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DC-DC vs. AC-AC Wireless Power Transfer Systems for Electric Vehicles

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Abstract: ***Electric vehicles are becoming increasingly popular as consumers seek out realistic ways to reduce their environmental footprint. New energy production technologies are urgently needed as the world's resources become ever more depleted. As a result, WPT offers a convenient, low-cost, and noiseless way to power up. Between twenty and thirty percent of transmission losses may originate from cables. Therefore, WPT strives to reduce the waste and pollution caused by the current methods of resource utilization. In this work, we compare and contrast dc-dc converters with ac-ac converters, the two most popular types of converters used in WPT systems for electric vehicles. Both converters have their benefits and drawbacks. In this piece, we compared different converters for charging EVs to determine the best one for the job. One way to lessen the load of inverter-side harmonics and coupling mechanism limits is to use a dc-dc converter. A high-frequency current generator using a direct ac-ac conversion for use in inductive power transfer (IPT). The suggested converter may generate high-frequency current from an ac power source without the need for a dc link, unlike conventional dc-ac converters***

Keywords: Electric vehicle (EV), DC-DC Converter, AC-AC Converter, Inductive Wireless Power Transfer (IWPT)

1. Introduction

Wireless charging provides numerous benefits over cable charging [1], including no risk of sparks or electric shock, no dust accumulation or contact loss, no mechanical wear, no maintenance challenges, and the ability to withstand adverse weather conditions including rain and snow. In addition to these benefits, charging electric vehicles with WPT can reduce the need for parking, save money on labor, and not negatively affect traffic flow. [2]. The WPT technology used in EVs can switch between using ac-ac and dc-dc converters. In this article, we'll be discussing both converters at length.

Power converters are required in IPT systems because the primary current must be generated at a high frequency. Power is often converted in a two-stage process, from 50/60 Hz mains to high frequency using ac-dc-ac technology. Therefore, there must be a first stage consisting of an ac-dc rectifier. The dc capacitor helps smooth out voltage fluctuations, and the ac-dc step is straightforward to put up. Costing more and taking up more space, adding more dc-link capacitors and semiconductor switches can reduce system reliability while increasing power losses and electromagnetic interference. [3].

When acquiring high-frequency power, a direct ac-ac converter can be used instead of a dc connection or bulky energy-storage components [4]. Matrix converters are commonly used nowadays to convert DC input power into AC.

Consumers want electric vehicles (EVs) with the lowest possible price and the highest possible efficiency within a reasonable price range. In Section 2, we break out the WPT in great detail. And EV WPT benefits from inductive WPT technology. The numerous converters found in EVs are discussed in detail in Section 3. In Sections 4 and 5, we learned about dc-dc converters and ac-ac converters, and in Section 6, we read about the differences between the two. There will be a lengthy analysis followed by a summary

2. Detailing of WPT System

Compared to wired charging, wireless charging is more convenient, safe, and reliable. It also eliminates the risks of sparking and shock from electricity, accumulation of dust, interaction loss, physical wear, repair problems, and wet and snowy environments. Fig.1 is a schematic depicting the core components of a wireless charging system for EVs. [6]

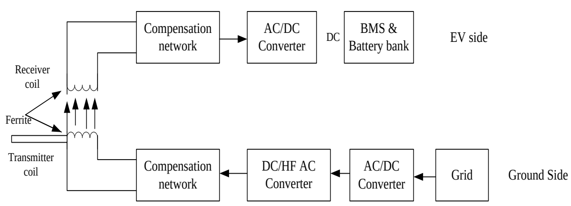

Figure 1: Main Block diagram for wireless charging Electric car

2.1 Types of WPT Systems

Figure 2 depicts the wide variety of WPT Systems available. It's power transmission in the near-field, from a few hertz to a few gigahertz. Both inductive and capacitive coupling are included.

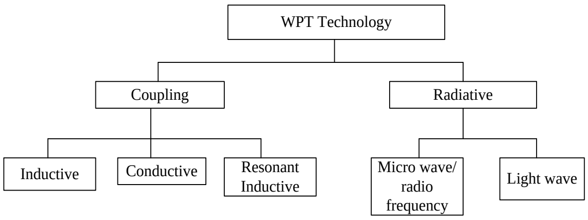

Figure 2: Types of WPT system

Both inductive power transfer (IPT) and resonant capacitive coupled power transfer (CCPT) are viable options for charging electric automobiles. Resonant (IPT) is typically employed in higher power applications, such as charging the batteries of electric vehicles. Both static and dynamic wireless charging benefit from resonant IPT's efficiency. Power transfer is best accomplished via inductive wireless transmission.

