to maintain an efficient charging process. For constant duty converters, two modulation techniques can be used to deal with the load variations [110, 111]. In pulse width modulation (PWM), the frequency is constant while the pulse width is varied. In pulse frequency modulation (PFM), the width of the pulse is constant while the frequency is variable. Instead of using a single modulation technique, both PWM and PFM can also be used [110]. In the PWM control, the switching noise can be predicted as the frequency is fixed. Therefore, the filtering process is easier [112]. On the other hand, the number of switching operations also remains the same due to the constant frequency irrespective of heavy or light load. Hence, the self consuming current is also fixed, which leads to high switching losses at light loads thereby reducing the efficiency [113, 114]. In the PFM control, the frequency increases when the load is heavy and it decreases when the load is light [110]. As the switching frequency decreases under light loads, the number of switching operations also decreases. This also decreases the switching losses. However, noise filtering in the PFM is

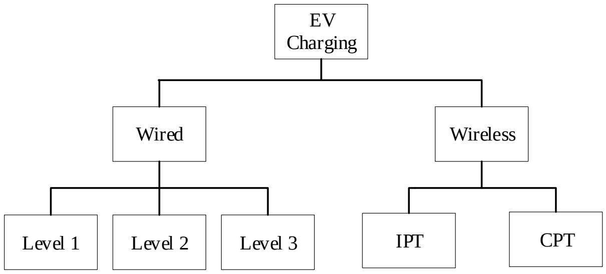


Fig. 4. An EV can be charged using wired or wireless methods. These techniques are divided into further categories depending upon the level of charge or the charging methodology.

difficult due to variation in the frequency [112]. Therefore, for heavy loads and loads with small variations, PWM is preferable [115]. For light loads and loads with significant variation, the PFM technique may be used, as a change in the frequency is unavoidable for operation with a changing load [116]. Due to this variation, the converter would need more work for regulating the current. Furthermore, the voltage may not remain stable and, as a result, zero voltage switching (ZVS) operation will be affected [83, 84]. The same is true for the current, thereby affecting the zero current switching (ZCS) operation [117]. Power transfer capacity and power loss can also be affected. However, variation in the battery voltage does not affect the resonance circuit. Misalignment also has negligible effect on resonance due to self inductance of the coils. Therefore, it is appropriate that the batteries are charged using the CC charging mode when the SoC drops well below the rated capacity due to load variation [107]. The input power factor of the inverter and the efficiency can be improved by using this method.

6. Electric vehicle charging techniques

The techniques used for the charging of an EV may be broadly categorised as wired or wireless. The wired conductive charging may be further subdivided into three different levels, which are level 1 (L-1), level 2 (L-2) and level 3 (L-3) [118, 119]. Likewise, the wireless charging techniques may be divided into two main categories, which are, the CPT and the IPT. The IPT is considered to be the preferred technique for wireless charging as compared with the CPT method [32, 60, 61]. The wireless charging techniques may also be subdivided into the static and the dynamic methods [86, 91]. These different techniques and their further division are shown in Fig. 4 [32, 86, 118].

6.1. Capacitive power transfer technique for charging

In a CPT system, the electric power is transferred using an electric field. When passing through the electrically isolated metal barriers, the electric field shows only small power losses [120]. Therefore, it is considered suitable for the charging of EVs [80]. Transmission of power is done by using the capacitors. These capacitors are formed by using metal plates that are cheaper. For example, the aluminium plates can be used as these are good conductors, have light weight and are low cost.

The alignment of the vehicle and the charging pad is important in a charging system. If there is a misalignment of position, detuning cannot be avoided in the CPT charging method [121]. The structure of a CPT charging system is simple, as metal plates are used instead of coils. Two capacitive couplers for the transmission of power are formed using four metal plates. These plates are placed horizontally and vertically depending upon the application. The CPT wireless charging system is suitable for short distance applications which typically require low power [122]. Usually, the distance is as small as 1 mm, which limits the applications of the CPT charging system [32]. In addition to the EV charging, some of the additional applications include, robot charging, light emitting diode (LED) driver, and excitation of synchronous motors [81].

The circuit topologies employing coupling capacitors in a CPT system are a cause of the distance limitation. A CPT circuit topology is classified either as a resonant topology or a non resonant topology [69]. The non resonant topology uses the PWM for the conversion. To supply smooth power to the circuit, a coupling capacitor is used as a power storage component. In a resonant topology, class E converter and series resonance converter are used [123]. A compensation circuit is used in which the coupling capacitor resonates with an inductor [97]. As a result, the coupling capacitance can be reduced while the resonant inductance and switching frequency are high. However, self resonant frequency limits the inductance and efficiency, whereas power capability of the converter limits the switching frequency. Another limiting factor of this topology is that it is sensitive to parameter variation which may be caused by misalignment.

6.2. Inductive power transfer technique for charging

A typical IPT system may be subdivided into two main parts i.e. the primary side, which transmits power and the secondary side, which receives power. In an EV charging system using the IPT, the primary side of the IPT system may be placed on or under the road while the secondary side is mounted on the moving vehicle [124, 125]. Primary side transfers power to the secondary side. The power source is mainly application dependent or the power requirements of the device used. If the device being charged is power hungry, then a single or three phase system can be used while on the other hand if the power requirements for the device are small, then small batteries can suffice [126]. To convert low frequency to high frequency, an inverter is used [127]. The power transfer between the primary coil and the secondary coil of an IPT system takes place due to the mutual coupling between the two coils.

A physical contact between the EV and the charger is not required in an IPT system, as coupling technique with a small gap between the coils is used for the wireless transfer of power. Therefore, the IPT is considered to be the prime method for the wireless charging of an EV [32, 60, 61, 128].

The working principle of an IPT system is the same as that of a transformer, as electromagnetic induction is used for the transfer of power from the transmitting primary coil to the receiving secondary coil [129]. An IPT system may use resonance for an efficient power transfer [130]. The IPT provides a convenient charging process as it does not need any physical connection [131]. Charging can be done while the EV is steady or in a state of motion [35, 132]. The design of magnetic structures is of prime consideration in an EV charging system. Shapes and sizes of the materials that are used in the designing of magnetic structures are the prime parameters for the determination of coupling and magnetic flux leakage between the coils [133, 134]. The power transfer capability can be directly influenced by the magnetic coupling. Leakage may result if the coupling is not optimum. The leakage flux is that magnetic flux which does not take part in the power transfer in an IPT system. International Commission on Non Ionising Radiation Protection has a guideline that the leakage magnetic flux density should not be more than 27 micro Tesla (μT) when exposed to human beings as it is harmful beyond this threshold [135].

6.2.1. Static charging

All EVs have battery related problems, such as, heavy weight, high cost, long charging time and short driving range. The arrangement of a large number of available electric chargers on a route can be viewed as a reasonable methodology to alleviate this problem [136, 137]. Wired chargers are fixed, and therefore, a vehicle has to stop at a charging station for the purpose of charging. Moreover, the mechanical connectors should be maintained routinely. Handling the wires and the mechanical connectors is dangerous especially in wet and dry conditions [138]. These issues can be resolved by adopting a wireless charging system. In a static wireless charging system, an EV still has to stop for charging, but there is no hassle of maintaining and connecting mechanical connectors.

To charge an EV using the IPT static wireless charging technique, the vehicle is parked on the charging pad at a charging station. The vehicle or the battery need not have a physical connection with the charging system. Misalignment between the assembly installed on the EV and the charging pad is acceptable to a certain degree [139, 140, 141]. This technique is appropriate for shopping malls and offices as the vehicle is parked for a specific time interval. Large battery pack is required in this technique as previously seen for conductive charging systems [142]. Dynamic charging system helps to overcome the problem of large battery [35, 143]. A summary and comparison of various static charging technologies is provided in Table 4.

6.2.2. Dynamic charging

Dynamic wireless charging is an ideal candidate for the WPT methodology, as this allows the vehicle to be charged while it is in motion. This also increases its travelling range [171], saves driver and passengers' time and improves their safety. The maintenance costs are also reduced, as the mechanical connectors are no more needed for charging [172, 173]. Roadway powered EV is one way to employ dynamic WPT. With this method, the EV is charged dynamically by the WPT and does not require a long time for charging. By using this technique, the public transport can be charged even on stops when the passengers get down or board the bus or taxi [174]. This idea can also be used on highways. Certain paths can be consistently powered to charge EVs [175]. This will reduce the size of the battery pack, initial cost, complexity and weight of the vehicle. Range also increases by the use of this technique [176]. Two types of magnetic couplers are used for dynamic charging [177, 178]. In the first type, a single longitudinal coupler is laid down while in the second type, the coupler is divided into segments. The segmented coupler is more advantageous as compared to the longitudinal coupler [179]. In the segmented coupler approach, only that segment is energised where the receiving system of the vehicle is currently present. This helps reduce power losses [180]. The challenges involved in this technique are high initial cost, installation is to be distributed possibly along highways and complex management for scheduling. This technique is still being developed and only a few dynamic charging systems are available. A summary of various dynamic wireless charging systems is provided in Table 5.

A commonly used wireless charging system is proposed in [181], which is based upon the IPT mutual inductance model. In the mutual inductance model, a two port network is obtained by transforming the T type transformer. It is the most commonly used and simple model. Likewise, in [69], a double sided LCC compensation technique is proposed. In this technique, the transmitting and the receiving sides use external capacitors and inductor. This technique is not affected by the changing voltage of the battery in battery charging applications [182]. This is possible due to the resonant circuit. In this technique, unity power factor is achieved and, therefore, it has high efficiency. In [71], a topology which uses the CC and the CV charging modes with double sided LCC technique is proposed. Flaws of the IPT charger can be overcome by using this technique. Another model to dynamically charge an EV is proposed in [183]. This model is described and discussed in Section 6.2.2.1 as a typical example.

One of the major disadvantages of dynamic wireless charging is low efficiency [184, 185]. For the purpose of high efficiency of power exchange, various systems have been proposed, such as, compelling pickup tuning, pickup voltage strategies, proficient pickup modules [186, 187] and resonant inverters [50] for wireless power exchange.

6.2.2.1. A typical model of electric vehicle dynamic wireless charging system

Some of the key elements of a DWCS for an EV are the power track and the battery. A major part of the economic expense of a DWCS is also due to these two elements [188]. Therefore, the battery and the power track should be optimised and a special consideration should be given

Table 4
Stationary wireless charging systems for electric vehicles.

Organisation	Year	Vehicle type	Power (kW)	Frequency (kHz)	Air gap (mm)	Efficiency (%)	Reference
University of Auckland (UoA)	1997	Golf car	20	30	50	90	[144]
	2002	Mini bus	60	30	30	90	[145]
	2010	Car	3	30	200	85	[146]
KAIST	2009	Golf bus	3	20	10	80	[147]
	2014	Car	15	20	180	80	[148]
	2016	Prototype	3.3	90	200	96	[149]
WiTricity Corporation	2010	Car	3.6	85	100-250	90	[150]
	2010	Car, SUV	7.7	85	100-250	90	[151]
	2019	Car, SUV	11	85	100-250	90	[151]
Conductix Wampfler	2010	Bus	20	20	-	-	[152]
Qualcomm Halo	2010	Car	3.6	85	160-220	90	[153]
	2010	Car	7	85	160-220	90	[153]
	2017	Car	20	85	160-220	90	[153]
Plugless Power	2011	Car	3.3	19.5	100	90	[154]
	2013	Prototype	3.6	19.5	100	90	[155]
	2016	Car	7.2	19.5	100	90	[156]
Oak Ridge National Laboratory (ORNL)	2012	Prototype	3.3	19.5	100-160	90	[157]
	2013	Prototype	6.6	19.5	100-160	80	[158]
	2014	Prototype	10	19.5	100-160	89	[158]
	2018	Prototype	50	88.5	150	95	[159]
	2018	Prototype	120	88.5	152	97	[160]
Bombardier Primove	2013	Car	3.6	20	10 - 30	85	[161]
	2013	Car, SUV	7.2	20	10 - 30	85	[161]
	2014	Car, SUV	22	20	10 - 30	85	[161]
	2014	Bus	200	20	10 - 30	85	[161]
Toshiba	2014	Car	7	-	170	-	[162]
	2017	Bus	44	85	100	-	[163]
Wuhan University	2017	Prototype	6	100	300	81	[164]
WAVE	2019	Bus	50	-	-	-	[165]
IPT Technology	-	Bus	50	-	130	92	[166]
	-	Bus	100	-	130	92	[166]

to these two elements while designing a dynamic charging system [184]. An online electric vehicle (OLEV) system uses dynamic wireless charging to charge the vehicles while they are in motion [91, 183]. The following conditions are defined for the operation of this system:

- To serve passengers on a defined route the same OLEV buses are used.
- Speed of the bus and the driving cycle are predefined.
- When a bus is not in use, it is parked at a bus station.
- Once a bus completes its driving cycle, it stays at the bus station for charging. The interval is called the resting or dwell time.

These rules are defined on the basis of the OLEV system model [189] that was implemented in an actual city.

6.2.2.2. Design parameters of a dynamic charging system

As discussed in Section 6.2.2.1, the battery and the power track are the key design components of a DWCS. The vehicles that are used in the OLEV system [183] have the same battery size and let it be represented by E_{max}. Total length of the power track should also be known. This is required to find the number of tracks that need to be laid on the route and the length of each track [189]. The base station in this system is used as a point of reference, and the distance travelled from the base station is represented by x. The first point, which is the starting point of the track is represented by x_i^s and the last point which is the end point is represented by x_i^e. The first point and the last point of the system may be the same base station. In this case, the distance at the start i.e. the first point is described by $x = 0$, and the distance at the end point is described by $x = L$. These are actually the

Table 5
Dynamic wireless charging systems for electric vehicles.

Organisation	Power (kW)	Frequency (kHz)	Air gap (mm)	Efficiency (%)	Reference
KAIST	3	20	10	80	[167]
	6	-	170	72	[168]
	17	-	170	72	[169]
	62	-	130	74	[148]
	100	-	200	75	[148]
UoA	20	15	500	85	[145]
ORNL	20	20	150	90	[157]
IPT Technology	180	-	-	90	[170]

distances from the base station [189]. A service is defined as one circular trip of the vehicle. There are a of total N number of power tracks so that $i = 1, 2, 3, ...N$. To keep the total cost of the system to a minimum [183], the length of the charging track given by the end points (x_i^s, x_i^e), and the size of the battery, E_{max} should be optimised. A method for the economic analysis of this problem is provided in [183].

6.2.3. Charging pad

Transmitting pads, whether single or multiple, can be energised by a single power supply in both SWPT and DWPT. Multiple power supplies are not necessarily needed for multiple transmitting pads [190]. There are different types of structures of charging pads, such as, circular, rectangular or double D coils [191, 192]. Various types of materials are used for the construction of coils. Copper is a commonly used material, but other materials are also being tested [193]. High temperature superconductors (HTS) are suitable due to their properties [194]. A single transmitting pad is used by SWPT, while in DWPT, there are other possibilities too. For example, a single long rail or multiple transmitting pads can be used for the charging of an EV [195]. There are pros and cons of both the methods. A long rail can help reduce the number of components and control difficulty [179]. The advantage of using a long transmitting rail is that when an EV comes in the near field of the rail, it provides constant power and current to the EV. However, cost of the components increases if the rail is energised by a single power source [196]. Moreover, this also results in a system with a single point of failure, and the entire system would shut down if there were a problem at a single point. As a result, the reliability of the system is compromised. Furthermore, if there is a significant difference between the size of the EV and that of the rail, then this results in decreasing the coupling between the two. Hence the system becomes inefficient [4]. The coupling can also be affected by the air gap and the coil distance. There is an inverse relation between the distance and the coupling. The size of the coils also matters. Similarly, if there is a large difference in the primary and the secondary coil sizes, then again this results in a small coupling between them.

