Wireless Charging Systems for Electric Vehicles

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The transportation systems have been an integral part of various civilizations since the earliest of times. Advancements are made from time to time depending upon the feasibility, durability, efficiency and ease of access in the locomotives from trains to motor-cycles. The alarming issues regarding global warming and emission of greenhouse gases, arising in recent decades, are brought the conquest to explore more dependable and less harmful sources of energy as compared to fossil fuels into concern around the scientific community in the field of transport. This concern has brought the electrification of transportation under global attention. Since the railways are being connected with overhead conducting rails through pantograph sliders, the electric vehicles (EVs) have been a topic of immersive interest. Electric locomotives are successfully developed in railway systems for many years. Because trains run on a fixed track, going all-electric is easier than going all-electric with electric cars. As compared to railways, EVs have a more flexible and complex mode of conveyance due to which they cannot be powered the same way. Apart from this, EV charging methods take more time, and with a plug-in charging technique, only one car may be charged at a time in a specific slot, which is neither flexible nor convenient.

Keywords: Electric Vehicles , stationary wireless charging(SWC), Dynamic wireless charging (DWC), load efficiency, wireless charging, Capacitive Wireless Power Transfer, Permanent Magnetic Gear Wireless Power Transfer, Inductive Wireless Power Transfer, Resonant Inductive Wireless Power Transfer.

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1. INTRODUCTION

As EVs, unlike combustion engine cars that use fossil fuels, run entirely on electricity, giving them a significant advantage over alternative approaches for addressing the energy problem and lowering pollution emissions. More and more efforts are taken by our government leads to increment in production of EVs, with the mandatory 10% regulatory credit system for all companies (US,Europe).

EVs are required to be equipped with batteries or other high power energy storage units in order to operate successfully. There are numerous other aspects and technical challenges in the EV battery design that need to be overcome for efficient operation of EVs such as high power density, high energy density, affordability, accessibility, long term usability, feasible weight and ease of charging. Currently, lithium-ion batteries are the most cost-effective option, but research on aluminum-ion batteries is underway, which has the potential to transform the system even further owing to its better energy density and dependability. The EVs can be charged through both wired and wireless chargers as any other electronic device. Still the EVs are not a preferred road locomotive among the majority class as the charging and efficiency is altogether a big technical challenge to overcome. The conventional EV battery requires a charging time of half to almost an hour which is much more than the conventional refueling with an attractive running time so the consumer is required to plug it in from time to time to prevent the battery from running out. It really brings some trouble as people may forget to plug-in and find themselves out of charging later on.

The likelihood of charging automobiles, using the plug-in technique will be lowered with wireless charging technologies. There are two types of wireless charging for electric vehicles: fixed and dynamic. Electric vehicles must be parked in a specific location to use the stationary wireless charging. In dynamic mode, EVs get electric power from the power rail without making contact, even while moving. This may be accomplished by burying cable lines beneath the roadways. Wireless charging systems have an advantage over plug-in charging systems in terms of dependability, simplicity, and adaptability. Wireless charging is a new approach that tackles battery technology's fundamental problems, such as low driving range and extended recharging time. The interaction between EVs and the grid could be done without a physical link using this technology. When compared to traditional plug-in EVs, the DWC-EV can charge a battery more often, since it can do so, while the vehicle is in motion, from the charging infrastructure installed on the road. The purpose of this paper is to provide an overview of wireless charging solutions for Electric vehicles (EVs). EVs might be a useful tool in the fight against energy shortages and pollution.

2. COMBUSTION CARS v/s ELECTRIC VEHICLES

Battery operated Electric Vehicle (BEVs) and plug in hybrid electric vehicle (PHEVs) are effective solutions to the problem of harmful greenhouse emissions by the internal combustion vehicles. They do not run on gasoline or any kind of fossil fuels which produce harmful carbon emissions. EVs promise on providing an eco-friendly and cost effective mode of transport to the average customers. They seem to be a better option over traditional combustion automobiles on the front but they somehow contribute to the global warming index in various indirect ways. A study was conducted to understand the economic and environmental effects of BEVs and ICEVs over the next decade. It conducted a critical study of the entire manufacturing process of EVs from research and development (R&D) and production to the raw materials with evaluation of each component thoroughly. It came up with some complex and distinctive results upon the environmental and economic impact of EVs. Economically, the EVs have an advantage over traditional vehicles as the cost of electricity to run the vehicle over a distance of one mile is quite less than the cost of fuel to drive a traditional car over the same distance. Even the cost of maintenance of battery powered electric motor system in BEVs is much less than that for the vehicles with internal combustion engines. Apart from this, the price per KWh for lithium ion battery packs has reduced from $ 1126 in 2010 to $300 in 2015.

As per the environmental perspective, although BEVs considerably contribute much less to the harmful greenhouse emissions than ICEVs on the fore front, it has some complex backend impact upon the environment which is much more than that of the traditional vehicles in which it is profoundly centralized to the combustion of gasoline fuel in the engine. The metals used in the manufacturing of lithium-ion batteries combined with the pollutants generated from the power plants is much more than the emissions from ICEVs. The EVs are not yet very affordable as compared to ICEVs as well as their complex environmental impact makes it essential for the consumer to choose between EVs and ICEVs [1].