2.2 Inductive WPT

The electromagnetic field is useful in explaining the IWPT system. The IWPT system performs like conventional transformers. In an alternating current (ac), a magnetic field is created around a conductor (primary side coupler) in accordance with Ampere's law. The primary magnetic coupling is linked to the magnetic coupler on the other end, producing a field of magnets that varies with time.

When a voltage is produced across the secondary coil as a result of the connected field, Faraday's law is demonstrated. Figure 3 is a block diagram of the IWPT system. A rectifier was used to convert the induced voltage to a DC power signal. This energy can be used to recharge the battery [7]. By matching the frequency of the secondary coil to the operational frequency, system performance is enhanced. With radio frequency technology, the air gap restriction can be pushed to as much as 20 cm, however at the expense of efficiency [8].

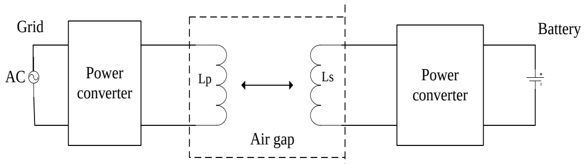

Figure 3: Inductive WPT Illustration

The power and maximum efficiency of IWPT can be derived as, True power transfer can be presented as,

$$P_{ps} = \omega M\, I_p I_s \sin\varphi ps \qquad (1)$$

Active power transfers among the two coils are depicted in Fig.3. The subsequent study will take into account the power of Lp to Ls. There has been a transfer. Whenever the current via Lp to Ls is at its highest. Eqn illustrates the sum of the reactive power fluxes among two coils. (2)

$$\varphi ps = \frac{\pi}{2}$$

$$Q = \omega\left(L_p I_p^{\,2} + L_s I_s^{\,2} + 2M I_p I_s \cos\varphi ps\right) \qquad (2)$$

The maximum efficiency is described below as shown in eq 3 and eq 4

$$f(\varphi ps) = \frac{|P_{ps}|}{Q}\left|\frac{\omega M I_p I_s \sin\varphi ps}{\omega\left(L_p I_p^{\,2} + L_s I_s^{\,2} + 2M I_p I_s \cos\varphi ps\right)}\right| \qquad (3)$$

The Maximum efficiency can be defined by the formula,

$$\eta_{\max} = \frac{k^2 Q_1 Q_2}{\left(1+\sqrt{1+k^2 Q_1 Q_2}\right)^2} \qquad (4)$$

Where quality factors is given by in Eqn. (5)

$$Q_1 = \frac{\omega L_p}{R_p} \;\&\; Q_2 = \frac{\omega L_S}{R_S} \qquad (5)$$

3. Sophisticated Electric Vehicle Converters

An EV major load, the three-phase electric motor, is driven by a three-phase inverter that receives power from the HVDC bus. Separate dc-dc converters [9] link all of the power the inputs to the HVDC bus. In this case, the EV's HV-DC bus has a voltage of 400–750 V. Furthermore, a dc-dc voltage is required to propel the EV via an EM, as the voltage that is results by the battery pack is significantly lower compared to the voltage required by the EM [10]. To propel the EM by converting the DC batteries into variable-frequency AC, a traction inverter is required. A case could be made against raising the output AC voltage level, nevertheless. A case might be made against using a high-voltage transformer in place of a dc-dc converter to increase the inverter's output AC voltage level. DC-DC converters appear to be excellent choices for EV and HEV transmissions owing to their reliability, cost-effectiveness, small dimensions & lightweight nature. The dc-dc converter and the DC-AC inverters constitute two of the most important electronic power supplies in the whole setup.