Contrary to this, if more transmitting pads are used, then more power supplies, high frequency inverters and a large number of components are used in the topology. However, this topology has redundancy, and is more reliable as the single point of failure is avoided [4, 197]. If a fault occurs in a system, the system may still function. Moreover, an efficient use of switching can decrease the number of active components. As multiple transmitting pads are used in this system, only that transmitting pad can be switched on where EV passes, and all the remaining pads can be switched off. This will result in enhancing the required coupling and lowering the electromagnetic radiation [195]. However, this topology increases the cost, and the system complexity would also increase. The spacing between the pads is also an important parameter in this system, which requires optimisation. If the distance between the consecutive pads is too small, then unwanted coupling may develop between the pads thereby leaking energy [198]. If the distance between the pads is too large, then this reduces the undesired coupling, but the power cannot be transferred continuously. This also results in a negative effect on the grid network.

The magnetically coupled coils of an inductive WPT system behave as a transformer, and the air gap between these coils results in a high leakage inductance [199]. For this reason, they are called loosely coupled coils. To enhance the system efficiency, these coils are usually used along with capacitors so that a resonant circuit is achieved. Series and parallel combinations of capacitors and inductors may be used for this purpose [87]. The compensating circuit is connected between the inverter and the primary coil on the transmitting side, while it is connected between the rectifier and the secondary unit on the receiving side. The main purpose of using the capacitors along with the inductors is to optimise the reactive power.

6.2.4. Magnetic structures for the IPT system

Many designs of magnetic structures [193, 200, 201] have been developed by researchers for the IPT charging system. Some of the widely used magnetic structures for the charging of an EV are,

- bipolar pad (BPP),
- circular pad (CP), and

- double D (DD).

For the operation of single phase mode, CP and DD magnetic structures are used as the primary pads [202]. The number of phases in the magnetic structures are determined by the number of coils that are used in them [203]. Different types of magnetic fields can be produced by different arrangements of the magnetic structures. The magnetic field produced as a result of the CP structure is directed outwards from the centre of the coil, whereas it is generated in the direction of one axis of the pad in the DD structure [202]. To produce magnetic field on a single side, ferrite is used underneath the coils in CP and DD structures. This results in the improvement of the coefficient of coupling between the transmitting and the receiving coils. In the CP structure, the magnetic field scatters. As a result, there is a small leakage magnetic flux [204]. Moreover, when the secondary is not aligned well, then this results in lowering of the coupling factor.

In a DD structure, the coil is wound such that two magnetic poles of opposite polarity are created [133]. This results in concentrating the magnetic field in the space between the poles. Consequently, the tolerance to misalignment and magnetic coupling is better in comparison with that in the CP structure [203]. However, the magnetic flux leakage is higher in DD as compared with the CP structure. In BPP, there are two mutually decoupled coils. By changing the phase and the magnitude of the primary currents, these can be used in many different modes [205]. In BPP, the currents that are used for driving the coil are in phase or out of phase by 180° so that magnetic field equivalent to the CP or the DD can be generated respectively [124]. To generate a different magnetic shape, it can operate out of phase at other angles rather than 180^o. Due to the ability of phase variation and ease of switching, the BPP is a suitable candidate because performance can be improved by switching the modes.

6.2.5. *Circuit for inductive wireless power transfer*

An inductive WPT can be modelled using an equivalent electric circuit [65]. Such an equivalent model circuit is shown in Fig. 5. Self inductance of the primary coil is represented by L_T and for the receiving coil it is represented by L_R. The mutual induction is denoted by M and the resistance of the source is designated as R_S. The load is denoted by the resistance R_L. The coefficient of coupling, k, between the primary and the receiving coils is an important parameter, and is given by,

$$k = \frac{M}{\sqrt{L_T L_R}}. \tag{1}$$

Voltage equations of the transmitting and the receiving coils are given by,

$$\begin{aligned} V_S &= Z_T I_T + j\omega M I_R, \\ 0 &= j\omega M I_T + Z_R I_R. \end{aligned} \tag{2}$$

Transmitting and receiving impedances are represented by Z_T and Z_R respectively. These impedances are given by,

$$\begin{aligned} Z_T &= R_S + j\omega L_T, \\ Z_R &= R_L + j\omega L_R. \end{aligned} \tag{3}$$

Angular frequency of V_s is represented by ω. The quality factors of the transmitter and the receiver coils are given by,

$$\begin{aligned} Q_T &= \frac{\omega L_T}{R_S}, \\ Q_R &= \frac{\omega L_R}{R_L}. \end{aligned} \tag{4}$$

6.2.6. *Compensation requirements*

For an adequate amount of power transfer to the load, secondary capacitors are required in an IPT system. If the secondary capacitors are not used, then the input voltage should be large enough, which is not desirable [206]. As the secondary coil has large impedance, the current on the load side is small. A possible solution to this problem is the increment in the input voltage. This will result in an increase in the efficiency of power transfer to the load. However, this will also result in a large amount of current in the primary coil. As a result of this, there would be more energy loss and thus overall efficiency will be reduced [207]. Therefore, it is not a feasible and optimal solution.

Self inductance of a coil represents its capability to produce magnetic flux intensity for a given value of an applied current. For good magnetic flux intensity, coils which result in a high quality factor are used [208]. Similarly, capacitors which result in the highest quality factor of the resonant circuit are used on the transmitting primary and the receiving secondary sides [209]. Current amplitude is decreased by reducing the reactance of the coils. Consequently, the power transfer efficiency of the WPT system increases and it is at its maximum at the resonance frequency. At resonance, there would be energy interchange between the capacitor and the inductor coil. Therefore, only a small amount of energy is needed to sustain the oscillations [69, 206]. The capacitors are required not only for maximum power transfer, but also for the CC and the CV operation and to obtain ZPA [210]. These capacitors act as storage for reactive power which is supplied to or received from the primary and the secondary coils.

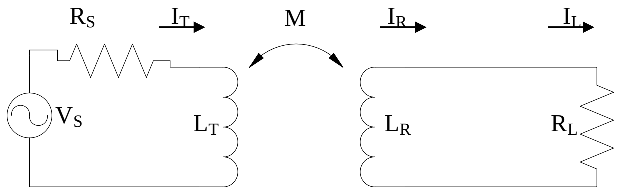
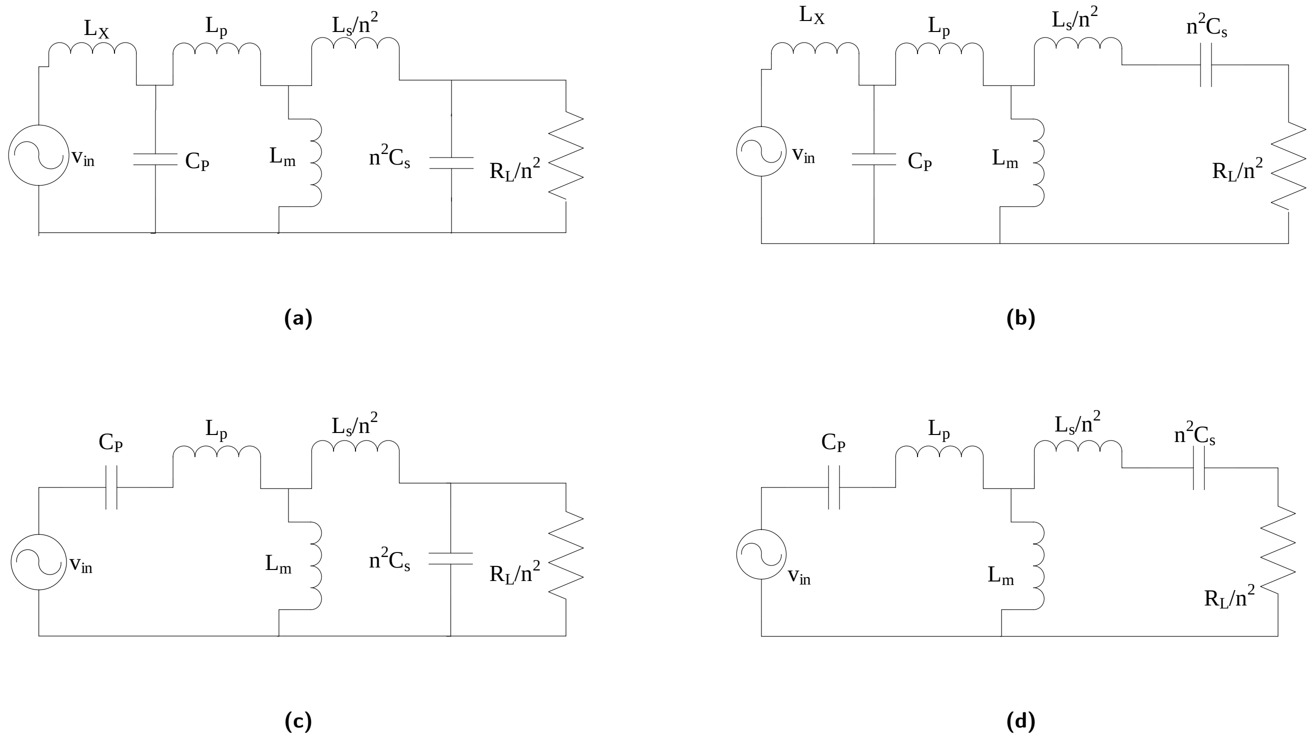


Fig. 5. An inductive wireless power transfer system can be represented using an equivalent circuit.



(a) (b)

(c) (d)

Fig. 6. AC equivalent model of IPT method (a) parallel-parallel (b) parallel-series (c) series-parallel (d) series-series.

6.2.7. Topologies

The four IPT topologies that are categorised based on the connection of the capacitor with the coil and described in Section 4 are discussed and analysed in this section for their suitability in battery charging applications. These four frameworks [65] as described in Section 4, are (a) parallel-parallel (PP), (b) parallel-series (PS), (c) series-parallel (SP), and (d) series-series (SS). Their AC equivalent models are shown in Fig. 6.

Let the leakage inductance of the primary side coil be represented by L_p and that of the secondary side be denoted by L_s. Similarly, let C_p represent the capacitance of the compensation capacitor on the transmitting side, and let C_s denote the capacitance of the capacitor on the receiving side. The magnetising inductance is represented by L_m. The resonating frequency [211] which attains the condition of zero phase angle (ZPA) in the SS topology is given as blow:

$$f_r = \frac{1}{2\pi\sqrt{L_1 C_p}} = \frac{1}{2\pi\sqrt{L_2 C_s}}, \tag{5}$$

where,

$$L_1 = L_m + L_p, \tag{6}$$

is the self inductance of the transmitting coil. For the receiving coil, it is given by

$$L_2 = L_m + L_s, \tag{7}$$

If the capacitances, C_p and C_s, of the compensation capacitors are appropriately sized, then the self inductances of both the transmitting and the receiving coils are compensated. Therefore, the output current is not affected by the load conditions and is independent of the load. Hence operating at the resonant frequency, f_r, the input impedance becomes zero. By achieving the ZPA condition, the CC operation is possible. From (5), it can be seen that there are two resonating frequencies, where output voltage does not depend upon the load i.e. CV operation.

In the CV mode, the operating frequency should be high. As a result of the high frequency, the resonant tank will operate in the inductive region [212]. Hence ZVS condition can be achieved for the operation of primary switches.

$$f_{cv} = \frac{1}{2\pi\sqrt{L_p C_p}} = \frac{1}{2\pi\sqrt{L_s C_s}}. \tag{8}$$

The converter is not required to be operated at the frequency f_{cv} because there are some problems related to this operation. As an example, when there is a light load, the phase of the input impedance is large. As a result of this, there is a high turn off current. Therefore, the efficiency is compromised and the switching losses increase. Meanwhile, the power transfer capability is decreased and there is an increment in the conduction loss due to large reactive power.

Like the SS topology, the CC or CV modes can be operated by using the SP topology as well [207, 213]. In this technique, the ZPA condition can be achieved when it operates as a voltage source independent of the load [214]. However, when it operates as a CC source, then its input impedance becomes inductive. Therefore, while operating in the CC mode, this topology cannot achieve the ZPA condition [65]. As compared with the SS and the SP topologies, the PS topology only operates in the CV mode, and the CC mode cannot be implemented in it. On the other hand, the CC mode is implemented in the PP topology but it does not support the CV mode [105]. An overview of the comparison of these four IPT topologies is given in Table 6 [65, 214]. From Table 6, it can be observed that, it is not possible to achieve both the CV and the CC modes with ZPA condition from one of the above topologies.

7. Wireless charging system control

7.1. Wireless charging system efficiency

To achieve an efficient and effective EV wireless charging system, some key aspects should be taken into consideration [215]. An EV wireless charging system is designed such that the maximum operational efficiency is obtained irrespective of the increase or decrease in the load and the coefficient of coupling due to misalignment or variation in the air gap [206]. Maximum efficiency is achieved due to factors which can be categorised in three groups [216]. First group deals with the change of the load. Impedance matching techniques are used to obtain an optimum impedance [217]. Active and passive impedance matching techniques are used for this purpose. Passive elements i.e. capacitors and inductors are used in the passive impedance matching, while in the case of active impedance matching DC-DC converters are employed to match the load [218, 219]. The second group deals with the output control including frequency control and variation in the load [220, 221]. The third group deals with the input power control [222]. The input reactive power is minimised so that the efficiency of the system is increased. The output voltage should remain the same.

The system efficiency is also affected by the coupling coefficient [200]. Techniques have been suggested so that the maximum tracking efficiency is obtained with output voltage control and load variation [223, 224]. For example, in the WPT systems, multiple pads can be employed on the primary side. This is named as two step tracking method [225]. By using this technique, the primary current ratio and the secondary load impedance are optimised. For maximum system efficiency, the ratio and the direction of the current in the transmitting side primary coil may also be modified. To increase the WPT system efficiency, improved design of pads, compensation networks and control strategies have been proposed [69, 124, 65]. In WPT systems, power efficiency and energy efficiency are treated as two different terms. Power efficiency is that which is measured at any given time when there is an alignment between the transmitting and the receiving coils. Energy efficiency is measured for a specific time period [226]. Efficiency of the system can also be increased by timely switching on and switching off the primary pads.

Table 6
Comparison of IPT topologies.

Topology	Mode of operation	ZPA
PP	CC	Yes
PS	CV	Yes
SP	CC CV	No Yes
SS	CC CV	Yes No

7.2. System misalignment

The efficiency of power transfer in an IPT based WPT system is dependent upon the coefficient of coupling between the transmitter and the receiver coils [203]. If there is an increase in lateral misalignment, then it decreases the mutual inductance. As a result, the transmitted power and, hence, the charging system efficiency decreases [223]. For different driving conditions, lateral positions of vehicles in the desired lane should be tested in the case of DWCS. It has been suggested that the lateral misalignment can be treated as a random variable with normal distribution [227]. Therefore, given the speed of the vehicle v, and knowing the test results, the standard deviation s can be calculated using the normal distribution [228]. Some work on the lateral misalignment of vehicles has been done and a few techniques to improve the system efficiency have been proposed [203, 124]. These techniques involve adaptive impedance matching circuits, different pad structures, three coil detection system and two dimensional coil position. Frequency control can also play an important role to improve the system efficiency.

7.3. Power control

Some research work has been done for the development of the control methods to regulate the battery charge profile in a WPT system [212]. The proposed methods can be categorised into primary, secondary and dual sided control [229]. The primary pad current is utilised for the control of the power flow on the primary side. Some information and parameters are sent by the secondary side to the transmitter side by means of a wireless communication system for the primary side control [230]. These parameters may include current, battery voltage, and the SoC. A wireless communication system can also be employed for sending information about the charging process, detection of the vehicle and to regulate the battery charging profile. The latency of the wireless communication system should be considered while designing the control system for the wireless charger.

By active rectification or by adding the DC/DC converter, the charging current on the secondary side can be controlled [231]. The secondary converter and the full bridge inverter should be controlled at a time using the dual side control [232]. To achieve this, the communication link between the two sides should be fast and reliable [233]. For the stationary WPT systems, this dual sided control [234] has been implemented whereas the communication speed and reliability are the bottlenecks for the dynamic WPT systems.