The EVs are popularly categorized into three major categories as BEV, PHEV and HEV (Hybrid EV). Consumers moving towards the adaptation of EVs as the primary mode of transport need accessible charging stations. Charging stations at workplaces and public destinations along with domestic charging facilities would boost the growth of EV transportation worldwide. US and parts of Europe have prominent charging facilities for EV where charging stations are equipped with one or more charging posts that consists of EVSE (Electric Vehicle Supply Equipment) ports attached with connectors which are plugged-into the vehicles to charge them. Various charging equipment serve their own specific purpose based on the application and requirement. The J1772 connector is widely considered for AC (level 1 and level2) type charging, meanwhile the CHAdeMO and CCS is preferred for DC fast charging which provides approximately 60 to 80 miles of range in 20 minutes of charging [2].

3. HYBRID ELECTRIC VEHICLES

When the power requirement is minimal, the HEV employs an electric propulsion system. This is especially useful in low-speed situations. It also saves gasoline because the motor is completely turned off during idle times. This contributes to a reduction in greenhouse gas emissions. The ICE can charge the batteries, and the HEV can replenish energy through regenerative braking. As a result, HEVs are predominantly ICE-powered vehicles that utilize an electrical drive train to increase economy or efficiency. During vehicle start-up, the ICE may use the motor as a generator to generate some electricity and store it in the battery. Passing necessitates an increase in speed, both the ICE and the motor power the power train. The power train uses regenerative braking to charge the battery by running the motor as a generator while braking.

To extend the all-electric range of HEVs, the PHEV idea was developed. It features both ICE and electrical power train, just like a HEV, but the distinction is that the PHEV uses electric propulsion as the primary driving force, necessitating a greater battery capacity than HEVs. PHEVs start in pure electric mode, run on energy, and then rely on the ICE to boost or charge the batteries when the batteries are low on charge. The ICE is used to extend the range in this case. HEVs cannot charge their batteries directly from the grid, but PHEVs can also employ regenerative braking. PHEVs also have a lower carbon footprint than HEVs since they can run totally on electricity for the most of the time. They also utilize less gasoline, resulting in cheaper operating expenses. Table 1 shows the comparison between HEV and PHEV.

Table 1. Comparison between HEV and PHEV [3]

	HEV	PHEV
Battery capacity(Hyundai Ioniq)	1.56 kWh	8.9kWh
Charging	This type of vehicle cannot be charged by plugging-in in a port. The battery is charged automatically.	This type of vehicle can be plugged into a wall outlet or charging port to charge the batteries.
Cost	There isn’t a big difference but HEV are cheaper than PHEV	

4. OPERATING PRINCIPLES OF EV

An electric motor replaces the internal combustion engine in all-electric vehicles (EVs). The vehicle's electric motor is powered by a huge traction battery pack, which must be charged at a charging station or via a wall outlet. The car does not have a tailpipe and does not have the traditional liquid fuel components such a fuel pump, fuel line, or fuel tank since it operates on electricity. The electrical energy that drives the motor is stored in a battery pack in all-electric vehicles (EVs). BEVs (battery electric vehicles) are another name for electric automobiles (BEVs). The vehicle's electric battery is charged by hooking it into an electric power source. Despite the fact that power generation contributes to air pollution, the United States Environmental Protection Agency considers all-electric cars to be zero-emission vehicles since they emit no direct exhaust or emissions. Commercially available EVs include both heavy-duty and light-duty models. They are often more costly than comparable conventional and hybrid cars. Although some costs might be recovered via fuel savings, or state incentives.

5. FACTORS TO BE CONSIDER

5.1 Technology factors

Technology variables are inextricably linked to EV features like driving range and charging time. EV adoption is hampered by limited driving range and expensive purchasing costs. Furthermore, electric cars take longer to charge than vehicles with combustion engines, EVs take 30 minutes to charge at a fast-charging station, whereas non-electric cars can refill in around 4 minutes. Other technological issues, including battery life, trunk capacity, and peak speed, are also considered technical obstacles to consumer acceptance.

5.2 Environmental factors

Environmental variables have an indirect impact on EV adoption but are outside the direct control of EV producers. Environmental variables like fuel costs, customer habits, and the availability of charging stations may all be considered. Fuel costs are shown to be the greatest predictors of HEV adoption, and the relative price of electricity would have a similar effect on EV adoption. It is observed that nations with greater GDP have a larger readiness to pay for electric vehicles. According to data, lowering EV tariffs and improving charging infrastructure has a favorable impact on EV adoption.Customers gradually accept and welcome the new trend because of the significant role that EVs occupy. Consumers, on the other hand, frequently have a conservative attitude toward new products owing to a lack of necessary information, which means they do not buy them until these uncertainties are resolved. Manufacturers should take compelling steps to satisfy customer demands in order to encourage EV adoption in the future [4][5][6].

5.3 Driving Range

Today's EVs generally have a relatively shorter range (per charge) than comparable conventional gas vehicles. The efficiency and driving range of EVs vary substantially based on driving conditions. Extreme temperature conditions outside also reduce the range as power is consumed in maintaining the cabin temperature. The higher driving speeds also reduce the driving range as energy is used in overcoming the increased drag. Rapid acceleration also reduces more range as compared to the gradual acceleration. Hauling heavy loads or driving upon inclined tracks may also reduce the range [7].

