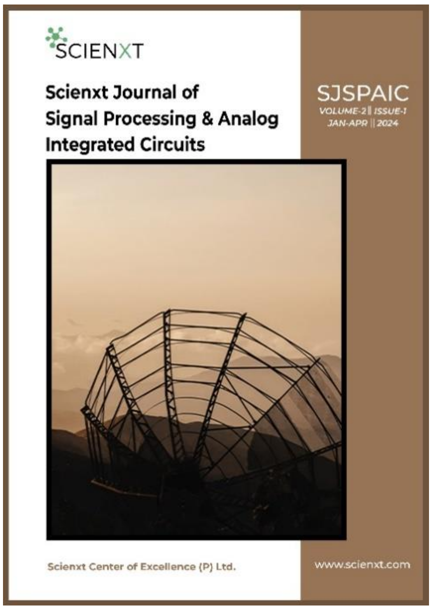

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Wireless bidirectional power system for electric vehicles - A review

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Abstract:

Wireless Electric Transfer (WET) is a cutting-edge technology that allows power to be transmitted without physical contact. Most power technology is being converted to wireless technology by various methods as technology advances. Even if electric vehicles and plug-in hybrids are relatively new and viable, it is insufficient to keep the power source unplugged a night befor e. When an electric car park in a designated parking area with a transmitter circuit in place, charging will begin automatically. The Inductively Coupled Power Transfer System (ICPT) was discovered to be an excellent way for charging electric automobiles wirelessly an fter a study of a few wireless charging systems (Electric Vehicles). Bidirectional IPT (Inductively Coupled Power Transfer System) presented in this paper is suitable for Vehicle to Grid (V2G) systems. For Electric Vehicle charging, this Bidirectional Wireless Power Transfer is a dependable, powerful, and effective technology. Wireless power approaches comprise two classes: non-radiative and radiative. The study will also improve the system's practicality, dependability, and efficiency.

Keywords:

Electric vehicles, inductively coupled power transfer, wireless power transfer, vehicle to grid.

1. Introduction:

Electric vehicles (EVs) are getting popular in the locomotive industry due to their lower energy use and superior performance over gasoline-powered vehicles [Metwly, M.Y. et al. 2020, Khaligh, A., and Dusmez, S. 2012, Yilmaz, M., and Krein, P. T. 2012, Ma, M., et al. 2017]. Many nations, including China, Canada, India, the United States (US), a few countries of Europe, have already implemented government incentive schemes to encourage the progress of electric vehicles [Khaligh, A., and D'Antonio, M. 2019],[Reimers, J. 2019]. The United States and Canada, for example, have enacted the Zero Emission Vehicle policy that gives financial incentives for the sole of ultra-low emission and zero-emission vehicles, as well as improvements to public EV charging infrastructure. China offers financial incentives for energy-efficient electric vehicles. India has likewise set an aim of producing completely electric vehicles by 2030. Being the largest car market in the European Union, Germany provides EVs with a 10-year tax dispensation and price allocation. To fulfill the large incoming energy demand and respond to the expanding demand for electric vehicles, it is conseque ntly required to build chargers and develop worldwide power infrastructure.

The onboard charger (OBC) allows electric vehicles to get charged directly from the AC grid, and it is largely utilized inlocomotive industries due to its benefit, particularly in comparison to the enormous volume of off-board charging systems and its high cost [Lee, I. O. 2015, Erb, D. C., et al. 2010, Lee, B. K., et al. 2017, Xiao, Y., et al. 2019]. Because of their low battery deterioration and inexpensive hardware requirements, unidirectional OBCs are popular [Uddin, K., et al. 2018]. The current state of electric vehicles, on the other hand, has proven its ability as a mobile energy source. By returning electrical energy to the grid, bidirectional OBCs enable Vehicle to Grid (V2G) capability, which may be useful whenever peak power is needed [Liu, Z., et al. 2016],[Semsar, S., et al. 2020].Furthermore, bidirectional On Board Chargers enable EV owners to utilize their vehicles for purposes like delivering V2H or V2L power during a grid outage or delivering V2V function during any emergency [Wei, C., et al. 2019, Nassary, M., et al. 2019,Taghizadeh, S., et al. 2020]. Bidirectional OBCs are widely forecasted in order to become the ruling charging solution in the near future [Fahem, K., et al. 2017], despite several limitations [Gould, C., et al. 2013], such as increased cost of the system, dependability, weight, complex smart grid architecture executionand low power density[Escoda, J., et al. 2013],[Lai, J. S., et al. 2015].