7.4. Communication

The communication between the primary and the receiving sides is an important consideration in EV wireless charging systems [235, 236, 237]. Security and reliability of the system are dependent upon the time that is taken for the data exchange between the transmitting and the receiving sides. Some parameters that are important and play a role for the optimum communication are minimum delay, short to medium range coverage and the need to support multiple vehicles [206]. Some communication techniques for EV wireless charging systems have been discussed in the literature, such as, those proposed in [233, 238, 239]. The other communication options include short range communication standards and protocols, such as, Wi-Fi, i.e. IEEE 802.11, Bluetooth, i.e. IEEE 802.15.1 and Zigbee, i.e. IEEE 802.15.4.

In this section, we have discussed the aspects related to the wireless charging control of EVs. System misalignment is an important consideration which affects the wireless charging system efficiency. Power control is used to maintain the charge profile of the EV battery system. To help achieve effective control of an EV wireless charging system, communication between the primary and the receiving secondary sides is important for the exchange of important data and control information.

8. Electric vehicle batteries

In an EV, batteries are used for the storage of electrical energy, which is supplied by the charging system. Some parameters of a charging system, such as, charge rate and charging time, may depend upon the type, size and other characteristics of the batteries. Therefore, batteries play an important role in the overall system performance [240, 241]. In this section, we briefly discuss different types of batteries which are commonly used in EVs. We also provide a short description of different types of models which are used for the study and investigation of these batteries.

8.1. Battery types

There are different types of batteries that may be used in the EVs for storage of the energy supplied by the charging system. The most common types of batteries which have been used in the EVs include lead acid, nickel cadmium (NiCad), nickel metal hydride (NiMH) and lithium ion (Li-ion) batteries [242, 243]. In the following, we give a brief description of each type of these batteries.

8.1.1. Lead acid

It is one of the earliest types of batteries that was developed. It dominated the market before other types of batteries were introduced. Lead acid batteries are low cost and have high availability [244]. However, these batteries have low specific energy and therefore are quite heavy. These batteries are not recommended to be discharged below 50% of their capacity as it would shorten their life [245]. While in operation and while being charged, these batteries may emit chemical fumes which should be vented.

8.1.2. Nickel cadmium

Nickel cadmium batteries have specific energy higher than a lead acid battery but smaller than a Li-ion battery [246, 247]. It can tolerate deep discharge compared to other types of batteries and is considered suitable for use under rough conditions. Moreover, NiCad batteries have a high life cycle [244]. However, these batteries may have charging problems at high temperatures. Furthermore, NiCad batteries should be disposed off carefully as these batteries use cadmium which is a toxic heavy metal.

8.1.3. Nickel metal hydride

NiMH batteries have high specific energy and have long lives. These batteries provide nearly constant voltage even when the SoC is low [244, 248]. They are also considered environment friendly. However, they have low efficiency when being charged and discharged. Moreover, charging these batteries at a fast rate may result in temperature rise [249]. They have a high self discharge rate and do not perform well under cold weather conditions.

8.1.4. Lithium ion

Li-ion batteries have high specific energy and high energy density compared with the other types of batteries [241, 244]. These batteries have high cell voltage, good life span and low self discharge rate. They have fast charging ability as compared with the other battery types [247]. The load characteristics are also good and a Li-ion battery provides a reasonably constant cell voltage. However, the performance of these batteries is sensitive to temperature [250]. Moreover, their capacity may drop with age and after a certain number of charge discharge cycles.

Apart from these common batteries, other types, such as, sodium nickel chloride [251] and ultracapacitors [252] are also being investigated for use in EVs. However, due to their high cell voltage, high energy efficiency and low self discharge rate, the Li-ion batteries are preferred for use in EVs. The other types of batteries that have been discussed may also be used for supplementary usage or in small and medium EVs. A quantitative comparison of the different types of batteries is given in Table 7 [242, 253, 254, 255].

8.2. Battery models

Drivetrain is connected with the battery pack and provides power to the vehicle so that the vehicle can move. Hence, the battery is an important component in a wireless charging system, and its electrical properties should be investigated and analysed [256]. Performance of a battery depends upon many factors, such as, capacity, temperature, battery life, state of health and state of charge (SoC) [257].

Table 7
Comparison of different types of batteries [242, 253, 254, 255].

Parameter	Lead acid	Nickel cadmium (NiCad)	Nickel metal hydride (NiMH)	Lithium ion (Li-ion)
Specific energy (W·h/kg)	30-50	35-80	35-80	120-300
Specific power (W/kg)	150-200	150-450	150-450	200-450
Energy density (W·h/L)	60-75	140-400	140-400	200-300
Nominal voltage (V)	2	1.2	1.2	3.6
Number of life cycles	400-800	800-2000	800-2000	600-3000
Self discharge per month	3-20%	30%	30%	1-5%
Energy efficiency	82.5%	72.5%	70%	90%
Environmental impact	High	Low	Low	Very low
Cost ($/W·h)	0.15-0.30	0.30-0.60	0.30-0.60	0.50-2.50

Therefore, different types of battery models [258, 259, 260] have been proposed. Each model has its own utility so that each model may be used for the analysis of a different aspect of a battery. There are pros and cons of each type of model. These models are categorised as electrochemical, electrical and mathematical models.

8.2.1. Electrochemical model

Electrochemical models [261, 262] depend upon the electrochemical reactions that take place between the electrodes and the electrolyte. These models are used for the investigation of the electrical behaviour of the battery. Although the electrochemical models are complex and the associated computations are costly, they are accurate. Some examples of electrochemical models include single particle model [263], extended single particle model [259], pseudo two dimensional model [264] and simplified pseudo two dimensional model [265].

8.2.2. Mathematical model

Mathematical models are developed for the analysis of various aspects of a battery, such as, thermal behaviour [266], capacity fading [267] and SoC [268]. The mathematical models can be categorised as analytical or stochastic models [258, 269]. Mathematical equations based upon the physical properties of the battery are used to model the battery in an analytical model. Examples of analytical models include [270] and [271]. Stochastic models use discrete time Markov chains for the battery modelling. Examples of stochastic battery models include [272] and [273]. The mathematical models are simpler compared with the electrochemical models. However, their accuracy is comparatively low and practical implementation of these models may not be possible. They are usually used to model system level behaviour of the battery [260].

8.2.3. Electrical model

A battery may be represented by an electrical model, which is implemented with the help of an electrical circuit. The circuit usually consists of resistors and capacitors in combination with other components [274]. Electrical models are less complex, and are easy to implement. These are used for the estimation of SoC, a parameter which is used for the calculation of the efficiency of the WPT. The key advantage of these battery models is that these are dependent upon the open circuit voltage and internal resistance and help determine the SoC. Some examples of the electrical models include Thevenin based model [275], impedance based model [276], and runtime based model [277]. Some models use a combination of these models and are referred to as hybrid models [278, 279].

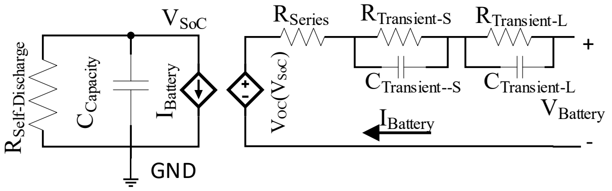


Fig. 7. An electrical model of a battery can be used for the estimation of various parameters, such as, SoC, open circuit voltage and transient response.

An example of an electrical equivalent model of a battery is shown in Fig. 7 [278, 279]. This model is compatible with different battery types, such as, lead acid, NiCad, NiMH, Li-ion and other electrochemical batteries [278, 279]. The SoC, capacity and runtime of the battery are modelled using the current controlled current source ($I_{Battery}$) and the capacitor ($C_{Capacity}$) on the left side. Self discharge when the battery is stored and is not being used, is modelled by the resistor $R_{Self-Discharge}$. The voltage across the capacitor ($C_{Capacity}$), is used for the quantification of the SoC. For example, when $V_{SoC} = 1$, it implies that the battery is fully charged i.e. the SoC is 100%. On the other hand, $V_{SoC} = 0$ implies that the battery is fully discharged i.e. the SoC is 0%. The voltage controlled voltage source $V_{OC}(V_{SoC})$ models the non linear relation between the open circuit voltage (V_{OC}) and the SoC. The resistor (R_{Series}) and two parallel RC networks are used for modelling the transient response. The resistor (R_{Series}) characterises the instantaneous voltage drop in the step response. The RC network comprising $R_{Transient-S}$ and $C_{Transient-S}$ are used for the short time constant, and the RC pair consisting of $R_{Transient-L}$ and $C_{Transient-L}$ is responsible for the long time constant of the step response [278]. The model provides good accuracy without being complex, and it also helps determine the transient response. By utilisation of the battery model, open circuit voltage and resistance are measured for each time interval. The power that is used for moving the vehicle and the power that is provided by the charging pad are used for the determination of the power of the battery. The voltages, resistance of the battery, and the battery power can be used for the measurement of the current drawn or provided by the battery.

To enhance the adaptability of a model, it may be extended to measure the effects of temperature and life cycle on the capacity [280]. This can be done by the utilisation of correction functions. For the determination of correction functions, practical data of batteries are used. The capacity that is available after N charging cycles determines the battery life [281]. The discharge of a battery from 100% to 0% and recharging to 100% is considered as one cycle. To enhance the life of a battery, EV manufacturers recommend bounds on the accessible range of batteries. Safety margin of 20% is usually used in a charge discharge cycle. Therefore, the battery cycle is in the range of 80% and 20% of the rated capacity [280]. As the number of cycles increases, there is a linear decrement in the available capacity.

Another parameter that affects the battery available capacity is the temperature [282]. Battery available capacity is a fraction of the rated capacity at extreme temperatures while it is near the rated capacity when the temperature is normal. The delivered capacity is also affected by the discharge rate.

9. Discussion and future research

With the development and advancement of the enabling technologies, the societal acceptance of EVs has increased and more people are now driving these vehicles than before. EVs require a sufficient number of batteries for energy storage to maintain a reasonable driving range. EV wireless charging is an important enabling technology which has many benefits compared with the traditional wired charging. It allows the EVs to be charged without the use of connectors. With the dynamic wireless charging, the EVs can be charged while in motion. The wireless charging solution reduces the battery size and the initial cost, saves time and extends the driving range. However, many aspects of wireless charging solutions still require further improvement which is possible through technological development.

Some of these aspects and the desired features of an EV wireless charging system include high efficiency, high energy density, fast charging ability, optimum size, tolerance for misalignment, large air gap, and operational safety and security [283]. However, it is difficult to achieve all these objectives and trade offs are needed to develop a practical EV wireless charging solution [38]. For example, fast charging systems are limited by the physical dimensions of the magnetic coils. Usage of high operating frequency can help reduce the coil size as the quality factor is improved, and the coil current and the number of turns are reduced without affecting the amount of transferred power. However, the high operating frequency results in higher switching losses in the inverter [284]. Furthermore, semiconductor devices at high frequency may result in high temperatures and thereby may require a cooling system. Therefore, optimum coil design requires a trade off between the coil size and the charging speed. In addition to fast charging ability, other parameters, such as, power density, energy efficiency, leakage flux and tolerance to misalignment are determined by the coil design [192]. Therefore, optimum coupler design to achieve the aforementioned objectives is an active research area, which is recommended for future research.

For a highly efficient WPT, the primary and the secondary side coils should be perfectly aligned [285, 286]. Even a slight misalignment of the coils reduces the coefficient of coupling and results in decreasing the efficiency of the WPT [287]. The misalignment results in flux leakage thereby reducing the system efficiency. The flux leakage may also cause a linkage with a nearby metal object which not only results in energy loss but it may also damage the object. Therefore, misalignment in wireless charging systems is an important challenge which should be overcome [288]. Different methods have been proposed to increase the misalignment tolerance. These proposed methods use different types of coil geometries, combining coils of different geometries into one unit, overlapping configuration, and resonance frequency tuning circuits. These methods may require additional space and they also add to the weight [289]. Therefore, they have limited applications in EVs. Similarly, improved compensation topologies and radio based methods have also been proposed to handle misalignment [121]. Alternative methods which do not depend upon altering the coil geometry, such as vehicle tracking and autonomous guidance system are also being explored to address the misalignment problem [236]. For example, sensors may be used for the detection and measurement of misalignment between the transmitter and the receiver coils. Afterwards, an autonomous control system is used for the alignment of the receiver coil with the transmitter. For SWCS, these methods can be used along with autonomous parking systems [237]. However, in the case of DWCS, application of these methods requires additional considerations, such as, type of vehicle and vehicle speed. For future research, it is recommended that the deployment of the sensor systems may be investigated for the improvement in the alignment. The misalignment can also be compensated using electromagnetic meta material. In addition, the misalignment effect may be handled by using active compensation networks and coupler systems. Improved communication and control systems may also be investigated to solve the misalignment problem.

When a wireless charging system is being used for the charging of an EV, there is an open space between the wireless charger and the EV. A foreign object may fall within this open space while the EV is being charged [290, 291]. The foreign objects which are a cause of concern, include metal objects, such as a toy or a tool, and living objects, such as an animal. In the case of a metal object, the strong magnetic field will result in the flow of eddy currents thereby heating the object. As a result, the charging system may deviate from the normal operation and cause a safety accident [288]. If it is a living object, the strong magnetic field may result in harm to the living being [292]. Therefore, a wireless charging system should employ foreign object detection (FOD) which comprises metal object detection (MOD) and living object detection (LOD) [288]. These detection systems can be broadly categorised into three different types based upon the working principles i.e. system parameter based detection, wave based detection and field based detection methods [292]. For the detection, the system parameter based detection methods may use the electrical parameters, such as, voltage, current and power, or non electrical parameters, such as, temperature and pressure [293]. The detection methods employing the electrical parameters are suitable for MOD in low power applications. These are low cost methods as no additional equipment is required. However, the detection accuracy is also low [294]. The detection methods which employ non electrical parameters use inexpensive sensors and are suitable for both MOD and LOD. These can be used in both low and high power applications. Their accuracy is also low [295]. The wave based methods may use different types of sensors for the detection, such as proximity and ultrasonic sensors, radars and imaging or thermal cameras. The detection may utilise different types of waves determined by the components, such as mechanical waves or electromagnetic waves. These methods may be used for both MOD and LOD and for low and high power applications depending upon the equipment being used. The cost as well as the accuracy of these methods is high [296]. The field based detection methods exploit the electromagnetic field for FOD. These methods are suitable for both low and high power applications and are able to detect metal as well as living objects. These methods have medium to high cost. Their accuracy is high [297]. For future research, wave based or field based detection methods or a combination of the two may be used for FOD due to their high accuracy. In the further research, the detection accuracy of these methods should be improved subject to the constraints of cost, complexity, space and weight.

It is generally considered that EVs equipped with DWCS require small sized batteries [298]. This reduces the weight of the EVs as well as the cost. However, small batteries may suffer from degradation due to deep discharge and higher number of charge cycles [299]. This may result in the reduction in the overall life of the batteries. Therefore, this will require frequent replacement of batteries thereby adding to the long term cost. In addition, small batteries will require a higher number of charging tracks with more power. Therefore, if the batteries are too small, then they may degrade quickly and will require frequent replacement, and will also require large charging infrastructure. Hence, the overall cost of the system will increase. Some work has been done to evaluate the optimum size of the batteries and the wireless charging system [183, 188, 300, 301]. However, the previous work is limited e.g. only a certain vehicle type is considered in a limited environment in [188]. Furthermore, the cost of the batteries and the EVs has also changed over time. Therefore, further research to determine the optimum size of the batteries and the charging infrastructure is needed in future while taking the aforementioned factors and constraints into consideration.

Interoperability among different types of charging systems and EVs is another problem which should be solved. For example, the secondary side on the EV is designed such that it has a high coefficient of coupling with the primary side which is installed on the wireless charging side so that the power transfer is achieved with high efficiency [302]. For this to happen, parameters such as, shape, size, and compensation networks of both the sides should be compatible with each other [303]. Therefore, there is a need for the standardisation of wireless charging systems. A standard SAE J2954 has been adopted to facilitate this objective [304]. However, this standard is limited only to SWCS for light duty EVs. Therefore, medium and heavy duty EVs are not able to benefit from the infrastructure which is based upon this standard [305]. Interoperability among light, medium and heavy duty EVs would facilitate usage of the same infrastructure among these vehicle types, thereby reducing the cost of building the infrastructure. Similar to the SWCS, the interoperability among different types of DWCS would also enable the usage of the DWCS infrastructure by various types of EVs. In addition, compatibility among the SWCS and the DWCS is also desirable. It should be possible to charge an EV with a single charging assembly using either the SWCS or the DWCS. Therefore, to facilitate operability and compatibility among different types of charging infrastructure, and various classes of EVs, there is a need for further standardisation in the future.