6. AC-DC CHARGING

In the realm of electric mobility, both AC and DC are essential. The grid provides AC electricity, which is subsequently converted to DC and stored in the battery. In case of electric cars, the converter is integrated into the vehicle. It's referred to as "onboard charger," but it's actually a converter. It converts AC to DC electricity before feeding it into the car's battery. Most chargers use AC power, which is the most popular charging option for electric vehicles today. Unlike AC chargers, DC chargers have the converter built in into the device. It means that it can supply power straight to the vehicle's battery, bypassing the onboard charger. When it comes to EVs, DC chargers are bigger, bulkier and quicker.The charging curve is another significant distinction between AC and DC charging. The power is going to an EV when an AC charging is used as shown by a flat line in Fig.1. This is owing to the onboard charger's tiny size, which can only accept a limited amount of power over a prolonged length of time. DC charging, on the other hand, results in a charging curve that degrades with time. This is because the EV's battery accepts a faster flow of power at first, but gradually requests less as it approaches full capacity. EV adoption may be sluggish if a reliable charging infrastructure is not in place. Home charging or public charging, depending on the municipal layout, may become the preferred charging method. Number of technical problems with rapid charges, including grid peak power limitations, heat control, and the requirement for a dependable battery management system can be confronted.[8][9][10].Fig1 shows the EV charging techniques with AC charger and DC charger and Fig2 depicts the EV battery charging speeds in case of AC and DC chargers.

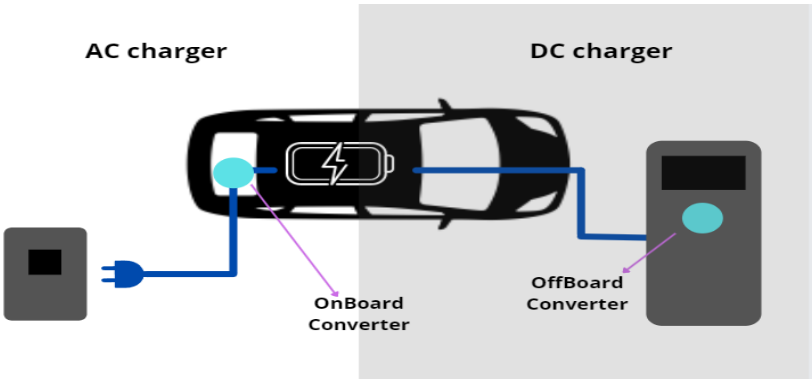

Fig. 1.: An EV charging techniques with AC charger and DC charger

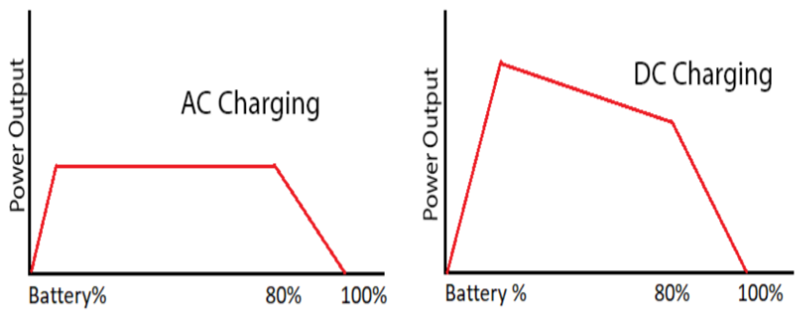

Fig2. EV battery charging speeds in case of AC and DC chargers

6.1 CHARGING COMPONENTS

6.1.1 Battery Pack: The battery in an electric vehicle serves as a storage device for electrical energy in the form of DC power. The battery utilized is a rechargeable battery that has been assembled to create a traction battery pack. Electric vehicle batteries come in a variety of shapes and sizes. Currently, the lithium-ion battery type is the most commonly utilized.

6.1.2 Power Inverter: The inverter converts direct current from the battery to alternating current, which is then utilized by an electric motor. In addition, an electric car's inverter can convert AC current generated by regenerative braking to DC current, which may subsequently be utilized to recharge the battery.

6.1.3 Controller: The controller's primary purpose is to regulate the flow of electrical energy from batteries and inverters to electric motors. The frequency or voltage fluctuation that enters the motor will be determined by this pedal setting. In a nutshell, this device controls the speed of the electric traction motor and the torque it generates, by managing the flow of electrical energy supplied by the traction battery. The operation of electric vehicles will be determined by this component.

6.1.4 Electric traction motor: The electric traction motors spins the gearbox and wheels because the controller receives electrical power from the traction battery. Some hybrid electric vehicles use a generator-motor that serves as both propulsion and regeneration. Generally Brushless DC motor is used in EVs.

6.1.5 Charger: In simple terms, it charges the internal battery. External sources of energy, such as the utility grid or solar power plants are used to power the chargers. AC power is converted to DC power, which is then stored in the battery. Electric vehicle chargers are divided into two categories: On board charger, off board charger.