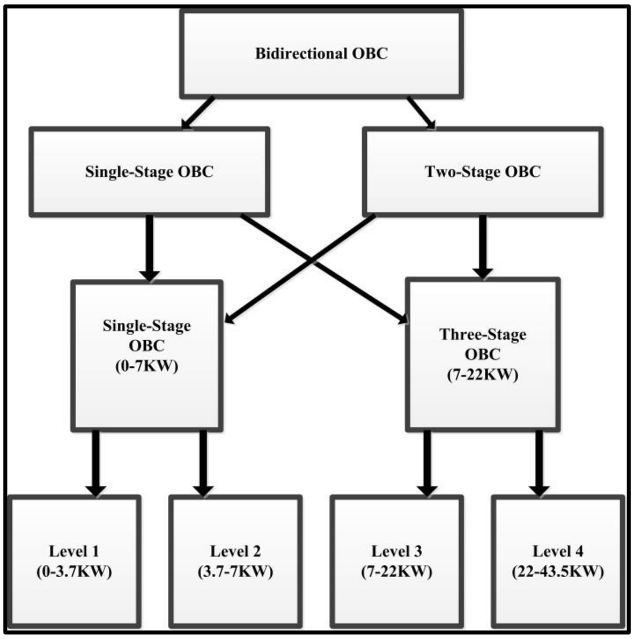


Figure. 1: Classification of bidirectional on board charger

Fig. 1 depicts the primary categorization of bidirectional On Board Chargers, which comprise single- stage On Board Chargers and two-stage On Board Chargers. Single-phase On board Chargers have a power range of 0-7kW, whereas three-phase OBCs have a power range of 7kW-22kW. The charging time relates inversely to the power level. Since faster charging times are in demand, bidirectional On Board Chargers of high power are highly anticipated inthe future. Although most of the single-phase topologies can generate upto 7kW, substantial switch stress must be avoided. Up to 22kW can be achieved using a three-phase OBC architecture. The specific topology may be chosen based on the desired charging time and the power rating. Currently, the bidirectional OBCs are mostly in need of level-2 AC charging, with a power range of 3.7kW-22kW. Because level-1 OBC is supposed to be less costly and of low power,it is inapplicable for transmissionbidirectionally. Level-3 AC charging, havinga power range of22kW-43.5kW, reduces the time of charging due to battery deterioration, but reverse power flow is often restricted from 6.6kW to 12kW [Phimphui, A., andSupatti, U. 2019], [Kisacikoglu, M. C., et al. 2011].However, broad ranges of input and output voltage are necessary to fulfill global charging standards and charge batteries of large voltagesrated 800Vapprox . Bidirectional OBCs piqued the curiosity of a number of manufacturers. For instance, Nissan has grown V2H functionality for its 2013 Leaf model. Every future Leaf vehicle will be V2G efficient. Tesla and BYD Tang, a Chinese electric vehicle manufacturer, created the V2L and V2V features in 2019. Bidirectional OBCs were also developed by Honda and BMW.By 2020, most OBCs will be able to reach power levels of 6 to 10 kW, with some, for example, the Renault Zoe, reaching 22kW.

Furthermore, the OBC's power density is currently 3.3 kW/L, and its greatest efficiency is projected to be over 97 percent. The US Drive OBC objective for 2025 is shown in Table. 1 [Electrical and Electronics Technical Team Roadmap, 2017]. The OBCs power density and specific power are approximated to be 4.6 kW/L and 4 kW/kg, respectively, with 98 percent peak efficiency, according to the data.

Table. 1: The US drive OBC circuits

OBC Target	***PFC***	***DC/DC***	***OBC***
Specific Power (kW/kg)	4	4	4
Power Density (kW/L)	4.6	4.6	4.6
Efficiency (%)	>99	>98	98

Owing to the hike in the fame of Electric Vehicles, more safety measures and operations for on board chargers are necessary. Table. 2 reveals the categorization and future opportunities of common standards.