AC motors are frequently employed for providing traction in HEVs and EVs; these motors are supplied power via an inverter, which is afterwards supplied power by a dc-dc converter. Both unidirectional & bidirectional converters that convert DC to DC are utilized in EVs. Sensors, which are controls, entertainment, utilities, and safety devices, are only some of the loads that can be supplied by unidirectional dc-dc converters [9]. Additional uses include DC motor drives, and electrically powered traction. Bidirectional DC-DC converters are required for the use of regenerative braking, power emergencies, & charging batteries. Whenever energy is transferred from a low-voltage source (such a battery or super capacitor) to a high-voltage load, this process is known as "boosting" [13]. During regenerative braking, energy is returned to the battery (buck mode) from the low-voltage bus [11]. [12]. When the vehicle's internal combustion engine (ICE) or electric drive (ED) fails to power the motor, the bidirectional dc-dc converter steps in to keep everything running smoothly and safely. High-power bidirectional DC-DC converters are growing increasingly important for those mentioned considerations. Several types of converter topologies include:

Sr. no.	Converter topologies	Details
1	Buck Converter	For a given dc input voltage, the step-down buck converter will produce a typical output voltage which is smaller.
2	Boost converter	It is impossible for the output voltage of a boost converter to be lower than its input voltage.
3	Buck-Boost converter	A buck-boost converter's voltage output might be greater than or less than the voltage that is input.
4	Cuk converter	There are advantages (such as a continuous current, less current ripple, etc.) to having a higher or lower output voltage than with a buck-boost converter.
5	SEPIC converter	There is no direction reversal like in a Buck-boost or Cuk converter, but the voltage produced might be either greater or lesser than the voltage that is input.

4. DC-DC Converter

The primary function of a dc-dc converter is to transform input power into output power suitable for the load. If it can transform voltage into current, it might be used to charge batteries. The dc-dc converter has impedance-changing capabilities [9]. A dc-dc conversion is typically used when charging the power source of an EV to guarantee dependable and safe functioning.

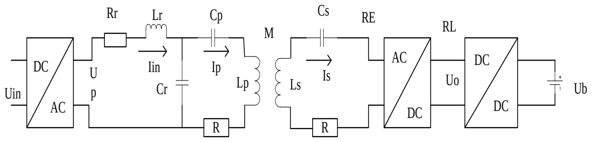

Figure 4: EV Wireless Charger

Figure 4 depicts the internal workings of a wireless charging station for EVs. Using Eq.7, we can determine the system's voltage profit by determining the ratio of the voltage that is generated to the voltage input.

$$G_V = \left|\frac{U_S}{U_p}\right| = \frac{\omega^2 ML_r \dfrac{R_{eq}}{R_S + R_{eq}}}{R_{Lr}\left[\dfrac{(\omega M)^2}{R_S + R_{eq}} + R_P\right] + (\omega L_r)^2} \quad (7)$$

It is possible to determine the result of the inverter's current by,

$$I_{in} \approx \frac{M^2 U_p{}^2}{L_r{}^2 R_E} \quad (8)$$

Inverter output current total amount of harmonics is stated as

$$\sum_{n=3}^{\infty} -\frac{4U_{in}}{\pi}\frac{\cos(n\omega t)}{(n^2-1)\omega L_r} \quad (9)$$

$$= -\frac{U_{in}}{\pi\omega L_r}\left[\cos(\omega t) + (2\omega t - (2k+1)\pi)\sin(\omega t)\right] \quad (10)$$

$$\omega t \in (k\pi (k+1)\pi) k = 0, \pm 1, \pm 2, ...$$

The only things that can influence the harmonic content of an inverter's output are indeed the DC voltage source, the operating frequency, and the compensating inductance [14]. In other words, the inverter transfer efficiency can be improved and electromagnetic interference reduced by maximizing the calculation of the compensatory inductance value during the process of system design [15]. Equations (9) and (10) represent the harmonics produced by the dc-dc converter.

5. AC-AC Converter

A novel ac-to-ac WPT technique is introduced for EV charging applications, which helps to reduce both expenses and architectural intricacy. Via superimposing a high-frequency switching signal by wireless coils, an ac/ac converter may directly transmit a 60 Hz grid frequency ac input to the load [16]. The power converter can be able to keep its high-frequency resonance through the use of discrete energy injection control and natural circuit oscillation. High-frequency current function combined zero-current switching has been preserved through the development of a variable-frequency controlling scheme [17]. It decreases a converter's vulnerability to switching stress, power losses, & electromagnetic interference. In Fig.5 is the AC converter structure in its configured state. Controlled energy injection from the demand side is used in a direct ac/ac converter to produce high-frequency current on the main circuit of a WPT generator [18].