6.1.6 DC-DC Converter: This is an electric car component that converts higher-voltage DC power from the propulsion battery pack to the lower-voltage DC electricity required to operate vehicle accessories and replenish the auxiliary battery. In many cases a secondary 12V battery is used for low power consuming tasks.

6.1.7 Thermal Cooling System: This system keeps the engine, electric motor, power electronics, and other components within a safe operating temperature range.

6.1.8 Charging Port: Fig.3 shows the major components of any Electric vehicle. The charging port enables the vehicle to charge the traction battery pack by connecting to an external power source. Different manufactures add different type of charging port unlike the most mobile manufacturers, for example Tesla’s charging port is much different than Hyundai’s charging port [11]

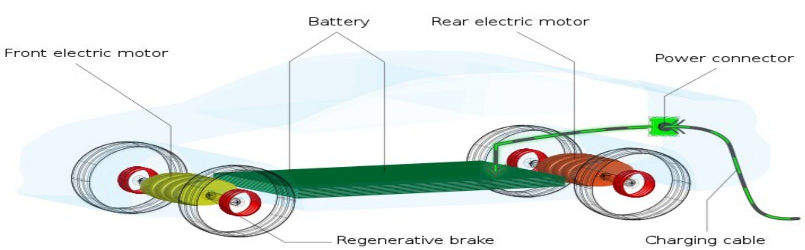

Fig. 3. Some major components of any Electric vehicle

7. ENCRYPTION IN CHARGING

Tritium, an Australian firm, is a pioneer in the field of encrypted charging. Without swiping a card or paying on the spot, the charger software recognizes the vehicle and can safely charge the EV's battery while authorizing payment from the owner's account. The charger does not need to be aware of financial information, making it secure in the event of physical theft. Both the car and the charger require a secure way of communication with one another, and each automobile requires technology which is up to the original equipment manufacturer (OEM) to build into it.

8. VARIOUS CHARGING SOLUTIONS

Conductive charging necessitates an electrical connection between the car and the charging outlet and offers several charging options, such as level 1, level 2, and level 3 charging as shown in Table 2, as well as high charging efficiency owing to the direct connection [12]

Table 2. Charging power in level 1,2 and 3 [12]

EVSE Type	Power Supply	Charger power	Approx. Charging time for 24 KWH battery
AC Lvl1 Residential	120/230V and 12-16A	~ 1.44kW - 1.92Kw	~ 17 hours
AC Lvl2 Commercial	210-240V and 15-80A	~ 3.1kW - 19.2Kw	~ 8 hours
DC Lvl3 Fast charging	300-600V(DC) and 400A	~ 120kW - 240Kw	~ 30mins

9. COMMERCIAL CHARGING

Over 80% of all EV charging now takes place at home. At public charging stations, AC charging through a wallbox or – in the great majority of cases – DC Fast Charging are both accessible. Charging in a public location may be 3 to 10 times faster than charging at home. An AC charger powers the electric vehicle's onboard charger, which converts AC current to DC and enables the battery to charge. Due to space constraints, the onboard charging mechanism can only provide a limited amount of power to the battery. As a consequence, charging takes longer, but a DC fast charger bypasses the internal charging system and sends current directly to an electric vehicle's battery. As a result, charging is usually substantially quicker.

10. SAFETY MEASURES

10.1 Moisture: We all know that electricity and water don't mix well. Electricity should only flow via the charging connections when the contact between the socket and the vehicle is rock-solid and firmly closed. All of the car's components should be properly secured against moisture intrusion.

10.2 Extreme Temperatures: Battery performance degrades as electrical resistance rises at low temperatures. As a result, your electric vehicle will not be able to go as far Similarly When electric cars are just parked in the heat, charging may take longer, reducing the overall range. There should be a mechanism in place that allows electric vehicles to detect unusual load on batteries and manage the workflows accordingly.

10.3 High-Voltage: As soon as a problem is detected, the battery's power flow should be addressed. The battery should immediately separate from the other high-voltage components and connections within milliseconds, just as it would in the event of an accident. The 12-volt electrical system, on the other hand, should continue to function in case of emergency lighting etc. A sudden fire is extremely improbable due to this safety precaution alone.

10.4 No flammable fuel: While liquid gasoline spilled from a petrol or diesel vehicle may catch fire and cause an explosion, electric car batteries burn slowly and give plenty of time to evacuate from an accident scene, which l comes very handy in particular times.

10.5 Noise Emitter for electric cars: Of course, it's not only the passengers of electric vehicles who are concerned about safety; many pedestrians and bikers are as well. It is possible to notice if any conventional engine vehicle approaching nearby while crossing the road, people can listen to them, but with EVs it is very difficult as they make almost no sound while running. [13][14][15].