Table. 2: OBC Standards

Classification	**Standards References**	**Scopes**
Power Quality Standards	IEEE-519 SAE J2894 IEC 61000 GB/T 14549	Required for stable harmonics limitation for currentand voltage Power quality required for chargers of plug-in EVs in US (THD<10%) Required for power supplies in Europe (THD<8% for medium and low voltage) China's harmonics standards for power supplies (THD<5% for low vol tage)
V2G Standards	IEEE 1547 UL 1741	Interconnection standards for grid and dispersed energy resources. Compared to UL1741, IEEE 1547 includes tests for voltage imbalance, frequency saltation and phase angle
Safety Standards	UL 2202 IEC 60950 ISO 6469	Needed for safety reasons for charging s ys tems of EVs which is supplied by a branch ci rcuit of up to 600V for recharging the battery Required for safety purposes of technology equipment for a voltage rating less than 600V Required for safety purposes for personal safety and Electric Vehicle storage s ys tem

OBC Connector Standards	CCSI SAE JI772 IEC62196 GB/T 20234	North America standard : up to 240V AC and 16/80A AC European standard : up to 500V AC and 32/63A AC Chinese standard : up to 440V and 32A AC

2. Wireless power transmission:

WPT is a broad word that mentions varieties of technical aspects of energy transfer using electromagnetic fields. The WPT is based on ICPT mechanization that carries electrical energy from power sources to loads without wires, giving it more flexibility, precision, and safety. It is a technique that uses magnetic coupling to transmit power without wires. Hence, the transmission distance must be significant for WPT technology to be widely applied in industrial and everyday applications [Wikipedia contributors, Wikipedia]. Increases in the cost of petroleum and charging through wire result in power dissipation losses and the risk of electric shock. As a result, WPT is more efficient in a variety of ways. The WPT system uses the high-power transfer factor to perform active charging in different functions, such as EVs. Current research is mostly focused on low-cost, easy and dependable electric vehicle charging [Li, S., and Mi, C. C. 2014].

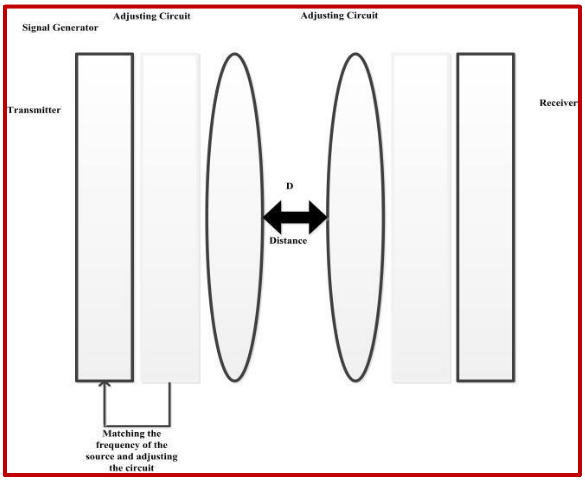
IPT is a method of transferring electricity without making anybody contact. It is a technology that uses inductive coupling to transmit power wirelessly, providing trustability, cheap cost, clarity, and safety. According to the literature, numerous IPT systems have used various EV circuit topologies. However, this technology is incompatible with V2G applications requiring bidirectional power transfer to charge electric vehicles. Therefore, abidirectional IPT system has been put forward in [Madawala, U. K., andThrimawithana, D. J. 2011]. An effective solution for charging electric cars is a bidirectional WPT system ["Join the element14 Community, for Online Electronic Resources and Support", 2018].According to WPT's EV technology, a voltage thata closed loop conductor induces is directly proportionate to the change in flux rateencompassed by the loop. A similar idea applies to transformers,where the primary and secondary sides are parted, one side being on the ground while another on vehicle underpart. Based onprior surveys ["laser power beaming fact sheet," 2018], the paper proposes an IPT system for bidirectional Electric Vehicle charging.