In the light of this study, some further aspects of wireless charging systems, in addition to those discussed in the above paragraphs, are identified to have research gaps, require further development and are recommended for future research. These include, design and construction of feasible, robust and stable DWCS, safety and protection against hazards, accurate metering and billing systems for both SWCS and DWCS, wireless charging communications and control systems security and evaluation of impact of wireless charging infrastructure on the power grid.

10. Conclusion

We have discussed and reviewed charging of electric vehicles using wireless power transmission. Wireless charging is considered a better alternative to traditional wired charging systems as it is user and environment friendly. Furthermore, it eliminates the need for wires and mechanical connectors, and therefore, avoids the associated hassles and hazards. Wireless charging systems also reduce the range anxiety and enhance the system efficiency. The wireless power transmission, in general, takes place using either microwave, laser or mutual coupling. However, only mutual coupling based techniques are generally used for wireless charging. The mutual coupling based techniques, inductive and capacitive power transfer, are employed for contactless power transfer and charging of electric devices. Both these techniques are discussed, compared and contrasted, and it is concluded that the inductive power transfer has advantages and is the prime method for wireless charging of electric vehicles. For this purpose, static, semi or quasi dynamic or completely dynamic methods of wireless charging can be employed. These modes of wireless charging of electric vehicles are explained in this article. In addition, important aspects of a wireless charging system, such as, charging pad, compensation topologies, system misalignment, communication and control are reviewed and discussed. As various parameters of a charging system are determined by the batteries, a brief overview of battery types and models is also provided.

CRediT authorship contribution statement

Muhammad Amjad: Conceptualisation of this study, Original draft preparation. **Muhammad Farooq-i-Azam:** Conceptualisation, Writing - review & editing, Supervision. **Qiang Ni:** Methodology, Writing - review & editing, Supervision. **Mianxiong Dong:** Methodology, Writing - review & editing. **Ejaz Ahmad Ansari:** Analysis, Writing - review & editing.

References

[1] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, M. Soljačić, Wireless power transfer via strongly coupled magnetic resonances, Science 317 (5834) (2007) 83–86. doi:10.1126/science.1143254.

[2] S. Chhawchharia, S. K. Sahoo, M. Balamurugan, S. Sukchai, F. Yanine, Investigation of wireless power transfer applications with a focus on renewable energy, Renewable and Sustainable Energy Reviews 91 (2018) 888–902. doi:https://doi.org/10.1016/j.rser.2018.04.101.

[3] S. D. Barman, A. W. Reza, N. Kumar, M. E. Karim, A. B. Munir, Wireless powering by magnetic resonant coupling: Recent trends in wireless power transfer system and its applications, Renewable and Sustainable Energy Reviews 51 (2015) 1525–1552. doi:https://doi.org/10.1016/j.rser.2015.07.031.

[4] X. Zhang, Z. Yuan, Q. Yang, Y. Li, J. Zhu, Y. Li, Coil design and efficiency analysis for dynamic wireless charging system for electric vehicles, IEEE Transactions on Magnetics 52 (7) (2016) 1–4. doi:10.1109/TMAG.2016.2529682.

[5] A. N. Azad, A. Echols, V. A. Kulyukin, R. Zane, Z. Pantic, Analysis, optimization, and demonstration of a vehicular detection system intended for dynamic wireless charging applications, IEEE Transactions on Transportation Electrification 5 (1) (2019) 147–161. doi:10.1109/TTE.2018.2870339.

[6] M. Longo, D. Zaninelli, G. Cipriani, V. Di Dio, R. Miceli, Economic analysis on the use of wired and wireless recharging systems, in: 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I CPS Europe), 2017, pp. 1–6. doi:10.1109/EEEIC.2017.7977704.

[7] F. M. Eltoumi, M. Becherif, A. Djerdir, H. Ramadan, The key issues of electric vehicle charging via hybrid power sources: Techno-economic viability, analysis, and recommendations, Renewable and Sustainable Energy Reviews 138 (2021) 110534. doi:https://doi.org/10.1016/j.rser.2020.110534.

[8] D. M. Vilathgamuwa, J. P. K. Sampath, Wireless Power Transfer (WPT) for Electric Vehicles (EVs)—Present and Future Trends, Springer Singapore, Singapore, 2015, pp. 33–60. doi:10.1007/978-981-287-299-9_2.

[9] A. Vallera, P. Nunes, M. Brito, Why we need battery swapping technology, Energy Policy 157 (2021) 112481. doi:https://doi.org/10.1016/j.enpol.2021.112481.

[10] F. Tuchnitz, N. Ebell, J. Schlund, M. Pruckner, Development and evaluation of a smart charging strategy for an electric vehicle fleet based on reinforcement learning, Applied Energy 285 (2021) 116382. doi:https://doi.org/10.1016/j.apenergy.2020.116382.

[11] M. Abdolmaleki, N. Masoud, Y. Yin, Vehicle-to-vehicle wireless power transfer: Paving the way toward an electrified transportation system, Transportation Research Part C: Emerging Technologies 103 (2019) 261–280. doi:https://doi.org/10.1016/j.trc.2019.04.008.

[12] S. R. Khutwad, S. Gaur, Wireless charging system for electric vehicle, in: 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES), 2016, pp. 441–445. doi:10.1109/SCOPES.2016.7955869.

[13] R. J. Flores, B. P. Shaffer, J. Brouwer, Electricity costs for an electric vehicle fueling station with level 3 charging, Applied Energy 169 (2016) 813–830. doi:https://doi.org/10.1016/j.apenergy.2016.02.071.

[14] X. Mou, R. Zhao, D. T. Gladwin, Vehicle-to-vehicle charging system fundamental and design comparison, in: 2019 IEEE International Conference on Industrial Technology (ICIT), 2019, pp. 1628–1633. doi:10.1109/ICIT.2019.8755057.

[15] M. Etemadrezaei, 22 - wireless power transfer, in: M. H. Rashid (Ed.), Power Electronics Handbook (Fourth Edition), fourth edition Edition, Butterworth-Heinemann, 2018, pp. 711–722. doi:https://doi.org/10.1016/B978-0-12-811407-0.00024-6.

[16] M. Molefi, E. D. Markus, A. Abu-Mahfouz, Wireless power transfer for IoT devices-a review, in: 2019 International Multidisciplinary Information Technology and Engineering Conference (IMITEC), IEEE, 2019, pp. 1–8.

[17] S. Y. Choi, S. J. Yoo, K. J. Lee, C. T. Rim, Wireless power system design for mobile robots used in nuclear power plants (2012).

[18] Z. Yan, B. Song, Y. Zhang, K. Zhang, Z. Mao, Y. Hu, A rotation-free wireless power transfer system with stable output power and efficiency for autonomous underwater vehicles, IEEE Transactions on Power Electronics 34 (5) (2018) 4005–4008.

[19] Z. Yan, Q. Siyao, Q. Zhu, L. Huang, A. P. Hu, A simple brightness and color control method for led lighting based on wireless power transfer, IEEE Access 6 (2018) 51477–51483.

[20] S. R. Khan, S. K. Pavuluri, G. Cummins, M. P. Desmulliez, Wireless power transfer techniques for implantable medical devices: A review, Sensors 20 (12) (2020) 3487.

[21] K. Chaudhary, D. Kumar, Satellite solar wireless power transfer for baseload ground supply: clean energy for the future, European Journal of Futures Research 6 (1) (2018) 1–9.

[22] S. Kumar, G. K. M. Jayprakash, Wireless power transfer for unmanned aerial vehicle (UAV) charging, Int. Res. J. Eng. Technol. 8 (8) (2017) 1939.

[23] L. Sun, D. Ma, H. Tang, A review of recent trends in wireless power transfer technology and its applications in electric vehicle wireless charging, Renewable and Sustainable Energy Reviews 91 (2018) 490–503. doi:https://doi.org/10.1016/j.rser.2018.04.016.

[24] C. Cheng, F. Lu, Z. Zhou, W. Li, C. Zhu, H. Zhang, Z. Deng, X. Chen, C. C. Mi, Load-independent wireless power transfer system for multiple loads over a long distance, IEEE Transactions on Power Electronics 34 (9) (2019) 9279–9288. doi:10.1109/TPEL.2018.2886329.

[25] J. Qu, L. He, N. Tang, C. K. Lee, Wireless power transfer using domino-resonator for 110-kv power grid online monitoring equipment, IEEE Transactions on Power Electronics 35 (11) (2020) 11380–11390. doi:10.1109/TPEL.2020.2989757.

[26] L. Blain, Nz to trial world-first commercial long-range, wireless power transmission, New Atlas (Aug 2020).

[27] M. Zucca, P. Squillari, U. Pogliano, A measurement system for the characterization of wireless charging stations for electric vehicles, IEEE Transactions on Instrumentation and Measurement 70 (2021) 1–10. doi:10.1109/TIM.2020.3046908.

[28] A. Ahmad, M. S. Alam, R. Chabaan, A comprehensive review of wireless charging technologies for electric vehicles, IEEE Transactions on Transportation Electrification 4 (1) (2018) 38–63. doi:10.1109/TTE.2017.2771619.

[29] F. Musavi, W. Eberle, Overview of wireless power transfer technologies for electric vehicle battery charging, IET Power Electronics 7 (1) (2014) 60–66. doi:https://doi.org/10.1049/iet-pel.2013.0047.

[30] C. Qiu, K. T. Chau, T. W. Ching, C. Liu, Overview of wireless charging technologies for electric vehicles, Journal of Asian Electric Vehicles 12 (1) (2014) 1679–1685. doi:10.4130/jaev.12.1679.

[31] T. M. Fisher, K. B. Farley, Y. Gao, H. Bai, Z. T. H. Tse, Electric vehicle wireless charging technology: A state-of-the-art review of magnetic coupling systems, Wireless Power Transfer 1 (2) (2014) 87–96. doi:10.1017/wpt.2014.8.

[32] J. Dai, D. C. Ludois, A survey of wireless power transfer and a critical comparison of inductive and capacitive coupling for small gap applications, IEEE Transactions on Power Electronics 30 (11) (2015) 6017–6029. doi:10.1109/TPEL.2015.2415253.

[33] Z. Bi, T. Kan, C. C. Mi, Y. Zhang, Z. Zhao, G. A. Keoleian, A review of wireless power transfer for electric vehicles: Prospects to enhance sustainable mobility, Applied Energy 179 (2016) 413–425. doi:https://doi.org/10.1016/j.apenergy.2016.07.003.

[34] Y. J. Jang, Survey of the operation and system study on wireless charging electric vehicle systems, Transportation Research Part C: Emerging Technologies 95 (2018) 844–866. doi:https://doi.org/10.1016/j.trc.2018.04.006.

[35] C. Panchal, S. Stegen, J. Lu, Review of static and dynamic wireless electric vehicle charging system, Engineering Science and Technology, an International Journal 21 (5) (2018) 922–937. doi:https://doi.org/10.1016/j.jestch.2018.06.015.

[36] P. Machura, Q. Li, A critical review on wireless charging for electric vehicles, Renewable and Sustainable Energy Reviews 104 (2019) 209–234. doi:https://doi.org/10.1016/j.rser.2019.01.027.

[37] N. Korakianitis, G. A. Vokas, G. Ioannides, Review of wireless power transfer (WPT) on electric vehicles (EVs) charging, AIP Conference Proceedings 2190 (1) (2019) 020072. doi:10.1063/1.5138558.

[38] H. Feng, R. Tavakoli, O. C. Onar, Z. Pantic, Advances in high-power wireless charging systems: Overview and design considerations, IEEE Transactions on Transportation Electrification 6 (3) (2020) 886–919. doi:10.1109/TTE.2020.3012543.

[39] A. Triviño, J. M. González-González, J. A. Aguado, Wireless power transfer technologies applied to electric vehicles: A review, Energies 14 (6) (2021). doi:10.3390/en14061547.

[40] R. González Ayestarán, G. León, M. R. Pino, P. Nepa, Wireless power transfer through simultaneous near-field focusing and far-field synthesis, IEEE Transactions on Antennas and Propagation 67 (8) (2019) 5623–5633. doi:10.1109/TAP.2019.2916677.

[41] B. Hu, H. Li, T. Li, H. Wang, Y. Zhou, X. Zhao, X. Hu, X. Du, Y. Zhao, X. Li, T. Qi, M. Helaoui, W. Chen, F. Ghannouchi, A long-distance high-power microwave wireless power transmission system based on asymmetrical resonant magnetron and cyclotron-wave rectifier, Energy Reports 7 (2021) 1154–1161. doi:https://doi.org/10.1016/j.egyr.2020.12.026.

[42] J.-X. Wang, Y.-Z. Li, G.-C. Li, K. Xiong, X. Ning, Investigation of a gravity-immune chip-level spray cooling for thermal protection of laser-based wireless power transmission system, International Journal of Heat and Mass Transfer 114 (2017) 715–726. doi:https://doi.org/10.1016/j.ijheatmasstransfer.2017.06.111.

[43] N. Shinohara, Y. Kubo, H. Tonomura, Wireless charging for electric vehicle with microwaves, in: 2013 3rd International Electric Drives Production Conference (EDPC), 2013, pp. 1–4. doi:10.1109/EDPC.2013.6689750.

[44] M. S. Hossain, A. Barua, Charging electric vehicles via microwave energy transmission and analysis of advanced energy storage system, in: 2013 International Conference on Informatics, Electronics and Vision (ICIEV), 2013, pp. 1–6. doi:10.1109/ICIEV.2013.6572702.

[45] Y. Rathod, L. Hughes, Simulating the charging of electric vehicles by laser, Procedia Computer Science 155 (2019) 527–534, the 16th International Conference on Mobile Systems and Pervasive Computing (MobiSPC 2019),The 14th International Conference on Future Networks and Communications (FNC-2019),The 9th International Conference on Sustainable Energy Information Technology. doi:https://doi.org/10.1016/j.procs.2019.08.073.

[46] I. Ahmed, E. A. ElGhanam, M. S. Hassan, A. Osman, Study of the feasibility of using microwave power transfer for dynamic wireless electric vehicle charging, in: 2020 IEEE Transportation Electrification Conference Expo (ITEC), 2020, pp. 365–370. doi:10.1109/ITEC48692.2020.9161475.

[47] L. Huang, A. P. Hu, Defining the mutual coupling of capacitive power transfer for wireless power transfer, Electronics Letters 51 (22) (2015) 1806–1807.

[48] C.-H. Lin, M. Amir, M. Tariq, M. Shahvez, B. Alamri, A. Alahmadi, M. Siddiqui, A. R. Beig, Comprehensive analysis of IPT v/s CPT for wireless EV charging and effect of capacitor plate shape and foreign particle on CPT, Processes 9 (9) (2021). doi:10.3390/pr9091619.

[49] L. Zhang, Y. Yang, Z. Jiang, Q. Chen, Q. Yan, Z. Wu, B. Zhang, J. Huangfu, H. Chen, Demonstration of topological wireless power transfer, Science Bulletin (2021). doi:https://doi.org/10.1016/j.scib.2021.01.028.

[50] K. Thiagarajan, T. Deepa, A comprehensive review of high-frequency transmission inverters for magnetic resonance inductive wireless charging applications in electric vehicles, IETE Journal of Research (2021) 1–11.

[51] M. A. Yousuf, T. K. Das, M. E. Khallil, N. A. A. Aziz, M. J. Rana, S. Hossain, Comparison study of inductive coupling and magnetic resonant coupling method for wireless power transmission of electric vehicles, in: 2021 2nd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST), IEEE, 2021, pp. 737–741.

[52] A. Akhil, S. Harisankar, K. Jishnu, S. Sreenand, V. Vijay, C. Asha, P. Preetha, Coupled wireless charging system for electric vehicles, in: 2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV), IEEE, 2021, pp. 475–479.