11. CONVENTIONAL v/s WIRELESS CHARGING

The powering and charging systems for electric vehicles are evolving rapidly. With increased market size and demand of electrified transport in the commercial sector, the technical aspects related to it such as the charging and power storage capacity of batteries are being modified along in order to provide a better performance. The conventional charging methods include level 1, level 2 and level 3 charging standards depending upon the power rating of the battery. The level 1 and level 2 charging include the AC charging systems while the level 3 charging system which implies the DC fast charging technique which is much more efficient than the previous two. The charging systems are available as unidirectional and bidirectional systems. The unidirectional system complies of vehicle to grid(V2G) interaction while the latter system includes grid to vehicle(G2V) application along with it which adds to the reliability of the entire grid system as in the case of overload, grid failure or any other unwanted scenario, the EVs can work as back-up sources supplying back to the grid due to the flexible bidirectional flow. The conventional conductive charging techniques somehow have a number of drawbacks in implementation and commercial usage. On-board chargers are required to carry a cable and charging plug while having proper isolation for on-board electronics. There are a number of complaints regarding the grit and grime upon the charging and supply equipment. The corded charger is easily exposed to all kinds of wear and tear due to pulling, dragging, attaching and detaching which might result in accidents. Therefore, auto OEMs and research institutes have instilled their attention towards wireless power charging technologies [16][17][18].

Wireless Power Transfer (WPT) is a significant solution to the addressed problems associated with corded chargers. A typical closed loop WPT system works upon the inductive coupling mechanism which is divided in two halves. It consists of a two-part transformer which generates a high-power AC (HPAC). The HPAC is received by the next half wirelessly. This HPAC is converted to significant DC by a rectifier which then is supplied to charge the battery further ahead. The various WPT technologies tested previously across the world are mentioned below-

- INDUCTIVE WIRELESS POWER TRANSFER
- CAPACITIVE WIRELESS POWER TRANSFER
- LOW FREQUENCY PERMANENT MAGNET COUPLING POWER TRANSFER
- RESONANT INDUCTIVE POWER TRANSFER
- RESONANT ANTENNAE POWER TRANSFER
- ON-LINE POWER TRANSFER

12. DRAWBACKS OF WIRED CHARGING

The main disadvantage of wired technology is that it does not offer the same level of mobility as wireless technology. You are physically restricted by the cable's reach. Another physical limitation of wired technology is that wires may be readily broken, which is less of an issue with wireless technology. Compared to conventional charging, which can result in a high-power supply or power fluctuations, which can harm your device, wireless charging is the safest way to charge your smart-phone since it only uses the power that the device requires.

13. WIRELESS CHARGING

Wireless charging can be traced all the way back to Nikola Tesla's creation in the late 1800s. Electromagnetic induction is used to transmit electricity between coils in wireless charging as it is currently done. A Qi-certified wireless charger employs tightly linked inductive technology to transmit energy using electromagnetic induction. Maintaining the frequency of resonance between the transmitter and receiver is the most essential aspect of wireless charging or wireless charging to remain efficient. Compensation networks are built on both sides to keep the resonance frequency constant. Inductive coupling is the most popular method of high-power WPT. Recent advances in the semiconductor sector for high-frequency and high-power applications have opened the way for advancements in high-power inductive WPT. Inductive WPT has various advantages over wired connections and is used in a variety of applications including wearable electronics, health care, and the automobile sector. The use of WPT in stationary charging electric cars and dynamic charging electric vehicles are exploded in recent years. The combustion automobile has 16 percent energy efficiency, whereas the electric car has 85 percent energy efficiency. The charging stations' technological structure must guarantee that the correct power, voltage, and current are provided to each electronic circuit. It should guarantee that the low-voltage and high-voltage (HV) circuits are isolated. Power circuit protection must be provided by the model against electrical disturbances that might affect internal or external circuits. **Fig4** depicts the basic block diagram of an Electric vehicle's Wireless charging technology

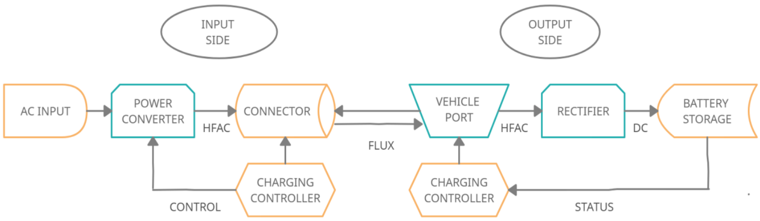

Fig. 4: Basic block diagram of an Electric vehicle's Wireless charging technology

14. WIDE-BAND-GAP SEMICONDUCTOR

Band gap energy is the amount of energy necessary for electrons and holes to move from the valence band to the conduction band. The band gap of Si (Silicon) is 1.12 eV. (electron volt). A semiconductor having a large band gap value is called a wide-band-gap (WBG) semiconductor. WBG semiconductors include SiC (Silicon Carbide) and GaN (Gallium Nitride). Because of the greater distance, WBG semiconductor power devices have the ability to operate at higher voltages, temperatures, and frequency. When it comes to the next generation of efficient power converter switches, wide band gap semiconductor materials are an excellent choice. One of the benefits is that improved efficiency, as a result of wide band gap semiconductor-based electronics, leads to enhanced power density as well as decreased size and weight, decreasing total system costs. The use of wide band gap semiconductor devices in power electronics also aids in the realization of greater operational switching frequencies. This is especially essential when the goal is ultimate power density. Even at high frequencies, GaN WBG semiconductors have a low total gate charge and a low voltage threshold of about 1.5 V, and gate-drive power is restricted to milli-watts.