The MIT researcher devised a system that employs two 5-turn copper coils to wirelessly light a 60W light bulb at a distance of 60cm, with 45 percentefficiency. Both coils will be oriented in the same direction and resonate at 9.9 MHz.One wire is attached to the light bulb, while the other i s connected to the power supply inductively [Kurs, A., et al. 2007]. To overcome magnetic losses, [Fnato, H., et al. 2010] recommend power distribution without the use of wires with capacitive coupling for imprecise connections.This work presents a wireless distribution of power based on capacitive coupling, which is excited by multi-stage switch mode exciting power to increase the available power. A microwave power beaming system was developed for delivering wireless power to Micro Aerial Vehicles in [Javadi, S., and Mohamedi, A. 2013]. A system for transmitting, receiving, and tracking data is included in the design. The transmitting system's antenna transmits a microwave beam at a frequency of 5.8 MHz.The delivered wireless power was 4 W, with a 9? Divergence angle. [Wang, N., et al. 2011] discusses a sophisticated method for supplying changing power multimode wireless sensor networks using lasers. When the laser is converted to a spatial light field having discrete-continuous phosphor elements in a wireless sensor network, the length of the wire of the solar cell is adjusted. Several scientists, including the eminent Nikola Tesla, sought to transport electricity wirelessly in the past, pursuedHenrich Hertz's work, who during the experiment concentrated on the distance of electromagnetic radiation. Tesla talked about many experiments he has done with a high-frequency oscillator in medicinal applications in his book [Tesla, N. 2015]. A group of MIT scientists drew worldwide concentration by giving power to a bulb of 60 wattsfloating in space 2 meters from the transmitting coils [Hui, S. R. 2016].

Heinrich Hertz's experiments, in which he transmitted high-frequency power using parabolic reflectors, are credited as the first effort at wireless power transmission [Everson, J. H. 1996]. Nicola Tesla presented the concept of wireless power in a broader sense in the 18th and 19th centuries. He transported electrical power using magnetic resonance technologies. Tesla also invented the "Electrostatic Method," often known as Capacitive Coupling [Kelley, A. W., and Owens, W. R. 1989], a wireless energy transmission demonstration. $S = \frac{d_2}{4\lambda}$ Where d_2 is the antenna's length or diameter, and λ is the wavelength. Near field,approaches include magnetic and electrostatic coupling, while distant field methods include a microwave and laser [Kesler, M. 2013].

2.1. Magnetic resonance:

In Wireless Power Transfer System, we use two coils, respectively operating as transmitter and receiver, each of which is coupled with a capacitor and has a mutual inductance effect. The supply is connected to one coil, while the loadis to another. An alternating current in the transmitter coil produces an alternating flux of the same frequency as the resonance frequency



of the receiver circuit. Fig. 2 depicts the magnetic resonance circuit as complete.

Figure. 2: The outline of the Magnetic Resonance system

2.2. Capacitive coupling power transmission:

Electric power transfer, which takes place by a dielectric, is known as capacitive coupling. Two electrodes, cathode, and anode, are used to transfer power capacitance. Electric fields are used to transport power between metal surfaces. An electric field is produced due to charging two plates with an AC source having high voltage. The transmitting plate receives an AC voltage from the transmitter. The reception plate receives an AC voltage via electrostatic induction, including an AC in the load [Aditya, K. 2016]. The operation of capacitive coupling is seen in Fig. 3.

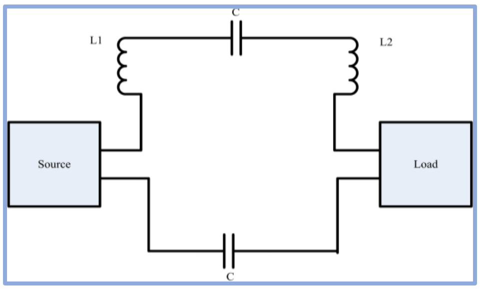


Figure. 3: Capacitive coupling

2.3. Microwave power transmission:

William C Brown, who invented Wireless Power Transfer technology, illustrated how microwaves might deliver power. In block diagram form, Fig. 4 depicts the concept of WPT in a microwave:

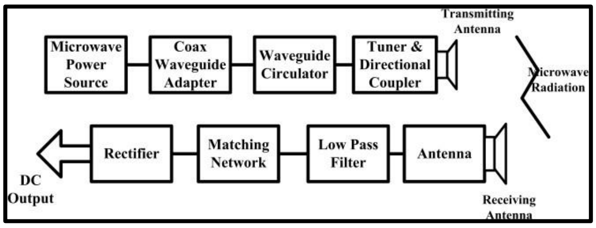


Figure. 4: Block diagram

The block diagram is divided into two sections: transmitting and receiving. The electronic control circuit controls the microwave power generated by the microwave power source. The waveguide circulator protects the mirrored power supply linked to the coax waveguide adaptor. The tuner opposed the impedance between the transmitting antenna and the microwave source. The directional coupler divides the attenuated signals based on the signal propagation direction. Power is transferred from the sending antenna to the receiving antenna via free space. The antenna's receiver receives the microwave guide's power, which converts it to DC. To preserve the output impedance circuit uses a filter and has the same impedance as the rectifying circuit. In addition, it has Scotty barriers diode, which converts power from AC to DC.

2.4. Laser power transmission:

Laser power beaming involves wireless power transfer from one point to the other with the help of laser light. The basic concept is similar to that of a solar power system, where light rays strike a Photo Voltaic cell, which changes the solar energy to electrical energy; however, with Laser Power Beaming, laser light is transformed into energy by a PV cell. "Power may be transported by air, space, or optical fibers, similar to how communication signals are conveyed now, and it could reach as far as the moon." Fig. 5 depicts a simplified view of the laser approach.

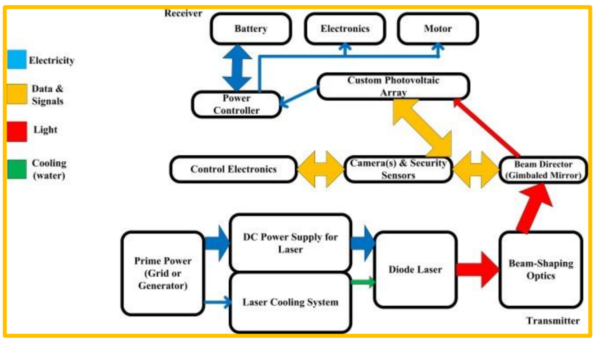


Figure. 5: Flowchart of the laser power beaming method

3. Methodology:

The primary side of the resonant coil is paired with the secondary side in this ICPT approach. The primary resonator boosts the primary coil current while also increasing magnetic flux. In theory, a ring will be formed from a distant magnetic field if some energy is given to a capacitive load. The resonant circuit is a fundamental component of a wireless energy transfer system. As shown in Fig. 6, a generic circuit comprises Resistance, Inductance, and Capacitance in a series or parallel combination.

In electric circuits, the frequency interval surrounding energy oscillates. The inductor stores capacitive and magnetic energy, while the resistor dissipates energy. The WPT system comprises magnetically coupled main and secondary coils, rectifiers, inverters, and compensating circuits. Components are depicted in Fig. 7 shown below as well asthe conversion of grid-to-load power conversion.

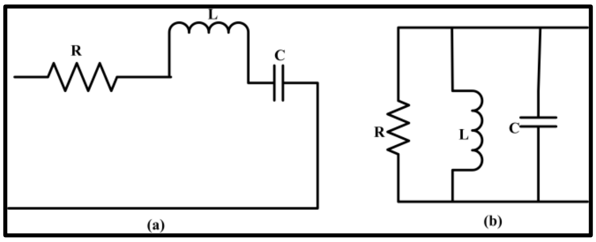


Figure. 6: (a) series RLC circuit (b) parallel RLC circuit

A converter converts AC to DC power, which gets transformed into AC power of high frequency. Due to its high frequency, alternating current in the primary side produces a fluctuating magnetic field, which induces an alternating voltage in the secondary. The rectified AC of high frequency is utilized for charging batteries [Chand, J., 2018].