[53] S. Ghimirey, C. Roy, A. Sengupta, Wireless electricity transfer using inductive power transfer system, in: Advanced Computational Paradigms and Hybrid Intelligent Computing, Springer, 2022, pp. 325–333.

[54] S.-J. Jeon, D.-W. Seo, Effect of additional transmitting coils on transfer distance in multiple-transmitter wireless power transfer system, IEEE Access (2022).

[55] Y. Meng, G. Yan, P. Jiang, K. Zhao, W. Wang, F. Chen, H. Zhuang, A novel wireless power transfer system with two parallel opposed coils for gastrointestinal capsule robot, Sensors and Actuators A: Physical 321 (2021) 112413. doi:https://doi.org/10.1016/j.sna.2020.112413.

[56] A. Mahmood, A. Ismail, Z. Zaman, H. Fakhar, Z. Khan, M. Sajjad Ul Hasan, S. H. Ahmed, A comparative study of wireless power transmission techniques, Journal of Basic and Applied Scientific Research (01 2014).

[57] S. Shrestha, D. Baniya Kshatri, B. Shrestha, A brief overview of wireless power transfer techniques, International journal of advanced smart convergence 4 (06 2015). doi:10.7236/IJASC.2015.4.2.1.

[58] F. Lu, H. Zhang, H. Hofmann, C. C. Mi, An inductive and capacitive combined wireless power transfer system with LC-compensated topology, IEEE Transactions on Power Electronics 31 (12) (2016) 8471–8482. doi:10.1109/TPEL.2016.2519903.

[59] I. Karakitsios, F. Palaiogiannis, A. Markou, N. D. Hatziargyriou, Optimizing the energy transfer, with a high system efficiency in dynamic inductive charging of evs, IEEE Transactions on Vehicular Technology 67 (6) (2018) 4728–4742. doi:10.1109/TVT.2018.2816998.

[60] Y. Wang, Z. Dongye, H. Zhang, C. Zhu, F. Lu, A domino-type load-independent inductive power transfer system with hybrid constant-current and constant-voltage outputs, IEEE Transactions on Power Electronics 36 (8) (2021) 8824–8834.

[61] A. Mahesh, B. Chokkalingam, L. Mihet-Popa, Inductive wireless power transfer charging for electric vehicles–a review, IEEE Access 9 (2021) 137667–137713.

[62] P. Zhao, G. Zheng, R. He, Y. Liu, M. Fu, A 45-W two-stage wireless fast charger using unregulated inductive power transfer, IEEE Journal of Emerging and Selected Topics in Industrial Electronics 2 (3) (2021) 287–296.

[63] M. Mohammad, O. C. Onar, G.-J. Su, J. Pries, V. P. Galigekere, S. Anwar, E. Asa, J. Wilkins, R. Wiles, C. P. White, et al., Bidirectional LCC–LCC-compensated 20-kW wireless power transfer system for medium-duty vehicle charging, IEEE Transactions on Transportation Electrification 7 (3) (2021) 1205–1218.

[64] Z. Liu, L. Wang, C. Tao, S. Li, Y. Guo, F. Li, Analysis and design of wireless power transfer system based on inductor-capacitor-capacitor/none magnetic integration compensation circuit, International Journal of Circuit Theory and Applications 49 (11) (2021) 3811–3825.

[65] L. Li, Z. Wang, F. Gao, S. Wang, J. Deng, A family of compensation topologies for capacitive power transfer converters for wireless electric vehicle charger, Applied Energy 260 (2020) 114156. doi:https://doi.org/10.1016/j.apenergy.2019.114156.

[66] X. Shu, B. Zhang, Z. Wei, C. Rong, S. Sun, Extended-distance wireless power transfer system with constant output power and transfer efficiency based on parity-time-symmetric principle, IEEE Transactions on Power Electronics 36 (8) (2021) 8861–8871.

[67] H. Zhang, Y. Shao, M. Liu, C. Ma, A wide-load-range and compact mhz wireless power transfer system based on novel reactance compression design and edge inductor, IEEE Transactions on Power Electronics 36 (10) (2021) 11183–11195.

[68] N. u. Hassan, W. Lee, B. Lee, Efficient, load independent and self-regulated wireless power transfer with multiple loads for long distance IoT applications, Energies 14 (4) (2021) 1035.

[69] B. Shi, F. Yang, C. Hu, M. Ouyang, Modelling and improvement of oscillation problem in a double-sided LCC compensation network for electric vehicle wireless power transfer, eTransportation 8 (2021) 100108. doi:https://doi.org/10.1016/j.etran.2021.100108.

[70] F.-R. Hu, J.-S. Hu, On the asymptotic behavior and parameter estimation of a double-sided LCC-compensated wireless power transfer system, Machines 9 (11) (2021) 287.

[71] J. Deng, Q. Mao, W. Wang, L. Li, Z. Wang, S. Wang, G. Guidi, Frequency and parameter combined tuning method of LCC-LCC compensated resonant converter with wide coupling variation for EV wireless charger, IEEE Journal of Emerging and Selected Topics in Power Electronics (2021) 1–1doi:10.1109/JESTPE.2021.3077459.

[72] M. Simonazzi, A. Campanini, L. Sandrolini, C. Rossi, Design procedure based on maximum efficiency for wireless power transfer battery chargers with lightweight vehicle assembly, Energies 15 (1) (2021) 70.

[73] C. Xu, Y. Zhuang, C. Song, Y. Huang, J. Zhou, Dynamic wireless power transfer system with an extensible charging area suitable for moving objects, IEEE Transactions on Microwave Theory and Techniques 69 (3) (2021) 1896–1905.

[74] G. Zheng, P. Zhao, H. Li, M. Fu, Small-signal model of an inductive power transfer system using lcc-lcc compensation, IEEE Transactions on Industry Applications (2021).

[75] A. J. Natanzi, S. Vaez-Zadeh, A. Babaki, A. Zakerian, A single-phase wireless power transfer system with a high-frequency AC link converter in the secondary for three-phase applications, in: 2021 12th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC), IEEE, 2021, pp. 1–5.

[76] P. Eekshita, N. S. V. Narayana, R. Jayaraman, Wireless power transmission system, in: 2021 International Conference on Computer Communication and Informatics (ICCCI), IEEE, 2021, pp. 1–4.

[77] L.-C. Tang, S.-L. Jeng, E.-Y. Chang, W.-H. Chieng, Variable-frequency pulse width modulation circuits for resonant wireless power transfer, Energies 14 (12) (2021) 3656.

[78] Y.-D. Lee, K.-W. Kim, G.-W. Moon, A self-compensated planar coil with integrated single-switch regulator for wireless power transfer (WPT) systems, IEEE Transactions on Power Electronics 36 (10) (2021) 10954–10958.

[79] F. Zhao, J. Jiang, S. Cui, X. Zhou, C. Zhu, C. C. Chan, Research on bipolar nonsalient pole transmitter for high-power ev dynamic wireless power transfer system, IEEE Transactions on Power Electronics 37 (2) (2021) 2404–2412.

[80] B. Regensburger, S. Sinha, A. Kumar, S. Maji, K. K. Afridi, High-performance multi-mhz capacitive wireless power transfer system for ev charging utilizing interleaved-foil coupled inductors, IEEE Journal of Emerging and Selected Topics in Power Electronics (2020) 1–1doi:10.1109/JESTPE.2020.3030757.

[81] Z. Liu, Y.-G. Su, Y.-M. Zhao, A. P. Hu, X. Dai, Capacitive power transfer system with double T-type resonant network for mobile devices charging/supply, IEEE Transactions on Power Electronics 37 (2) (2021) 2394–2403.

[82] H. Zhang, F. Lu, H. Hofmann, W. Liu, C. C. Mi, A four-plate compact capacitive coupler design and LCL-compensated topology for capacitive power transfer in electric vehicle charging application, IEEE Transactions on Power Electronics 31 (12) (2016) 8541–8551. doi:10.1109/TPEL.2016.2520963.

[83] F. Corti, A. Reatti, Y.-H. Wu, D. Czarkowski, S. Musumeci, Zero voltage switching condition in class-e inverter for capacitive wireless power transfer applications, Energies 14 (4) (2021) 911.

[84] F. Gao, Z. Wang, L. Li, S. Wang, J. Deng, Analysis and design of double-sided lclc compensation parameters with coupling-insensitive zvs operation for capacitive power transfer, in: 2019 IEEE Energy Conversion Congress and Exposition (ECCE), 2019, pp. 576–581. doi:10.1109/ECCE.2019.8912902.

[85] S. Zimmer, P. Lucas, M. Helwig, A. Winkler, N. Modler, Systematic engineering of functionally integrated wireless power transfer systems for electric vehicles, Procedia Manufacturing 52 (2020) 241–249, system-Integrated Intelligence – Intelligent, Flexible and Connected Systems in Products and ProductionProceedings of the 5th International Conference on System-Integrated Intelligence (SysInt 2020), Bremen, Germany. doi:https://doi.org/10.1016/j.promfg.2020.11.041.

[86] A. El-Shahat, E. Ayisire, Y. Wu, M. Rahman, D. Nelms, Electric vehicles wireless power transfer state-of-the-art, Energy Procedia 162 (2019) 24–37, emerging and Renewable Energy: Generation and Automation. doi:https://doi.org/10.1016/j.egypro.2019.04.004.

[87] S. Reddi Khasim, C. Dhanamjayulu, Selection parameters and synthesis of multi-input converters for electric vehicles: An overview, Renewable and Sustainable Energy Reviews 141 (2021) 110804. doi:https://doi.org/10.1016/j.rser.2021.110804.

[88] M. Mubarak, H. Üster, K. Abdelghany, M. Khodayar, Strategic network design and analysis for in-motion wireless charging of electric vehicles, Transportation Research Part E: Logistics and Transportation Review 145 (2021) 102179. `doi:https://doi.org/10.1016/j.tre.2020.102179`.

[89] S. Chatterjee, A. Iyer, C. Bharatiraja, I. Vaghasia, V. Rajesh, Design optimisation for an efficient wireless power transfer system for electric vehicles, Energy Procedia 117 (2017) 1015–1023, "First International Conference on Power Engineering Computing and CONtrol (PECCON-2017) 2nd -4th March .2017." Organized by School of Electrical Engineering, VIT University, Chennai, Tamil Nadu, India. `doi:https://doi.org/10.1016/j.egypro.2017.05.223`.

[90] J. Zhang, T.-Q. Tang, Y. Yan, X. Qu, Eco-driving control for connected and automated electric vehicles at signalized intersections with wireless charging, Applied Energy 282 (2021) 116215. `doi:https://doi.org/10.1016/j.apenergy.2020.116215`.

[91] P. Lazzeroni, V. Cirimele, A. Canova, Economic and environmental sustainability of dynamic wireless power transfer for electric vehicles supporting reduction of local air pollutant emissions, Renewable and Sustainable Energy Reviews 138 (2021) 110537. `doi:https://doi.org/10.1016/j.rser.2020.110537`.

[92] X. Zhang, C. Zhu, H. Song, Basic concepts of static/dynamic wireless power transfer for electric vehicles, in: Wireless Power Transfer Technologies for Electric Vehicles, Springer, 2022, pp. 27–44.

[93] N. Mohamed, F. Aymen, M. Alqarni, Inductive power transmission system for electric car charging phase: Modeling plus frequency analysis, World Electric Vehicle Journal 12 (4) (2021) 267.

[94] G. Han, Design of capacitive coupling structure for position-insensitive wireless charging, IET Power Electronics 13 (2020) 1946–1955(9).

[95] F. Lu, H. Zhang, C. Mi, A two-plate capacitive wireless power transfer system for electric vehicle charging applications, IEEE Transactions on Power Electronics 33 (2) (2018) 964–969. `doi:10.1109/TPEL.2017.2735365`.

[96] J. Dai, D. C. Ludois, Capacitive power transfer through a conformal bumper for electric vehicle charging, IEEE Journal of Emerging and Selected Topics in Power Electronics 4 (3) (2016) 1015–1025. `doi:10.1109/JESTPE.2015.2505622`.

[97] V.-B. Vu, M. Dahidah, V. Pickert, V.-T. Phan, An improved LCL-L compensation topology for capacitive power transfer in electric vehicle charging, IEEE Access 8 (2020) 27757–27768. `doi:10.1109/ACCESS.2020.2971961`.

[98] S. Sinha, A. Kumar, B. Regensburger, K. K. Afridi, A new design approach to mitigating the effect of parasitics in capacitive wireless power transfer systems for electric vehicle charging, IEEE Transactions on Transportation Electrification 5 (4) (2019) 1040–1059. `doi:10.1109/TTE.2019.2931869`.

[99] Z. Zhang, H. Pang, A. Georgiadis, C. Cecati, Wireless power transfer—an overview, IEEE Transactions on Industrial Electronics 66 (2) (2018) 1044–1058.

[100] J. Stillig, N. Parspour, Classification of WPT systems: Categorization, differentiation and overview of industrial wireless power transfer systems, in: 2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), IEEE, 2020, pp. 1–6.

[101] C. Baguley, S. Jayasinghe, U. Madawala, Chapter 22 - theory and control of wireless power transfer systems, in: F. Blaabjerg (Ed.), Control of Power Electronic Converters and Systems, Academic Press, 2018, pp. 291–307. `doi:https://doi.org/10.1016/B978-0-12-816136-4.00023-3`.

[102] A. Kumar, S. Sinha, K. K. Afridi, A high-frequency inverter architecture for providing variable compensation in wireless power transfer systems, in: 2018 IEEE applied power electronics conference and exposition (APEC), IEEE, 2018, pp. 3154–3159.

[103] N. T. Tasneem, S. R. Suri, I. Mahbub, A low-power CMOS voltage boosting rectifier for wireless power transfer applications, in: 2018 Texas symposium on wireless and microwave circuits and systems (WMCS), IEEE, 2018, pp. 1–4.

[104] M. Gheisarnejad, H. Farsizadeh, M.-R. Tavana, M. H. Khooban, A novel deep learning controller for DC–DC buck–boost converters in wireless power transfer feeding CPLs, IEEE Transactions on Industrial Electronics 68 (7) (2020) 6379–6384.

[105] K. N. Mude, K. Aditya, Comprehensive review and analysis of two-element resonant compensation topologies for wireless inductive power transfer systems, Chinese Journal of Electrical Engineering 5 (2) (2019) 14–31. `doi:10.23919/CJEE.2019.000008`.

[106] A. Srilatha, A. Pandian, P. Srinivasa Varma, Power factor correction controller with buck boost converter for fast charging of electrical vehicles, Materials Today: Proceedings (2021). `doi:https://doi.org/10.1016/j.matpr.2020.11.097`.

[107] R. Collin, Y. Miao, A. Yokochi, P. Enjeti, A. Von Jouanne, Advanced electric vehicle fast-charging technologies, Energies 12 (10) (2019) 1839.

[108] Y. Guo, K. Huang, X. Hu, A state-of-health estimation method of lithium-ion batteries based on multi-feature extracted from constant current charging curve, Journal of Energy Storage 36 (2021) 102372. `doi:https://doi.org/10.1016/j.est.2021.102372`.

[109] Y. Chen, H. Zhang, S.-J. Park, D.-H. Kim, A switching hybrid LCC-S compensation topology for constant current/voltage EV wireless charging, Ieee Access 7 (2019) 133924–133935.

[110] M. W. Kim, J. J. Kim, A PWM/PFM dual-mode DC-DC buck converter with load-dependent efficiency-controllable scheme for multi-purpose iot applications, Energies 14 (4) (2021). `doi:10.3390/en14040960`.

[111] P. Xu, H. Wen, W. Hao, Y. Yang, J. Ma, Y. Wang, J. Zhou, Nonisolated switching-capacitor-integrated three- port converters with seamless PWM/PFM modulation, Solar Energy 224 (2021) 160–174. `doi:https://doi.org/10.1016/j.solener.2021.04.023`.

