International Journal on Advances in Engineering Technology and Science
Volume: 5, Issue: 2, 2024, e-ISSN: 2455-3131
DOI: 10.5281/zenodo.12597757

Analysis of Parallel-Series Compensation Circuit for Wireless Power Transfer of Electric Vehicle Charging Based on Resonant

Aaradhna Soni[1], Dr Shruti Dixit[2], Nividita Singh[3]

[1, 3]Assistant Professor, [2]Associate Professor
Sanjeev Agrawal Global Educational (SAGE) University, Bhopal

***Abstract*— Resonant wireless power transfer is a way of transferring electricity that does not require a wire to connect the transmitting and receiving coils. A power electronics converter is present on both sides. On the transmitting side, a cascaded single phase full bridge inverter is connected to a resonant wireless power transfer circuit, which is fed through the grid and connected to a power factor correction rectifier to boost power factor or make up for reactive power in order to lower the amount of input VA required. A resonant wireless power transfer operates on the resonance principle, in which maximum power is sent wirelessly to the receiving side. A parallel series connection is employed in this resonant WPT circuit, one of four topologies based on how capacitance is connected: either in series or in parallel. When high power charging is needed, a resonant power transfer circuit is employed because it can send power over longer distances than inductive power transfer. The quality factors of the transmitting and receiving sides as well as the effective coupling factor of the coil all affect Resonant WPT's efficiency.**

***Index Terms*— Electric vehicles, High-frequency single phase full bridge inverter, inductive charging, Magnetic resonance, Power factor correction (PFC) rectifier, Resonant wireless power transfer (WPT).**

I. INTRODUCTION

The resonant WPT method is used to transfer power with the help of magnetic resonance without any physical contact. Series–series topologies are used earlier [1-3]. In nations like India, the cost of fuels has been steadily rising due to the ongoing depletion of fossil fuels, which has had a significant influence on the economy.

As a result, the necessity for an electric vehicle is recognized in many nations, and the focus is placed on the electrification of cars as the sale of obsolete internal combustion engine vehicles declines with time. Most WPT systems are investigated of a single-phase type [4-5].

The resonance phenomenon will have a high-quality factor and high effective coupling factor as compared to inductive power transfer. The battery must be recharged for at least 4-6 hours after it has been used up, regardless of its cost or usable lifetime. Hence, the concept of wireless electric power transfer while the electric car is running along the route and is being charged. By creating a wireless power transfer system that is modular in nature and installed along the route that an electric car runs.

II. BLOCK DIAGRAM OF WIRELESS POWER TRANSFER CIRCUIT

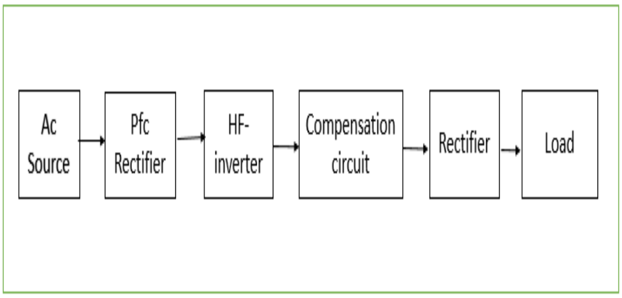


Fig.1- Complete set of WPT system

The above diagram shows to transfer of the power without having physical contact [6]. As the AC supply is fed from the grid in transmitting side that is fixed inside the road, a power factor correction rectifier is used to compensate reactive power and converted into DC voltage. And where it is provided to a high-frequency single phase full bridge inverter that converts into AC voltage. Therefore obtained AC voltage is given to the resonant wireless power transfer circuit and after that single phase Full-wave Bridge rectifier is connected to transform into DC voltage where the load is connected to absorb the power as required.

For efficient wireless power transfer, a high frequency is on the order of 15 kHz to 95 kHz, which is significantly higher than 50Hz of the electric grid. The desired frequency is achieved by combining a rectifier with an inverter. A full-bridge inverter is used to achieve high power transfer efficiency.

While there have been some attempts, inverters are often utilized to provide a current of high frequency on load side of inverter. Switch-mode power converters and linear amplifiers are two methods that can be utilized to provide current of high-frequency. Linear amplifiers are used where losses do not matter at low power efficiency is required due to losses in the linear region. For medium sized or large WPT applications, where power is a crucial factor, a switch-mode power converters are frequently utilized to create current of high-frequency.

WPT works to transfer power without connecting wires through magnetic coupling. Earlier Power can be transmitted through an air gap without direct contact using inductive power transfer (IPT) [7-9]. For 3.3kW power transfer for both the bipolar pad and the circular pad as secondary sides, the tri-polar pad primary is examined [10].