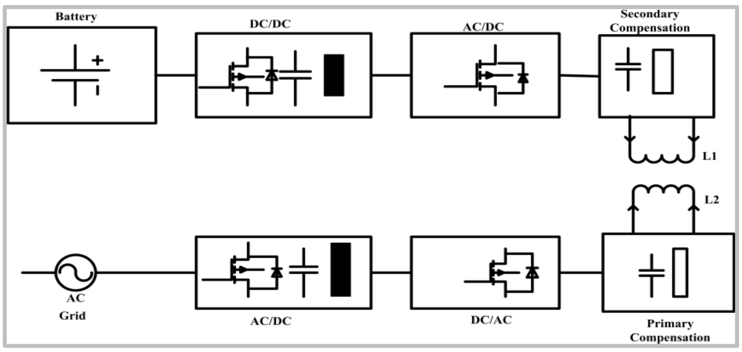


Figure. 7: General WPT block diagram

The resonant WPT system consists of primary and secondary coils coupled magnetically, power electronic converters (rectifiers and inverters), and compensating circuits. The components and power electronics conversion fromthe grid to load are shown in Figure 7. At firstthe input AC utility power getsconverted to DC, which gets converted to AC power again having high frequency by an inverter. An alternating magnetic field produced by the high-frequency AC current in the primaryinduces an alternating voltage in the secondary. The efficiency and the power transferred are greatly enhanced by resonating with the compensating circuits. Finally, the AC power of high frequency received by the secondary coil gets rectified to DC for charging the electric car batteries.

3.1. Quality factor and bandwidth:

The electric and magnetic fields are determined by the currents and charges stored in the RLC circuit. Also, energy loss occurs in the form of ohmic and radioactive losses as well. The Quality factor, also known as Q - factor, is determined by

$$Q = \omega_r \frac{W}{P} = \pi \frac{electrical\ and\ mechanical\ energy\ stored}{dissipated\ energy\ during\ one\ period}$$

Where, ω_r is the resonant frequency, P is the resistive power loss and W is the total amount of energy stored in electric and magnetic fields. Value of Q - factor defines the amount of power stored compared to the energy dissipated. For ω_r,, the Q - factor can be expressed as,

The bandwidth of a resonant circuit is

$$BrW = \frac{\omega r}{Q}$$

4. Operating Modes:

4.1. Unidirectional Mode (G2V):

Fig. 8 depicts a dc block that provides power to the circuit. The voltage provided to the inverter having high frequencyis 12 V. Initially, switch 1 is generally closed and connected to a coil 1 compensator. A second switch, switch 2, is attached here, and it remains open in a unidirectional fashion. Coil 1 starts getting energized and produces flux induced in coil 2. The secondary compensator starts working once coil 2 is powered on and absorbs coil 2. In unidirectional, switch 5 connected to the compensator remains typically open. After that, switch 3 is used, which remains closed in unidirectional mode.

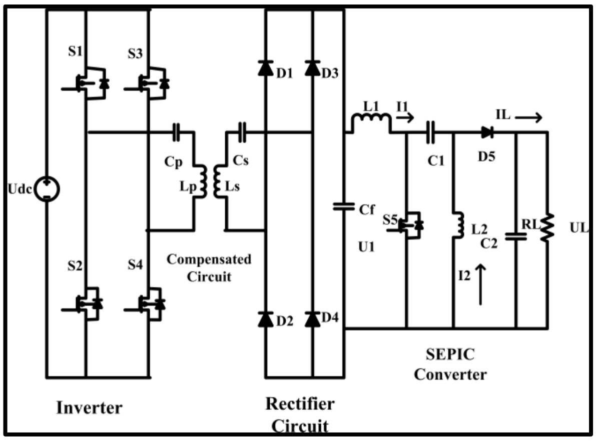


Figure. 8: Basic working principle of unidirectional wireless power transfer

4.2. Bidirectional Mode (V2G):

The bidirectional mode wireless power transfer is shown in Figure 8. Some switches must be disconnected to acquire voltage from this system. Firstly, the DC source is turned off, and switches 1 and 3 are kept open. Now the, switch 4 is closed. As a result, the voltage begins to flow towards the other side's high-frequency inverter connected to switch 4. Switches 2 and 5 remain in the closed position. Switch 5 is connected to the compensator, which begins to operate, and the voltage begins to blow towards coil 2. Coil 2 becomes energized, causing a magnetic flux to be induced in coil 1. Coil 1 energizes and voltages are produced. The produced output voltages are sent to the compensator by making switch 2 open. This is how bidirectional output is achieved.

The bold arrows in Fig. 9 stand for the bidirectional process, and the thin arrows stand for a unidirectional process for resonant inductive power transfer.