[112] L. Pamungkas, M. Tampubolon, Q. Lin, H.-J. Chiu, Performance comparison of primary side PFM and secondary side PWM for SS wireless power transfer CC/CV control strategy, in: 2018 IEEE International Power Electronics and Application Conference and Exposition (PEAC), IEEE, 2018, pp. 1–5.

[113] S. Mukherjee, S. K. Giri, S. Kundu, S. Banerjee, A generalized discontinuous PWM scheme for three-level NPC traction inverter with minimum switching loss for electric vehicles, IEEE Transactions on Industry Applications 55 (1) (2018) 516–528.

[114] A. Aghazadeh, N. Khodabakhshi-Javinani, H. Nafisi, M. Davari, E. Pouresmaeil, Adapted near-state PWM for dual two-level inverters in order to reduce common-mode voltage and switching losses, IET Power Electronics 12 (4) (2019) 676–685.

[115] R. Pandey, B. Singh, A high efficiency modular EV charger using bridgeless and resonant converters, in: 2020 IEEE Industry Applications Society Annual Meeting, IEEE, 2020, pp. 1–6.

[116] Y. Qu, W. Shu, L. Qiu, Y.-C. Kuan, S.-H. W. Chiang, J. S. Chang, A low-profile high-efficiency fast battery charger with unifiable constant-current and constant-voltage regulation, IEEE Transactions on Circuits and Systems I: Regular Papers 67 (11) (2020) 4099–4109. `doi:10.1109/TCSI.2020.3007827`.

[117] V. Z. Barsari, D. J. Thrimawithana, G. A. Covic, An inductive coupler array for in-motion wireless charging of electric vehicles, IEEE Transactions on Power Electronics 36 (9) (2021) 9854–9863.

[118] A. S. Al-Ogaili, T. J. T. Hashim, N. A. Rahmat, A. K. Ramasamy, M. B. Marsadek, M. Faisal, M. A. Hannan, Review on scheduling, clustering, and forecasting strategies for controlling electric vehicle charging: Challenges and recommendations, Ieee Access 7 (2019) 128353–128371.

[119] H. Wang, D. Zhao, Q. Meng, G. P. Ong, D.-H. Lee, A four-step method for electric-vehicle charging facility deployment in a dense city: An empirical study in singapore, Transportation Research Part A: Policy and Practice 119 (2019) 224–237.

[120] T. M. Mostafa, A. Muharam, A. Patrick Hu, R. Hattori, Improved cpt system with less voltage stress and sensitivity using a step-down transformer on receiving side, IET Power Electronics 12 (10) (2019) 2634–2641. arXiv:https://ietresearch.onlinelibrary.wiley.com/doi/pdf/10.1049/iet-pel.2018.6206, doi:https://doi.org/10.1049/iet-pel.2018.6206.

[121] B. Luo, R. Mai, L. Guo, D. Wu, Z. He, LC–CLC compensation topology for capacitive power transfer system to improve misalignment performance, IET Power Electronics 12 (10) (2019) 2626–2633.

[122] F. Pardo-Bosch, P. Pujadas, C. Morton, C. Cervera, Sustainable deployment of an electric vehicle public charging infrastructure network from a city business model perspective, Sustainable Cities and Society 71 (2021) 102957. doi:https://doi.org/10.1016/j.scs.2021.102957.

[123] S. Kuroda, T. Imura, Derivation and comparison of efficiency and power in non-resonant and resonant circuit of capacitive power transfer, in: 2020 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), IEEE, 2020, pp. 152–157.

[124] A. A. Mohamed, A. A. Shaier, H. Metwally, S. I. Selem, A comprehensive overview of inductive pad in electric vehicles stationary charging, Applied Energy 262 (2020) 114584. doi:https://doi.org/10.1016/j.apenergy.2020.114584.

[125] Y. Ai, X. Hu, X. Li, X. Zhang, Analysis and study of compact inductive power transfer systems for EV charging, Journal of Power Electronics 21 (5) (2021) 829–839.

[126] Ömer Gönül, A. C. Duman, Önder Güler, Electric vehicles and charging infrastructure in Turkey: An overview, Renewable and Sustainable Energy Reviews 143 (2021) 110913. doi:https://doi.org/10.1016/j.rser.2021.110913.

[127] Y. Tian, J. Tian, D. Li, S. Zhou, A multiple legs inverter with real time–reflected load detection used in the dynamic wireless charging system of electric vehicles, Energies 11 (5) (2018) 1275.

[128] M. Yilmaz, P. T. Krein, Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles, IEEE Transactions on Power Electronics 28 (5) (2013) 2151–2169. doi:10.1109/TPEL.2012.2212917.

[129] J. K. Nama, A. K. Verma, M. Srivastava, P. S. Tomar, An efficient inductive power transfer topology for electric vehicle battery charging, IEEE Transactions on Industry Applications 56 (6) (2020) 6925–6936. doi:10.1109/TIA.2020.3018419.

[130] X. Mou, D. T. Gladwin, R. Zhao, H. Sun, Survey on magnetic resonant coupling wireless power transfer technology for electric vehicle charging, IET Power Electronics 12 (12) (2019) 3005–3020.

[131] H. Jafari, M. Moghaddami, T. O. Olowu, A. Sarwat, M. Mahmoudi, Virtual inertia-based multi-power level controller for inductive electric vehicle charging systems, IEEE Journal of Emerging and Selected Topics in Power Electronics (2020) 1–1doi:10.1109/JESTPE.2020.3032898.

[132] D. Niculae, M. Iordache, M. Stanculescu, M. L. Bobaru, S. Deleanu, A review of electric vehicles charging technologies stationary and dynamic, in: 2019 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), IEEE, 2019, pp. 1–4.

[133] Z. Luo, X. Wei, M. G. S. Pearce, G. A. Covic, Multiobjective optimization of inductive power transfer double-D pads for electric vehicles, IEEE Transactions on Power Electronics 36 (5) (2021) 5135–5146. doi:10.1109/TPEL.2020.3029789.

[134] P. A. J. Lawton, F. J. Lin, G. A. Covic, Magnetic design considerations for high-power wireless charging systems, IEEE Transactions on Power Electronics (2022).

[135] E. Asa, M. Mohammad, O. C. Onar, J. Pries, V. Galigekere, G.-J. Su, Review of safety and exposure limits of electromagnetic fields (EMF) in wireless electric vehicle charging (WEVC) applications, in: 2020 IEEE Transportation Electrification Conference & Expo (ITEC), IEEE, 2020, pp. 17–24.

[136] B. Vaidya, H. T. Mouftah, Wireless charging system for connected and autonomous electric vehicles, in: 2018 IEEE Globecom Workshops (GC Wkshps), IEEE, 2018, pp. 1–6.

[137] K. N. Mude, Battery charging method for electric vehicles: From wired to on-road wireless charging, Chinese Journal of Electrical Engineering 4 (4) (2018) 1–15.

[138] F. Freschi, M. Mitolo, R. Tommasini, Electrical safety of plug-in electric vehicles: Shielding the public from shock, IEEE Industry Applications Magazine 24 (3) (2018) 58–63.

[139] F. Welzel, C.-F. Klinck, Y. Pohlmann, M. Bednarczyk, Grid and user-optimized planning of charging processes of an electric vehicle fleet using a quantitative optimization model, Applied Energy 290 (2021) 116717. doi:https://doi.org/10.1016/j.apenergy.2021.116717.

[140] Y. Yao, C. Tang, Y. Wang, Crossed flat solenoid coupler for stationary electric vehicle wireless charging featuring high misalignment tolerance, IET Electric Power Applications 14 (13) (2020) 2648–2658.

[141] A. Ramezani, M. Narimani, High misalignment tolerant wireless charger designs for EV applications, in: 2019 IEEE Transportation Electrification Conference and Expo (ITEC), IEEE, 2019, pp. 1–5.

[142] A. A. Mohamed, A. Meintz, L. Zhu, System design and optimization of in-route wireless charging infrastructure for shared automated electric vehicles, IEEE Access 7 (2019) 79968–79979.

[143] Y. Alwesabi, N. Mohammed, A. Al-Shargabi, Y. Wang, Energy demand estimation of electric buses considering dynamic wireless charging technology, in: 2021 International Congress of Advanced Technology and Engineering (ICOTEN), IEEE, 2021, pp. 1–5.

[144] G. Covic, Inductive power transfer (IPT) – powering our future, presentation (2010).
URL http://cemeold.ece.illinois.edu/seminars/CEME910Covic.pdf

[145] G. A. Covic, J. T. Boys, Inductive power transfer, Proceedings of the IEEE 101 (6) (2013) 1276–1289. doi:10.1109/JPROC.2013.2244536.

[146] G. A. Covic, J. T. Boys, Modern trends in inductive power transfer for transportation applications, IEEE Journal of Emerging and Selected Topics in Power Electronics 1 (1) (2013) 28–41. doi:10.1109/JESTPE.2013.2264473.

[147] Y. J. JANG, JaeryongYEO, Stochastic systems modeling for wireless charging electric vehicle, Tech. rep., Korea Advanced Institute of Science and Technology (KAIST) (2015).

[148] S. Li, C. C. Mi, Wireless power transfer for electric vehicle applications, IEEE Journal of Emerging and Selected Topics in Power Electronics 3 (1) (2015) 4–17. doi:10.1109/JESTPE.2014.2319453.

[149] S. Moon, G.-W. Moon, Wireless power transfer system with an asymmetric four-coil resonator for electric vehicle battery chargers, IEEE Transactions on Power Electronics 31 (10) (2016) 6844–6854. doi:10.1109/TPEL.2015.2506779.

[150] M. Kesler, Highly resonant wireless power transfer: Safe, efficient, and over distance, Tech. rep., Witricity Corporation, White paper (2017).

[151] WiTricity, Drive 11 evaluation system: Wireless charging for ev & phev platforms, Tech. rep., Witricity Corporation (2019).

[152] Project: Wireless charging for electric vehicles, Tech. rep., Conductix Wampfler (2010).

[153] No fuss, just wireless wireless charging for electric vehicles, Tech. rep., Qualcomm (2011).

[154] Pluglesstm level 2 EV charging system (3.3 kW) by Evatran group inc., Tech. rep., Evatran Group Inc. (2013).

[155] Plugless 3.6kW demonstration/benchtop system, Tech. rep., Plugless Power (2013).

[156] Plugless accepting reservations for 7.2 kW wireless charging system for Tesla model S, Tech. rep., Plugless Power (2016).

[157] R. Walli, ORNL surges forward with 20-kilowatt wireless charging for vehicles, Tech. rep., ORNL (2016).

[158] Wireless charging research activities around the world [society news], IEEE Power Electronics Magazine 1 (2) (2014) 30–38. doi:10.1109/MPEL.2014.2319511.

[159] J. Pries, V. P. N. Galigekere, O. C. Onar, G.-J. Su, A 50-kW three-phase wireless power transfer system using bipolar windings and series resonant networks for rotating magnetic fields, IEEE Transactions on Power Electronics 35 (5) (2020) 4500–4517. doi:10.1109/TPEL.2019.2942065.

[160] ORNL demonstrates 120-kilowatt wireless charging for vehicles, Tech. rep., Oak Ridge National Laboratory (October 2018).

[161] A. Vesco, F. Ferrero, Handbook of Research on Social, Economic, and Environmental Sustainability in the Development of Smart Cities, IGI Global, 2015.

[162] 7 kW wireless power transmission technology for EV charging, Tech. rep., Toshiba (2014).

[163] C. Morris, Toshiba wireless charger completes year-long field testing with electric buses, Tech. rep., Toshiba (April 2017).

[164] Z. Dai, J. Wang, M. Long, H. Huang, A Witricity-based high-power device for wireless charging of electric vehicles, Energies 10 (3) (2017). doi:10.3390/en10030323.

[165] Wave - wireless advanced vehicle charging, Tech. rep., WAVE (2019).

[166] IPT technology news and updates, Tech. rep., IPT Technology (2021).

[167] J. Kim, J. Kim, S. Kong, H. Kim, I.-S. Suh, N. P. Suh, D.-H. Cho, J. Kim, S. Ahn, Coil design and shielding methods for a magnetic resonant wireless power transfer system, Proceedings of the IEEE 101 (6) (2013) 1332–1342. doi:10.1109/JPROC.2013.2247551.

[168] J. Shin, S. Shin, Y. Kim, S. Ahn, S. Lee, G. Jung, S.-J. Jeon, D.-H. Cho, Design and implementation of shaped magnetic-resonance-based wireless power transfer system for roadway-powered moving electric vehicles, IEEE Transactions on Industrial Electronics 61 (3) (2014) 1179–1192. doi:10.1109/TIE.2013.2258294.

[169] B. Song, J. Shin, S. Chung, S. Shin, S. Lee, Y. Kim, G. Jung, S. Jeon, Design of a pickup with compensation winding for on-line electric vehicle (OLEV), in: 2013 IEEE Wireless Power Transfer (WPT), 2013, pp. 60–62. doi:10.1109/WPT.2013.6556881.

[170] Dynamic wireless charging of electric vehicles in motion, Tech. rep., IPT Technology (2020).

[171] X. Wu, G. Li, J. Zhou, A lightweight secure management scheme for energy harvesting dynamic wireless charging system, IEEE Access 8 (2020) 224729–224740. doi:10.1109/ACCESS.2020.3044293.

[172] K. Qiu, W. Naim, E. Shayesteh, P. Hilber, Reliability evaluation of power distribution grids considering the dynamic charging mode of electric buses, Energy Reports 7 (2021) 134–140, iCPE 2020-The International Conference on Power Engineering. doi:https://doi.org/10.1016/j.egyr.2021.02.012.

[173] A. Zakerian, S. Vaez-Zadeh, A. Babaki, A dynamic wpt system with high efficiency and high power factor for electric vehicles, IEEE Transactions on Power Electronics 35 (7) (2020) 6732–6740. doi:10.1109/TPEL.2019.2957294.

[174] K. Kouka, A. Masmoudi, A. Abdelkafi, L. Krichen, Dynamic energy management of an electric vehicle charging station using photovoltaic power, Sustainable Energy, Grids and Networks 24 (2020) 100402. doi:https://doi.org/10.1016/j.segan.2020.100402.

[175] H. Ngo, A. Kumar, S. Mishra, Optimal positioning of dynamic wireless charging infrastructure in a road network for battery electric vehicles, Transportation Research Part D: Transport and Environment 85 (2020) 102385.

[176] E. A. ElGhanam, M. S. Hassan, A. H. Osman, Deployment optimization of dynamic wireless electric vehicle charging systems: A review, in: 2020 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), IEEE, 2020, pp. 1–7.

[177] B. Song, S. Cui, Y. Li, C. Zhu, A narrow-rail three-phase magnetic coupler with uniform output power for EV dynamic wireless charging, IEEE Transactions on Industrial Electronics (2020) 1–1doi:10.1109/TIE.2020.3005072.

[178] S. A. Zaini, S. H. Yusoff, A. A. Abdullah, S. Khan, F. Abd Rahman, N. N. Nanda, Investigation of magnetic properties for different coil sizes of dynamic wireless charging pads for electric vehicles (ev), IIUM Engineering Journal 21 (1) (2020) 23–32.

[179] H. Wang, K. W. E. Cheng, An improved and integrated design of segmented dynamic wireless power transfer for electric vehicles, Energies 14 (7) (2021) 1975.

[180] C. Cai, M. Saeedifard, J. Wang, P. Zhang, J. Zhao, Y. Hong, A cost-effective segmented dynamic wireless charging system with stable efficiency and output power, IEEE Transactions on Power Electronics 37 (7) (2022) 8682–8700.

[181] G. R. Kalra, B. S. Riar, D. J. Thrimawithana, An integrated boost active bridge based secondary inductive power transfer converter, IEEE Transactions on Power Electronics 35 (12) (2020) 12716–12727. doi:10.1109/TPEL.2020.2984784.

[182] Q. Zhao, A. Wang, J. Liu, X. Wang, The load estimation and power tracking integrated control strategy for dual-sides controlled LCC compensated wireless charging system, IEEE Access 7 (2019) 75749–75761.

[183] S. Jeong, Y. J. Jang, D. Kum, Economic analysis of the dynamic charging electric vehicle, IEEE Transactions on Power Electronics 30 (11) (2015) 6368–6377. doi:10.1109/TPEL.2015.2424712.