There are several distinctions between GaN, SiC, and Si semiconductors. First, GaN semiconductors now target voltages ranging from 80V to 650V and provide medium power at the greatest switching frequency. GaN and SiC semiconductors have lower switching losses than Si-based semiconductors and achieve very high efficiency at maximum power density. When it comes to the differences between GaN and SiC power electronics semiconductors, SiC power semiconductors provide superior gate-oxide dependability, good ease of use, are highly durable, and utilize vertical transistor ideas as opposed to GaN, which is a lateral transistor. Silicon Carbide is superior in high-temperature and high-voltage applications, such as high-power string inverters. When it comes to maximum power density, GaN is superior.

The use of wide band gap semiconductor devices is becoming prominent with the booming EV market. Wide band gap semiconductors such as silicon carbide and gallium nitride have successfully proved to provide higher efficiency and ability to withstand extreme operating conditions over silicon. WBG devices enable the EV to charge faster providing high power density to obtain maximum driving range by boosting the power conversion mechanism. This can be achieved with the higher switching frequency to cut down by cutting down the switching losses. The use of WBG devices in onboard DCDC chargers would yield better high voltage gains due to better switching performance and low switching losses over traditional BJT and IGBT devices [19].

15. POWER CONVERTERS

As we discussed the utility and advantage of wide band gap materials like SiC and GaN over conventional silicon semiconductors. They can be used in traction inverters and on-board charging systems in order to yield maximum output on high load. The application of WBG semiconductors depends upon the requirement to be fulfilled. If we require a long-range backup for a city car then a silicon or IGBT solution would be most suitable over SiC and GaN but when a battery pack needs to be charged at a faster rate, then WBG semiconductors would be most suitable. The WBG devices provide advantage in power factor correction (PFC) due to negligible recovery charge. It saves the solution size by limiting the components count. Gallium nitride provides better efficiency over silicon and other semiconductors due to reduced switching and conduction power losses.

Efficient on-board charger must have a bidirectional application in the DC-DC converter stage as for the V2G implementation. But the problem with the bidirectional power flow is that when the converter is operated in the reverse mode then the switching frequency is solemnly controlled by the transformer capacitance and leakage inductance resulting in no manual control over gain and switching frequency in the power stage. Both GaN and SiC are suitably applicable in on- board charging systems for EVs. Silicon carbide has some advantages as it can be switched over higher frequencies due to larger band gap and better mobility with a short reverse recovery time of the diode. However GaN could be equally applicable when applied in similar topology at comparatively higher frequencies as it is already suitable at suitably operating over 1 MHz without any drawbacks.

16. INDUCTIVE CHARGING

Many individuals currently use inductive charging technologies in their daily lives. Whether it's industrial automation, autonomous guided vehicle systems, crane systems, or even toothbrushes, many systems are powered inductively for a long time. There is a lot of creativity in the notion of making the charging process for electric automobiles more efficient, dependable, and, most importantly, quicker. Inductive charging requires the automobile to merely park over or against a charging plate.

The actual charging takes place as a contactless energy transfer between the plate and the vehicle in an alternating electromagnetic field. The energy transfer's design and functioning are similar to those of a transformer with mechanically separated coils. An alternating current is provided to the main coil in inductive charging technology. This produces a magnetic field, which causes an alternating current in the electric car's secondary coil, which may then be used to charge the battery after rectification. Because the distance between the primary and secondary coils is just eight to twenty cm, the magnetic field between the charging plate and the secondary coil is concentrated in a small region [20].

16.1 ELECTROMAGNETIC INDUCTION:

An universal wireless charging system with a simple, small, low-cost circuit construction that uses induced magnetic flux produced between the power transmission and receiving sides to transfer electricity. It is also known for its great efficiency. Short transmission distance and sensitivity to misalignment are disadvantages.

16.2 MAGNETIC RESONANCE

Magnetic resonance is used to transfer power in this system, with resonators on both the sending and receiving sides. This technique is often utilized when a large transmission distance is needed, and it is being pushed for usage in electric vehicle charging applications. However, there is a problem with efficiency, which is around 60-70%.

16.3 ELECTRIC FIELD COUPLING

The transmission technique uses the phenomena of current flowing between electrodes at high frequency. It is used to create a capacitor by pointing electrodes on the power transmitting and receiving sides towards each other (harmonic current). Similar to electromagnetic induction, the transmission distance is small, but it is less sensitive to misalignment and generates less heat in the power supply block [21].

17. MAGNETIC INDUCTION

Magnetic induction is defined as "the phenomenon in which a magnetic field produces an electric field." When an electric field is created in a conductive material, the charge carriers are subjected to a force, resulting in the generation of an electric current in the conductor." A magnetic field is produced in the surrounding region by passing currents via coil, similar to how a transformer works. Bringing another coil adjacent to the magnetic field induces an electric current in the neighboring coil, resulting in wireless power transfer (WPT). However, if the coils are not very near together and also not properly aligned, this power transmission mechanism, known as inductive power transfer, would not work. Faraday's Law of Induction is the foundation of the Inductive Wireless Charging System (IWC). Magnetic resonance is used to improve WPT efficiency at longer distances with poor alignment between the source and the receiver. This entails "tuning" the receiver and source circuits such that they both magnetically resonate at the same frequency, substantially increasing WPT efficiency. The same principle is used for EV charging; wireless charging works by transferring energy through resonant magnetic induction between a conducting pad on the ground and a conducting pad beneath the floor of a compatible EV. Wireless charging is accomplished by the mutual induction of magnetic fields between the transmitter and receiver coils. The optimum operating frequency is between 19 and 50 kHz. Fig.5 illustrates the magnetic induction.