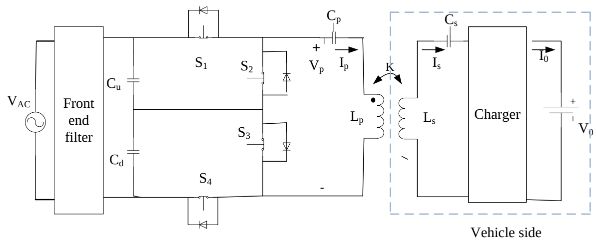

Figure 5: The ac/ac converter topology

The magnetizing impedance, ZM, is defined in terms of the connected inductors, j, through the equation ZM=jLM. The value of = 2fsw in each of these equations denotes the switching frequency of fsw. Depending on the basic grid voltage sign of the basic grid voltage at frequency f60, the sinusoidal input voltage Vi given in Eq 11 is either positive or negative

$$V_i = \{V_{i,\max} \sin(2\pi f_{60}), 0 < \omega, 2\pi$$
$$\{-V_{i,\max} \sin(2\pi f_{60}), \pi < \omega, 2\pi \quad (11)$$

Using Kirchhoff's voltage law, the voltage of each of the primary and secondary resonance conditions can be written in matrix form as shown in Eqn. (12).

$$\begin{bmatrix} V_i \\ 0 \end{bmatrix} = \begin{bmatrix} Z_P Z_M & -Z_M \\ -Z_M & Z_M + Z_S + R_L \end{bmatrix} \begin{bmatrix} I_P \\ I_S \end{bmatrix} \quad (12)$$

Operating the system at its resonant frequency, ωRas where $\omega_R = 1/\sqrt{L_P C_P} = 1/\sqrt{L_S C_S}$ Eqn (13) & Eqn. (14) represent the voltage and current transfer functions of the WPT structure, respectively.

$$|M_V| = \left|\frac{V_o}{V_i}\right| = \left|\frac{Z_P}{R_L} + \frac{Z_S(Z_P + Z_M)}{R_L + Z_M} + \frac{Z_P + Z_M}{Z_M}\right| \quad (13)$$

$$|M_I| = \left|\frac{I_S}{I_P}\right| = \left|\frac{Z_M}{Z_M + Z_S + R_L}\right| \quad (14)$$

6. Analogy amongst both Converters for EV

In light of whatever has been said above, let may draw an analogy amongst the methods used by a DC-DC converter and AC-AC converter

Parameters	DC-DC converter	AC-AC converter
Cost and Design	Since it only requires a single switch and a single diode, dc-dc is both inexpensive and easy to build.	The ac-ac conversion helps cut costs and simplify designs.
Implement	Power transformation, from the power input to load-specific output power, being the principal purpose of a dc-dc conversion. a direct ac/ac conversion which regulates energy input to the load to generate high-frequency current on the main circuit of a WPT systems.	Absent a dc link or cumbersome power-storage devices, a direct ac-ac conversion is a viable option for getting high-frequency power.
Harmonics	Larger harmonics are present in the ac-ac conversion used in EVs as opposed to the dc-dc converters.	A dc-dc conversion for EVs has fewer harmonic than an AC-AC converter.
Advantage	If you want to keep your load at its optimal level while still getting the right amount of power to it from your primary inverter, you can do so with the help of the ac-ac impedance conversion function.	Constant frequency operation of an AC converter is possible without the need for closed-loop control or additional converter stages. A direct ac-ac conversion is able to preserve circuit resonant and control the current's amplitude throughout the controlled phase with a lower frequency of switching and rather better waveforms. The converter also performs well in steady-state conditions and responds dynamically and extremely quickly

7. Conclusion

The inductive wireless power transmission system was studied as a result of the talks above. Moreover, descriptions of various ac and dc converter types are provided. So, it is examined which converters are useful for electric car wireless power transfer systems. The cost, efficiency, harmonic distortions, benefits, and drawbacks are used to compare the dc-dc converter with ac-ac converter. Because dc-dc converters emit fewer harmonics than ac-ac converters, we conclude that they are better suitable for WPT for EV.

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