[184] A. Ibrahim, F. Jiang, The electric vehicle energy management: An overview of the energy system and related modeling and simulation, Renewable and Sustainable Energy Reviews 144 (2021) 111049. doi:https://doi.org/10.1016/j.rser.2021.111049.

[185] D.-H. Kim, S. Kim, S.-W. Kim, J. Moon, I. Cho, D. Ahn, Coupling extraction and maximum efficiency tracking for multiple concurrent transmitters in dynamic wireless charging, IEEE Transactions on Power Electronics 35 (8) (2019) 7853–7862.

[186] Y. Huang, C. Liu, Y. Zhou, Y. Xiao, S. Liu, Power allocation for dynamic dual-pickup wireless charging system of electric vehicle, IEEE Transactions on Magnetics 55 (7) (2019) 1–6.

[187] M. Forato, M. Bertoluzzo, A modified LCC-compensated pickup topology for dynamic wireless power transfer systems, in: IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society, IEEE, 2018, pp. 4757–4762.

[188] S. Jeong, Y. J. Jang, D. Kum, M. S. Lee, Charging automation for electric vehicles: Is a smaller battery good for the wireless charging electric vehicles?, IEEE Transactions on Automation Science and Engineering 16 (1) (2018) 486–497.

[189] Y. J. Jang, E. S. Suh, J. W. Kim, System architecture and mathematical models of electric transit bus system utilizing wireless power transfer technology, IEEE Systems Journal 10 (2) (2016) 495–506. doi:10.1109/JSYST.2014.2369485.

[190] M. Amirpour, S. Kim, M. P. Battley, P. Kelly, S. Bickerton, G. Covic, Coupled electromagnetic-thermal analysis of roadway inductive power transfer pads within a model pavement, Applied Thermal Engineering 189 (2021) 116710. doi:https://doi.org/10.1016/j.applthermaleng.2021.116710.

[191] B. M. Mosammam, N. Rasekh, M. Mirsalim, A. Khorsandi, Electromagnetic analysis for DD pad magnetic structure of a wireless power transfer (wpt) for electrical vehicles, in: 2018 Smart Grid Conference (SGC), IEEE, 2018, pp. 1–6.

[192] R. K. Yakala, S. Pramanick, D. P. Nayak, M. Kumar, Optimization of circular coil design for wireless power transfer system in electric vehicle battery charging applications, Transactions of the Indian National Academy of Engineering 6 (3) (2021) 765–774.

[193] M. E. Bima, I. Bhattacharya, S. R. Hasan, Comparative analysis of magnetic materials, coil structures and shielding materials for efficient wireless power transfer, in: 2019 IEEE International Symposium on Electromagnetic Compatibility, Signal & Power Integrity (EMC+ SIPI), IEEE, 2019, pp. 95–100.

[194] P. Machura, H. Zhang, K. Kails, Q. Li, Loss characteristics of superconducting pancake, solenoid and spiral coils for wireless power transfer, Superconductor Science and Technology 33 (7) (2020) 074008.

[195] X. Mou, H. Sun, Analysis of multiple segmented transmitters design in dynamic wireless power transfer for electric vehicles charging, Electronics Letters 53 (14) (2017) 941–943. arXiv:https://ietresearch.onlinelibrary.wiley.com/doi/pdf/10.1049/el.2016.3340, doi:https://doi.org/10.1049/el.2016.3340.

[196] A. Dayerizadeh, H. Feng, S. M. Lukic, Dynamic wireless charging: Reflexive field containment using saturable inductors, IEEE Transactions on Industry Applications 56 (2) (2020) 1784–1792.

[197] C. Sun, T. Li, S. H. Low, V. O. Li, Classification of electric vehicle charging time series with selective clustering, Electric Power Systems Research 189 (2020) 106695. doi:https://doi.org/10.1016/j.epsr.2020.106695.

[198] A. Kamineni, M. J. Neath, A. Zaheer, G. A. Covic, J. T. Boys, Interoperable ev detection for dynamic wireless charging with existing hardware and free resonance, IEEE transactions on transportation electrification 3 (2) (2016) 370–379.

[199] Y.-C. Hsieh, Z.-R. Lin, M.-C. Chen, H.-C. Hsieh, Y.-C. Liu, H.-J. Chiu, High-efficiency wireless power transfer system for electric vehicle applications, IEEE Transactions on Circuits and Systems II: Express Briefs 64 (8) (2016) 942–946.

[200] Y. Yang, J. Cui, X. Cui, Design and analysis of magnetic coils for optimizing the coupling coefficient in an electric vehicle wireless power transfer system, Energies 13 (16) (2020) 4143.

[201] X. Shi, C. Qi, M. Qu, S. Ye, G. Wang, L. Sun, Z. Yu, Effects of coil shapes on wireless power transfer via magnetic resonance coupling, Journal of Electromagnetic Waves and Applications 28 (11) (2014) 1316–1324.

[202] Z. Huang, S.-C. Wong, K. T. Chi, Design of a single-stage inductive-power-transfer converter for efficient ev battery charging, IEEE Transactions on Vehicular Technology 66 (7) (2016) 5808–5821.

[203] J. Mai, Y. Wang, Y. Yao, M. Sun, D. Xu, High-misalignment tolerant IPT systems with solenoid and double D pads, IEEE Transactions on Industrial Electronics (2021) 1–1doi:10.1109/TIE.2021.3075841.

[204] M. G. Pearce, G. A. Covic, J. T. Boys, Reduced ferrite double D pad for roadway IPT applications, IEEE Transactions on Power Electronics 36 (5) (2020) 5055–5068.

[205] N. Rasekh, J. Kavianpour, M. Mirsalim, A novel integration method for a bipolar receiver pad using LCC compensation topology for wireless power transfer, IEEE Transactions on Vehicular Technology 67 (8) (2018) 7419–7428.

[206] A. C. Bagchi, A. Kamineni, R. Zane, R. B. Carlson, Review and comparative analysis of topologies and control methods in dynamic wireless charging of electric vehicles, IEEE Journal of Emerging and Selected Topics in Power Electronics (2021) 1–1doi:10.1109/JESTPE.2021.3058968.

[207] W. Zhang, C. C. Mi, Compensation topologies of high-power wireless power transfer systems, IEEE Transactions on Vehicular Technology 65 (6) (2015) 4768–4778.

[208] J. Sampath, A. Alphones, H. Shimasaki, Coil design guidelines for high efficiency of wireless power transfer (WPT), in: 2016 IEEE Region 10 Conference (TENCON), IEEE, 2016, pp. 726–729.

[209] K. A. Cota, P. A. Gray, M. Pathmanathan, P. W. Lehn, An approach for selecting compensation capacitances in resonance-based EV wireless power transfer systems with switched capacitors, IEEE Transactions on Transportation Electrification 5 (4) (2019) 1004–1014.

[210] J. Lu, G. Zhu, D. Lin, Y. Zhang, H. Wang, C. C. Mi, Realizing constant current and constant voltage outputs and input zero phase angle of wireless power transfer systems with minimum component counts, IEEE Transactions on Intelligent Transportation Systems 22 (1) (2020) 600–610.

[211] B. X. Nguyen, F. Hoong Choo, L. H. Koh, P. Tu, J. Singh Narli, A constant current and constant voltage compensation scheme for wireless charger, in: 2019 IEEE 4th International Future Energy Electronics Conference (IFEEC), 2019, pp. 1–6. doi:10.1109/IFEEC47410.2019.9015176.

[212] K. M. Tan, V. K. Ramachandaramurthy, J. Y. Yong, M. Tariq, Experimental verification of a flexible vehicle-to-grid charger for power grid load variance reduction, Energy 228 (2021) 120560. doi:https://doi.org/10.1016/j.energy.2021.120560.

[213] C. Fang, J. Song, L. Lin, Y. Wang, Practical considerations of series-series and series-parallel compensation topologies in wireless power transfer system application, in: 2017 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), IEEE, 2017, pp. 255–259.

[214] C. Jiang, K. Chau, C. Liu, C. H. Lee, An overview of resonant circuits for wireless power transfer, Energies 10 (7) (2017) 894.

[215] P. K. S. Jayathurathnage, A. Alphones, D. M. Vilathgamuwa, Optimization of a wireless power transfer system with a repeater against load variations, IEEE Transactions on Industrial Electronics 64 (10) (2017) 7800–7809.

[216] L. Murliky, R. W. Porto, V. J. Brusamarello, F. Rangel de Sousa, A. Triviño-Cabrera, Active tuning of wireless power transfer system for compensating coil misalignment and variable load conditions, AEU - International Journal of Electronics and Communications 119 (2020) 153166. doi:https://doi.org/10.1016/j.aeue.2020.153166.

[217] Q. Wang, W. Che, M. Dionigi, F. Mastri, M. Mongiardo, G. Monti, Gains maximization via impedance matching networks for wireless power transfer, Progress In Electromagnetics Research 164 (2019) 135–153.

[218] Z. Huang, S.-C. Wong, K. T. Chi, Control design for optimizing efficiency in inductive power transfer systems, IEEE Transactions on Power Electronics 33 (5) (2017) 4523–4534.

[219] Y. Jiang, L. Wang, J. Fang, C. Zhao, K. Wang, Y. Wang, A joint control with variable ZVS angles for dynamic efficiency optimization in wireless power transfer system, IEEE Transactions on Power Electronics 35 (10) (2020) 11064–11081.

[220] A. Koran, K. Badran, Adaptive frequency control of a sensorless-receiver inductive wireless power transfer system based on mixed-compensation topology, IEEE Transactions on Power Electronics 36 (1) (2020) 978–990.

[221] J. Tian, A. P. Hu, A DC-voltage-controlled variable capacitor for stabilizing the ZVS frequency of a resonant converter for wireless power transfer, IEEE Transactions on Power Electronics 32 (3) (2016) 2312–2318.

[222] A. A. S. Mohamed, D. Day, A. Meintz, M. Jun, Real-time implementation of smart wireless charging of on-demand shuttle service for demand charge mitigation, IEEE Transactions on Vehicular Technology 70 (1) (2021) 59–68. doi:10.1109/TVT.2020.3045833.

[223] X. Dai, X. Li, Y. Li, A. P. Hu, Maximum efficiency tracking for wireless power transfer systems with dynamic coupling coefficient estimation, IEEE Transactions on Power Electronics 33 (6) (2018) 5005–5015. doi:10.1109/TPEL.2017.2729083.

[224] Z. Wang, Y. Shi, X. Ma, Y. Wei, A coreless hybrid magnetic coupling coil structure for dynamic wireless power charging system, Energy Reports 6 (2020) 843–850, 2020 The 7th International Conference on Power and Energy Systems Engineering. doi:https://doi.org/10.1016/j.egyr.2020.11.123.

[225] D. H. Kim, D. Ahn, Maximum efficiency point tracking for multiple-transmitter wireless power transfer, IEEE Transactions on Power Electronics 35 (11) (2020) 11391–11400. doi:10.1109/TPEL.2019.2919293.

[226] B. Regensburger, J. Estrada, A. Kumar, S. Sinha, Z. Popović, K. K. Afridi, High-performance capacitive wireless power transfer system for electric vehicle charging with enhanced coupling plate design, in: 2018 IEEE energy conversion congress and exposition (ECCE), IEEE, 2018, pp. 2472–2477.

[227] R. Tavakoli, E. M. Dede, C. Chou, Z. Pantic, Cost-efficiency optimization of ground assemblies for dynamic wireless charging of electric vehicles, IEEE Transactions on Transportation Electrification (2021).

[228] Y. Pei, Y. Le Bihan, M. Bensetti, L. Pichon, Comparison of coupling coils for static inductive power-transfer systems taking into account sources of uncertainty, Sustainability 13 (11) (2021) 6324.

[229] M. Kim, D.-M. Joo, B. K. Lee, Design and control of inductive power transfer system for electric vehicles considering wide variation of output voltage and coupling coefficient, IEEE Transactions on Power Electronics 34 (2) (2018) 1197–1208.

[230] M. Khalilian, P. Guglielmi, Primary-side control of a wireless power transfer system with double-sided LCC compensation topology for electric vehicle battery charging, in: 2018 IEEE International Telecommunications Energy Conference (INTELEC), IEEE, 2018, pp. 1–6.

[231] F. Corti, A. Reatti, M. Pierini, R. Barbieri, L. Berzi, A. Nepote, P. De La Pierre, A low-cost secondary-side controlled electric vehicle wireless charging system using a full-active rectifier, in: 2018 International Conference of Electrical and Electronic Technologies for Automotive, IEEE, 2018, pp. 1–6.

[232] Z. Zhou, L. Zhang, Z. Liu, Q. Chen, R. Long, H. Su, Model predictive control for the receiving-side dc–dc converter of dynamic wireless power transfer, IEEE Transactions on Power Electronics 35 (9) (2020) 8985–8997.

[233] T. U. Solanke, P. K. Khatua, V. K. Ramachandaramurthy, J. Y. Yong, K. M. Tan, Control and management of a multilevel electric vehicles infrastructure integrated with distributed resources: A comprehensive review, Renewable and Sustainable Energy Reviews 144 (2021) 111020. `doi:https://doi.org/10.1016/j.rser.2021.111020`.

[234] S. Chen, H. Li, Y. Tang, Extending the operating region of inductive power transfer systems through dual-side cooperative control, IEEE Transactions on Industrial Electronics 67 (11) (2019) 9302–9312.

[235] E. ElGhanam, M. Hassan, A. Osman, I. Ahmed, Review of communication technologies for electric vehicle charging management and coordination, World Electric Vehicle Journal 12 (3) (2021). `doi:10.3390/wevj12030092`.

[236] M. Kavitha, D. Prasad, P. B. Bobba, Methods for overcoming misalignment effects and charging control of a dynamic wireless electric vehicle charging system, IET Electric Power Applications 13 (8) (2019) 1184–1192.

[237] M. Adil, J. Ali, Q. T. H. Ta, M. Attique, T.-S. Chung, A reliable sensor network infrastructure for electric vehicles to enable dynamic wireless charging based on machine learning technique, IEEE Access 8 (2020) 187933–187947.

[238] K. N. Qureshi, A. Alhudhaif, G. Jeon, Electric-vehicle energy management and charging scheduling system in sustainable cities and society, Sustainable Cities and Society (2021) 102990`doi:https://doi.org/10.1016/j.scs.2021.102990`.

[239] Y. Zhang, Y. Liu, Y. Huang, Z. Chen, G. Li, W. Hao, G. Cunningham, J. Early, An optimal control strategy design for plug-in hybrid electric vehicles based on internet of vehicles, Energy 228 (2021) 120631. `doi:https://doi.org/10.1016/j.energy.2021.120631`.

[240] Z. P. Cano, D. Banham, S. Ye, A. Hintennach, J. Lu, M. Fowler, Z. Chen, Batteries and fuel cells for emerging electric vehicle markets, Nature Energy 3 (4) (2018) 279–289.

[241] W. Chen, J. Liang, Z. Yang, G. Li, A review of lithium-ion battery for electric vehicle applications and beyond, Energy Procedia 158 (2019) 4363–4368, innovative Solutions for Energy Transitions. `doi:https://doi.org/10.1016/j.egypro.2019.01.783`.

[242] S. Sharma, A. K. Panwar, M. Tripathi, Storage technologies for electric vehicles, Journal of Traffic and Transportation Engineering (English Edition) 7 (3) (2020) 340–361, special Issue: Clean Alternative Fuels for Transport Vehicles. `doi:https://doi.org/10.1016/j.jtte.2020.04.004`.

[243] C. Iclodean, B. Varga, N. Burnete, D. Cimerdean, B. Jurchiş, Comparison of different battery types for electric vehicles, IOP Conference Series: Materials Science and Engineering 252 (2017) 012058. `doi:10.1088/1757-899x/252/1/012058`.

[244] M. U. Karaoğlan, N. S. Kuralay, C. O. Colpan, Investigation of the effects of battery types and power management algorithms on drive cycle simulation for a range-extended electric vehicle powertrain, International Journal of Green Energy 16 (1) (2019) 1–11.