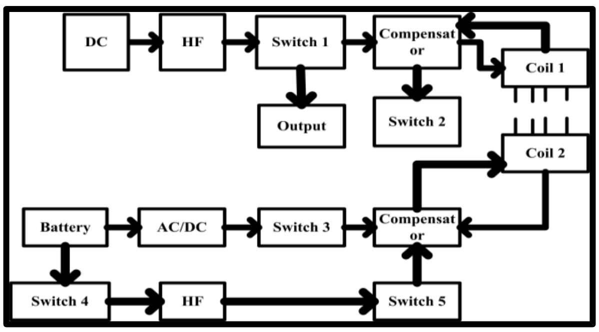


Figure. 9: Basic Working Principle of Bidirectional WPT [Moradewicz, A. J., andKazmierkowski, M. P. 2010]

4.3. Designing of coil:

Based on the design, three parameters comprise the core of WPT:

- CoilDesign

- TopologySelection
- Compensator Design

Designing the coil is the most important part. The followings should be kept in mind during the designing of the coil

- Material of the coil
- Selection of the coil size
- Type of winding
- Selection of magnetic sheet

The material of the coil is very important. Winding is done with pure copper wires. The size of the copper wire is also very important. It consists of internal resistance, wire thickness, current carrying capacity, width etc. Copper wire is also used for getting higher efficiency. Length of the wire depends upon of conditions of current and voltage.

Winding copper wire on aluminum sheet further increases efficiency by producing a strong magnetic field.An aluminum sheet protectsthe coil from heating up by absorbing the heat resulting in an increase in the strength ofmagnetic field [Bosshard, R., et al. 2012]. The compensator is highly essential since it hasa crucial role to play. There are varieties of topologies utilized for wireless power compensation design worldwide, depending on the requirement and need. The four main topologies are as follows:

- Series Series Topology (SS)
- Series Parallel Topology (SP)
- Parallel Series Topology (PS)
- Parallel Parallel Topology (PP)

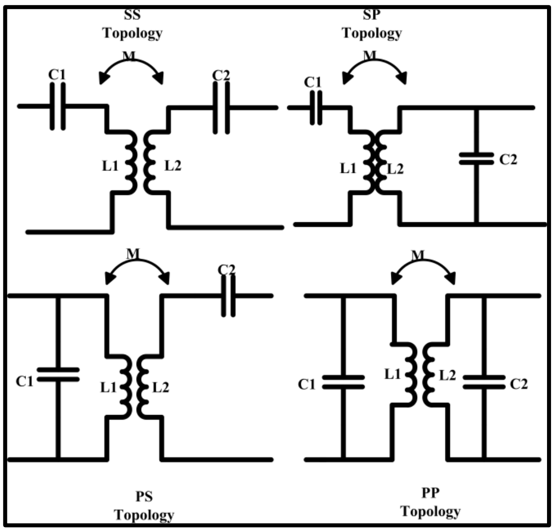


Figure. 10: Compensator Topologies [Aditya, K., and Williamson, S. S. 2014]

4.4. Comparisons of different bidirectional DC topologies:

Table. 3: Bidirectional DC DC Topologies

DC/DC Topology	***LLC***	***DAB***	***CLLC***	***Three-phase CLLC***
Input Voltage (V)	495-910	695-805	375-835	805
Output Voltage (V)	245-440	390-510	245-470	405
Switching Frequency (kHz)	90-148	100	200-1245	499
Power Density (kW/L)	-	1.9	7.5	9.5
Power Level (kW)	9.5	9.5	6.58	12.46
Efficiency (%)	99	99	98	>97.5
Switching Devi ces	Si C	Sic	Si C/GaN	Si C/GaN

5. Conclusions:

This document includes full pictures of a bidirectional wireless power system and its working modes and design. Wireless transmission can be done in a variety of ways. Inductive power transmission is the most appropriate method for electric vehicles. However,EVs must be paired with the appropriate charging infrastructure for the Smart Grid to function properly. In this regard, wireless chargers, which offer practical benefits for autonomous operation, should be used to enable EVs to provide supplementary services. The power flow of active and reactive power should be managed, and the control algorithms should be correctly constructed to achieve this purpose.

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