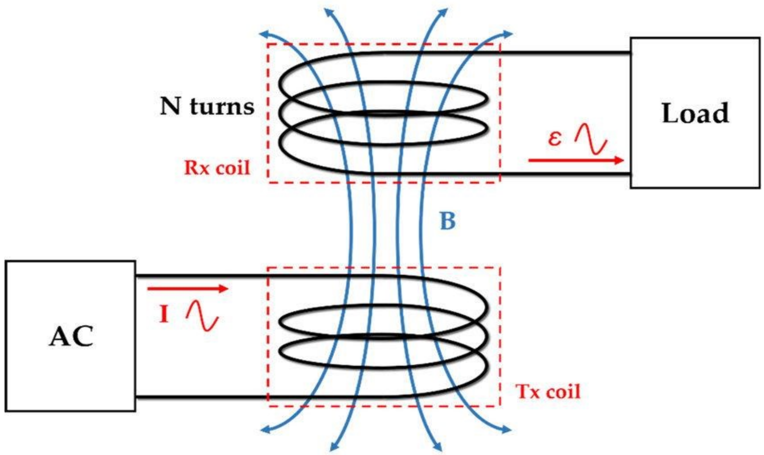

Fig. 5: Magnetic Induction

18. PROCESS OF WIRELESS CHARGING

In the transmission portion, oscillation circuits act as push-pull devices to send magnetic fields to the receiving coil. To transport electromagnetic energy from transmitter to receiver, the system employs coupled magnetic fields as a frequency. The utilization of resonance allows for large levels of power transmission (up to 11kW) as well as excellent efficiency (greater than 92 percent end-to-end) [22]. A magnetic loop antenna (copper coil) is used to generate an oscillating magnetic field, which can cause current to flow through one or more receiver antennas [24]. The quantity of induced current in the receiver antennas rises when the proper capacitance is used so that the loops resonate at the same frequency. This is known as resonant inductive charging or magnetic resonance, and it allows for larger distances between transmitter and receiver while increasing productivity. Power transmission distance is also affected by coil size. The higher the size of the coil or the number of coils, the greater the distance a charge may travel. When the coils are bigger, more energy may be transmitted wirelessly. Fig.6 shows the block diagram of wireless charging.

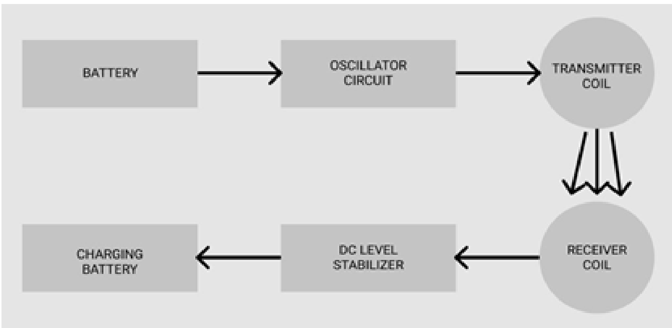

Fig. 6: Block diagram for wireless charging

19. MARKET FORCE

The global EV market had a valuation of $162.34 billion till 2019, and is estimated to touch the $802.81 billion mark by 2027. This is due to the increasing demand of efficient, high-performance, sustainable vehicles which catalyzed the growth of EV market. Although drawbacks like high manufacturing cost and low fuel economy would provide resistance in the growth of EV market. The global EV market is categorized on the basis of model type, vehicle type and region. It comes in three basic types on the basis of model such as BEV, HEV, PHEV. Meanwhile, vehicle type is distinguished as two-wheeler, four-wheeler, loading vehicles and commercial transport. By region the present active market for EVs is spread across North America, parts of Europe and Asia-Pacific countries. The major stakeholders in the EV market actively operating are Tesla, BMW Group, Nissan Motor Corporation, Toyota Motor Corporation, Volkswagen AG, General Motors, Daimler AG, Energica Motor Company S.p.A, BYD Company Motors, and Ford Motor Company. Gasoline and other fossil fuel are more likely to be exhausted in the near future. Therefore, the conquest of evolving renewable and sustainable sources of fuel in the energy and transportation sector brings the global acceptance of EVs into limelight. It has efficiency as high as 50% while the ICEVs have only 17%-21%. The escalating prices of petrol and diesel due to the depletion of fossil fuel reserves also gave rise to the demand for EVs. The automobile giants are working towards reducing the emission count and better cost benefits with advanced electric vehicles. They focus on manufacturing downsized engines for EVs. Smaller engines produce less emissions compared to larger engines and are highly cost effective which further add up to their utility. Thus, it further boosts the possibilities of growth for the global EV market. Electric vehicles sales projection from 2019 – 2027 is presented in Fig.7.