[245] H. Hao, K. Chen, H. Liu, H. Wang, J. Liu, K. Yang, H. Yan, A review of the positive electrode additives in lead-acid batteries, Int. J. Electrochem. Sci 13 (2018) 2329–2340.

[246] A. A. Habib, S. Motakabber, M. I. Ibrahimy, A comparative study of electrochemical battery for electric vehicles applications, in: 2019 IEEE International Conference on Power, Electrical, and Electronics and Industrial Applications (PEEIACON), IEEE, 2019, pp. 43–47.

[247] M. A. Hannan, M. M. Hoque, A. Hussain, Y. Yusof, P. J. Ker, State-of-the-art and energy management system of lithium-ion batteries in electric vehicle applications: Issues and recommendations, Ieee Access 6 (2018) 19362–19378.

[248] X. Chen, A. Chu, D. Li, Y. Yuan, X. Fan, Y. Deng, Development of the cycling life model of Ni-MH power batteries for hybrid electric vehicles based on real-world operating conditions, Journal of Energy Storage 34 (2021) 101999.

[249] A. Chu, Y. Yuan, J. Zhu, X. Lu, C. Zhou, The design and investigation of a cooling system for a high power Ni-MH battery pack in hybrid electric vehicles, Applied Sciences 10 (5) (2020) 1660.

[250] F. H. Gandoman, J. Jaguemont, S. Goutam, R. Gopalakrishnan, Y. Firouz, T. Kalogiannis, N. Omar, J. Van Mierlo, Concept of reliability and safety assessment of lithium-ion batteries in electric vehicles: Basics, progress, and challenges, Applied Energy 251 (2019) 113343.

[251] C. Capasso, D. Lauria, O. Veneri, Experimental evaluation of model-based control strategies of sodium-nickel chloride battery plus supercapacitor hybrid storage systems for urban electric vehicles, Applied energy 228 (2018) 2478–2489.

[252] V. K. Kasimalla, V. Velisala, A review on energy allocation of fuel cell/battery/ultracapacitor for hybrid electric vehicles, International Journal of Energy Research 42 (14) (2018) 4263–4283.

[253] W. Liu, T. Placke, K. Chau, Overview of batteries and battery management for electric vehicles, Energy Reports 8 (2022) 4058–4084. `doi:https://doi.org/10.1016/j.egyr.2022.03.016`.

[254] F. Altun, S. A. Tekin, S. Gürel, M. Cernat, Design and optimization of electric cars. a review of technological advances, in: 2019 8th International Conference on Renewable Energy Research and Applications (ICRERA), IEEE, 2019, pp. 645–650.

[255] R. Hanifah, S. Toha, S. Ahmad, Electric vehicle battery modelling and performance comparison in relation to range anxiety, Procedia Computer Science 76 (2015) 250–256, 2015 IEEE International Symposium on Robotics and Intelligent Sensors (IEEE IRIS2015). `doi:https://doi.org/10.1016/j.procs.2015.12.350`.

[256] M. Adaikkappan, N. Sathiyamoorthy, Modeling, state of charge estimation, and charging of lithium-ion battery in electric vehicle: A review, International Journal of Energy Research 46 (3) (2022) 2141–2165.

[257] M. Corno, G. Pozzato, Active adaptive battery aging management for electric vehicles, IEEE Transactions on Vehicular Technology 69 (1) (2020) 258–269. `doi:10.1109/TVT.2019.2940033`.

[258] A. Fotouhi, D. J. Auger, K. Propp, S. Longo, M. Wild, A review on electric vehicle battery modelling: From lithium-ion toward lithium–sulphur, Renewable and Sustainable Energy Reviews 56 (2016) 1008–1021. `doi:https://doi.org/10.1016/j.rser.2015.12.009`.

[259] W. Zhou, Y. Zheng, Z. Pan, Q. Lu, Review on the battery model and SOC estimation method, Processes 9 (9) (2021). `doi:10.3390/pr9091685`.

[260] S. Tamilselvi, S. Gunasundari, N. Karuppiah, A. Razak RK, S. Madhusudan, V. M. Nagarajan, T. Sathish, M. Z. M. Shamim, C. A. Saleel, A. Afzal, A review on battery modelling techniques, Sustainability 13 (18) (2021). `doi:10.3390/su131810042`.

[261] W. He, M. Pecht, D. Flynn, F. Dinmohammadi, A physics-based electrochemical model for lithium-ion battery state-of-charge estimation solved by an optimised projection-based method and moving-window filtering, Energies 11 (8) (2018) 2120.

[262] W. Li, Y. Fan, F. Ringbeck, D. Jöst, X. Han, M. Ouyang, D. U. Sauer, Electrochemical model-based state estimation for lithium-ion batteries with adaptive unscented Kalman filter, Journal of Power Sources 476 (2020) 228534.

[263] J. Li, K. Adewuyi, N. Lotfi, R. G. Landers, J. Park, A single particle model with chemical/mechanical degradation physics for lithium ion battery state of health (SOH) estimation, Applied energy 212 (2018) 1178–1190.

[264] X. Kong, G. L. Plett, M. S. Trimboli, Z. Zhang, D. Qiao, T. Zhao, Y. Zheng, Pseudo-two-dimensional model and impedance diagnosis of micro internal short circuit in lithium-ion cells, Journal of Energy Storage 27 (2020) 101085.

[265] B. Liu, X. Tang, F. Gao, Joint estimation of battery state-of-charge and state-of-health based on a simplified pseudo-two-dimensional model, Electrochimica Acta 344 (2020) 136098.

[266] C. Qi, Y. Zhu, F. Gao, K. Yang, Q. Jiao, Mathematical model for thermal behavior of lithium ion battery pack under overcharge, International Journal of Heat and Mass Transfer 124 (2018) 552–563. doi:https://doi.org/10.1016/j.ijheatmasstransfer.2018.03.100.

[267] K. Thirugnanam, E. R. J. T. P., M. Singh, P. Kumar, Mathematical modeling of Li-ion battery using genetic algorithm approach for V2G applications, IEEE Transactions on Energy Conversion 29 (2) (2014) 332–343. doi:10.1109/TEC.2014.2298460.

[268] X. Fan, W. Zhang, Z. Wang, F. An, H. Li, J. Jiang, Simplified battery pack modeling considering inconsistency and evolution of current distribution, IEEE Transactions on Intelligent Transportation Systems 22 (1) (2021) 630–639. doi:10.1109/TITS.2020.3010567.

[269] L. Tao, J. Ma, Y. Cheng, A. Noktehdan, J. Chong, C. Lu, A review of stochastic battery models and health management, Renewable and Sustainable Energy Reviews 80 (C) (2017) 716–732. doi:10.1016/j.rser.2017.05.12.

[270] F. Wang, M. Tang, A quantitative analytical model for predicting and optimizing the rate performance of battery cells, Cell Reports Physical Science 1 (9) (2020) 100192. doi:https://doi.org/10.1016/j.xcrp.2020.100192.

[271] L. M. Rodrigues, N. L. Bitencourt, L. Rech, C. Montez, R. Moraes, An analytical model to estimate the state of charge and lifetime for batteries with energy harvesting capabilities, International Journal of Energy Research 44 (7) (2020) 5243–5258. arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1002/er.5269, doi:https://doi.org/10.1002/er.5269.

[272] I. Chakraborty, S. P. Nandanoori, S. Kundu, K. Kalsi, Stochastic virtual battery modeling of uncertain electrical loads using variational autoencoder, in: 2020 American Control Conference (ACC), IEEE, 2020, pp. 1305–1310.

[273] Q. Xia, Z. Wang, Y. Ren, L. Tao, C. Lu, J. Tian, D. Hu, Y. Wang, Y. Su, J. Chong, et al., A modified reliability model for lithium-ion battery packs based on the stochastic capacity degradation and dynamic response impedance, Journal of Power Sources 423 (2019) 40–51.

[274] F. Heinrich, F.-D. Noering, M. Pruckner, K. Jonas, Unsupervised data-preprocessing for long short-term memory based battery model under electric vehicle operation, Journal of Energy Storage 38 (2021) 102598. doi:https://doi.org/10.1016/j.est.2021.102598.

[275] X. Ding, D. Zhang, J. Cheng, B. Wang, P. C. K. Luk, An improved thevenin model of lithium-ion battery with high accuracy for electric vehicles, Applied Energy 254 (2019) 113615.

[276] Q. Yang, J. Xu, X. Li, D. Xu, B. Cao, State-of-health estimation of lithium-ion battery based on fractional impedance model and interval capacity, International Journal of Electrical Power & Energy Systems 119 (2020) 105883.

[277] K. Sarrafan, D. Sutanto, K. M. Muttaqi, An electric circuit based EV battery model for runtime prediction and state of charge tracking, in: 2017 IEEE Transportation Electrification Conference (ITEC-India), IEEE, 2017, pp. 1–6.

[278] M. Chen, G. A. Rincon-Mora, Accurate electrical battery model capable of predicting runtime and iv performance, IEEE transactions on energy conversion 21 (2) (2006) 504–511.

[279] P. Machura, V. De Santis, Q. Li, Driving range of electric vehicles charged by wireless power transfer, IEEE Transactions on Vehicular Technology 69 (6) (2020) 5968–5982. doi:10.1109/TVT.2020.2984386.

[280] T. Le Varlet, O. Schmidt, A. Gambhir, S. Few, I. Staffell, Comparative life cycle assessment of lithium-ion battery chemistries for residential storage, Journal of Energy Storage 28 (2020) 101230.

[281] X. Lai, Z. Meng, S. Wang, X. Han, L. Zhou, T. Sun, X. Li, X. Wang, Y. Ma, Y. Zheng, Global parametric sensitivity analysis of equivalent circuit model based on sobol' method for lithium-ion batteries in electric vehicles, Journal of Cleaner Production 294 (2021) 126246. doi:https://doi.org/10.1016/j.jclepro.2021.126246.

[282] Y. Xie, X.-j. He, X.-s. Hu, W. Li, Y.-j. Zhang, B. Liu, Y.-t. Sun, An improved resistance-based thermal model for a pouch lithium-ion battery considering heat generation of posts, Applied Thermal Engineering 164 (2020) 114455.

[283] K. A. Kalwar, M. Aamir, S. Mekhilef, A design method for developing a high misalignment tolerant wireless charging system for electric vehicles, Measurement 118 (2018) 237–245. doi:https://doi.org/10.1016/j.measurement.2017.12.013.

[284] T. S. Pham, T. D. Nguyen, B. S. Tung, B. X. Khuyen, T. T. Hoang, Q. M. Ngo, L. T. H. Hiep, V. D. Lam, Optimal frequency for magnetic resonant wireless power transfer in conducting medium, Scientific Reports 11 (1) (2021) 1–11.

[285] K. Hwang, J. Cho, D. Kim, J. Park, J. H. Kwon, S. I. Kwak, H. H. Park, S. Ahn, An autonomous coil alignment system for the dynamic wireless charging of electric vehicles to minimize lateral misalignment, Energies 10 (3) (2017). doi:10.3390/en10030315.

[286] V.-B. Vu, A. Ramezani, A. Triviño, J. M. González-González, N. B. Kadandani, M. Dahidah, V. Pickert, M. Narimani, J. Aguado, Operation of inductive charging systems under misalignment conditions: A review for electric vehicles, IEEE Transactions on Transportation Electrification (2022).

[287] A. Ahmad, M. S. Alam, Y. Rafat, S. Shariff, Designing and demonstration of misalignment reduction for wireless charging of autonomous electric vehicle, eTransportation 4 (2020) 100052. doi:https://doi.org/10.1016/j.etran.2020.100052.

[288] B. Zhang, R. B. Carlson, J. G. Smart, E. J. Dufek, B. Liaw, Challenges of future high power wireless power transfer for light-duty electric vehicles—-technology and risk management, Etransportation 2 (2019) 100012.

[289] E. ElGhanam, M. Hassan, A. Osman, H. Kabalan, Design and performance analysis of misalignment tolerant charging coils for wireless electric vehicle charging systems, World Electric Vehicle Journal 12 (3) (2021) 89.

[290] J. Xia, X. Yuan, J. Li, S. Lu, X. Cui, S. Li, L. M. Fernández-Ramírez, Foreign object detection for electric vehicle wireless charging, Electronics 9 (5) (2020). doi:10.3390/electronics9050805.

[291] T. Meng, L. Tan, R. Zhong, H. Xie, X. Huang, Research on metal foreign object detection of electric vehicle wireless charging system based on detection coil, World Electric Vehicle Journal 12 (4) (2021). doi:10.3390/wevj12040203.

[292] Y. Zhang, Z. Yan, J. Zhu, S. Li, C. Mi, A review of foreign object detection (FOD) for inductive power transfer systems, eTransportation 1 (2019) 100002. doi:https://doi.org/10.1016/j.etran.2019.04.002.

[293] M. Moghaddami, A. I. Sarwat, A sensorless conductive foreign object detection for inductive electric vehicle charging systems based on resonance frequency deviation, in: 2018 IEEE Industry Applications Society Annual Meeting (IAS), IEEE, 2018, pp. 1–6.

[294] H. Jafari, M. Moghaddami, A. I. Sarwat, Foreign object detection in inductive charging systems based on primary side measurements, IEEE Transactions on Industry Applications 55 (6) (2019) 6466–6475.

[295] J. Lu, G. Zhu, C. C. Mi, Foreign object detection in wireless power transfer systems, IEEE Transactions on Industry Applications (2021).

[296] T. Sonnenberg, A. Stevens, A. Dayerizadeh, S. Lukic, Combined foreign object detection and live object protection in wireless power transfer systems via real-time thermal camera analysis, in: 2019 IEEE Applied Power Electronics Conference and Exposition (APEC), IEEE, 2019, pp. 1547–1552.

[297] S. Y. Chu, A.-T. Avestruz, Electromagnetic model-based foreign object detection for wireless power transfer, in: 2019 20th Workshop on Control and Modeling for Power Electronics (COMPEL), IEEE, 2019, pp. 1–8.

[298] N. Mohamed, F. Aymen, M. Alqarni, R. A. Turky, B. Alamri, Z. M. Ali, S. H. Abdel Aleem, A new wireless charging system for electric vehicles using two receiver coils, Ain Shams Engineering Journal 13 (2) (2022) 101569. `doi:https://doi.org/10.1016/j.asej.2021.08.012`.

[299] L. Hu, Y. Ye, Y. Bo, J. Huang, Q. Tian, X. Yi, Q. Li, Performance evaluation strategy for battery pack of electric vehicles: Online estimation and offline evaluation, Energy Reports 8 (2022) 774–784, 2021 International Conference on New Energy and Power Engineering. `doi:https://doi.org/10.1016/j.egyr.2022.02.026`.

[300] Z. Bi, L. Song, R. De Kleine, C. C. Mi, G. A. Keoleian, Plug-in vs. wireless charging: Life cycle energy and greenhouse gas emissions for an electric bus system, Applied Energy 146 (2015) 11–19.

[301] Y. J. Jang, S. Jeong, Y. D. Ko, System optimization of the on-line electric vehicle operating in a closed environment, Computers & Industrial Engineering 80 (2015) 222–235. `doi:https://doi.org/10.1016/j.cie.2014.12.004`.

[302] J. Xu, Y. Xu, Q. Zhang, Calculation and analysis of optimal design for wireless power transfer, Computers & Electrical Engineering 80 (2019) 106470. `doi:https://doi.org/10.1016/j.compeleceng.2019.106470`.

[303] M. Hassler, F. Niedermeier, J. Krammer, K. Diepold, A method for interoperable interface description of inductive power transfer systems, in: 2018 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), IEEE, 2018, pp. 1–5.

[304] H. E. Committee, Wireless Power Transfer for Light-Duty Plug-In/Electric Vehicles and Alignment Methodology (nov 2017). `doi:https://doi.org/10.4271/J2954_201711`.

[305] J. M. González-González, A. Triviño-Cabrera, J. A. Aguado, Design and validation of a control algorithm for a sae j2954-compliant wireless charger to guarantee the operational electrical constraints, Energies 11 (3) (2018) 604.