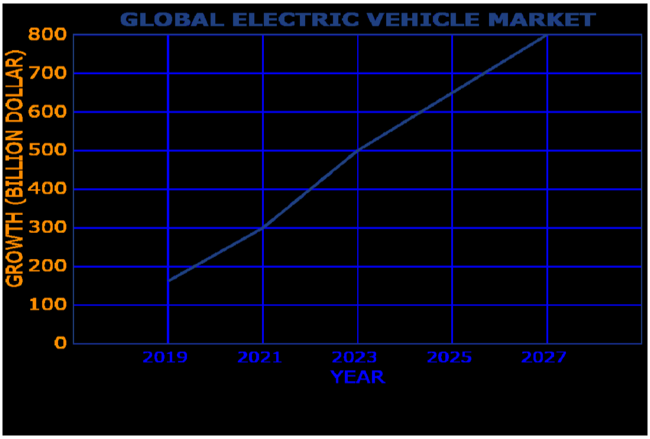

Fig7. Electric vehicles sales projection from 2019 – 2027

20. CHALLENGES

The process of charging an EV comes with great challenges. Higher efficiency is needed to minimize the cost and thermal management challenges as well as to lessen the environmental impact of wireless charging. The high voltage and high power necessary for EV charging brings into the picture of safety and cost of wireless charging systems. Installing wireless chargers in public places also comes with many challenges. The planning and installing the grid, and installing the conduction pads under the roads will take much resources, money and time. Transferring very high currents through charging cables and connectors pose a great danger. The infrastructure also needs to be weather and accident proof. The unavailability of efficient technology is a major concern [23].

21. AREAS OF IMPROVEMENT

The future of EV is very vast. The results depend on the focus of today. The consumption of EV increases in the coming times and people expect them to be more efficient, cost-effective, easy maintenance, long life, and eco-friendly. The most basic need is high mileage in a single charge or min charge. For this the charging time of the battery needs to be decreased and the batteries need to be more efficient so that there is no power loss. It is very important that, while making various parts, there is no harm caused to nature and the materials used are non-toxic. The material used in the battery needs to have high power density so that it charges in a short amount of time. While the materials are eco-friendly, they also need to be cheap, light, and have more storage capacity. In the coming times, the technology will be so updated that EV technology has to keep up with the trends. All sorts of consumers should be able to use the technology. As a result, it must be efficient, cheap, and simple to use. The more the efficiency of the model, the greater the distance it will traverse. As a result, the key areas for future research include improved battery technology, ultra capacitors to reduce voltage limits and achieve higher capacitance, fuel cells for efficiency, flywheels, turbines for grid power production, and various individual and hybrid configurations. The design of EV can be made more aerodynamic so less resistance is applied by the wind against the vehicle. This will result in less power consumption. The power generation at the grids can be made efficient by using modern ways like solar panel, wind turbine installation. While transferring the charge from grid to the road and then to the vehicle, the loss of energy should be minimal [24].

22. CURRENT RESEARCH

Currently there are multiple researches going on various aspects of EVs such as fast charging capabilities, high density batteries, more automation and more effective ways to produce energy for vehicles such as solar roofs etc. If charger method takes power from a single AC source, Level I and II chargers are considered to be slow. Allowing a charger to take power from several AC and/or DC sources is another method to make it quicker.

Despite the fact that lithium-metal batteries have a greater capacity than existing Li-ion batteries; their stability is a major concern due to the electrode materials' reactions with common electrolyte systems, to overcome that Nickel emerges as the answer as it is suitable material for cathodes. The high nickel concentration, on the other hand, brings with it additional problems like poor cycling and thermal instability. Despite the disadvantages of Ni-rich cathodes, much work has gone into developing materials that offer the perfect combination of high specific capacity and high safety features that the industry demands. To increase the structural stability of the cathodes, magnesium, calcium, aluminum, and titanium are lattice doped into the transition metal layer to limit oxygen escape and improve thermal stability.

Autonomous driving is anticipated to transform road traffic by reducing existing externalities such as accidents and traffic congestion. Autonomous driving has been a long-term project for carmakers, academics, and government agencies, and considerable progress has been achieved. However, there are still many uncertainties and difficulties to solve, since the deployment of an autonomous driving environment involves not only sophisticated automotive technology, but also human behavior, ethics, traffic management techniques, laws, liabilities, and other factors. As a result, automakers do not plan to commercialize completely autonomous cars anytime soon. However, once autonomous cars are technologically viable, legal and ethical issues may hinder their use [25][26][27].Table 3 presents the energy storage specifications.

Table 3. Different energy storage specifications

STORAGE TECH	LIFETIME(CYCLES)	EFFICIENCY(%)
Lead acid Batteries	200-300	75
NaS batteries	2000-3000	89
Metal Air batteries	100-200	50
Li-Ion batteries	300-500	95
Flow battery	1500-2500	75-85
SuperCapacitor	10e4 – 10e5	93-98
FES	10e5 – 10e7	90

23. CONCLUSION

Wireless charging is a logical progression in the advancement of electric automobiles. It is a highly easy and effective technique of charging the battery and may be put at home, on the road, or in other areas where electric cars stop. The future of EVs and wireless charging technology will demonstrate the advantages of adopting these to us. The suggested charging strategy would save a lot of time and resources, and the energy loss can also be reduced with effective modern technology. Albeit it will take some time to make this technology efficient but we'll surely get there one day. At the same time, it is essential to remember that it should not hurt the environment or deplete resources.

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