Applications for the inductive power transmission technique include battery charging, material handling systems, and clean rooms [11-12]. So, the battery charging of electric vehicles has potential as one of the uses of IPT systems. This paper introduces Parallel – series topology of the resonant WPT method in detail.

A. Power factor correction-rectifier

The AC supply be devoid of excessive voltage spikes, current harmonics, and other impurities to guarantee high quality. On-grid input current discontinuity leads to the non-linear rectification process that further reduces the power factor. So, a capacitor is added to the Diode rectifier to optimize the quality of the current waveform by decreasing distortions and to limit the reactive power flow from the power supply.

B. Single phase full bridge inverter

In this paper, the phase shift is driven as near to 100% as feasible using a full-bridge inverter. However it is made for increased power levels and voltage, the output current remains identical. [15].

Phase shifted full-bridge is related to the control technique where both legs individually operated at nearby 50% of duty cycle, and then phase-shifted of 180 degrees between two legs. A full-bridge does not go through the current shoot, Ensured by there should be a delay in turning OFF one switch and turning ON the other in the same leg. Phase shifted control technique is not used only for controlling the duty cycle rather than controlling some degree of switching losses. In this, it is impossible to reach phase shift of 100%, but it can reach up-to 99%.

C. Resonant Wireless power transfer circuit

When adding a capacitor or compensator to the coupling circuit on either side makes the circuit work as magnetic resonance. Due to this less power is required from the supply. The capacitor is charged under resonance conditions by the inductor's magnetic field collapsing, and the inductor's magnetic field is then built up by discharging the capacitor.

Functioning:

The transmitting and receiving coils must resonate in order for resonance to occur. Additionally known as resonant inductive coupling, the resonant coupling is a mechanism. Because a sufficient supply current is needed for efficient power transmission, efficiency suffers as a result of losses.

So, a capacitor is introduced in order to compensate for the reactive power in order to overcome it. Based on the parallel /or series connection of the capacitor on the transmitting /or receiving coil, numbers of different topologies are possible.

Resonant WPTs have more efficiency in power transfer due to more quality factors and power factors compared to inductive power transfer.

Resonant wireless power transfer can transfer power comparatively inductive power transfer to more distance. Different compensation topologies have emerged in recent years [13-14].

Different topologies:

(i) Series – series topology
(ii) Series – parallel topology
(iii) Parallel – series topology
(iv) Parallel – parallel topology

D. Parallel – series topology

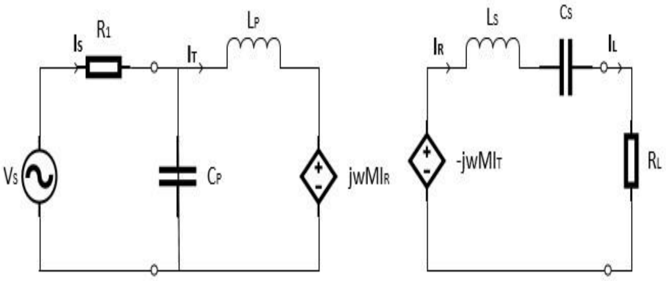


Fig.2- Circuit diagram of the parallel-series topology

III. MATHEMATİCAL MODEL

Vs is the high-frequency voltage source and L_P and L_S are the self- inductance of the transmitting and receiving coil. C_P and C_S are compensation capacitors in the transmitting and receiving coil and M is the mutual inductance between transmitting and receiving coil, and R_L is the load resistance [1].

Transmitting side impedance (Z_T) is given by,

$$Z_T = R_1 + \frac{1}{jwC_P + \frac{1}{jwL_P}} \qquad (1)$$

Receiving side impedance is given by,

$$Z_R = R_L + \mathrm{j}\,(\mathrm{w}L_S - \frac{1}{wC_S}) \qquad (2)$$

Resonating condition for receiving side is given by when,

Imaginary part of Z_R becomes zero.

It implies that, $w^2 = \frac{1}{L_S C_S}$ (3)

And For the transmitting side, two resonance conditions are possible, each of which would result in a distinct expression of the primary impedance (Z_T).

Now,

By applying superposition theorem on transmitting side, transmitting current $\bar{I}_T$ and source current $\bar{I}_S$ are given as:

$$\bar{I}_T = \frac{-j(\frac{\bar{V}_S}{wL_P})(R_1 + jwL_P)Z_2}{[Z_2R_1 + w^2M^2(1 + W^2{C_P}^2{R_1}^2)] + jwL_P}$$

$$\bar{I}_S = \frac{j(wM)^2(\frac{\bar{V}_S}{wL_P})(R_1 + jwL_P)(1 - jwC_PR_1)}{[Z_2R_1 + w^2M^2(1 + w^2{C_P}^2{R_1}^2)] + jwL_P}$$

In parallel- series topology $\bar{I}_R$ and $\bar{I}_L$ are same.

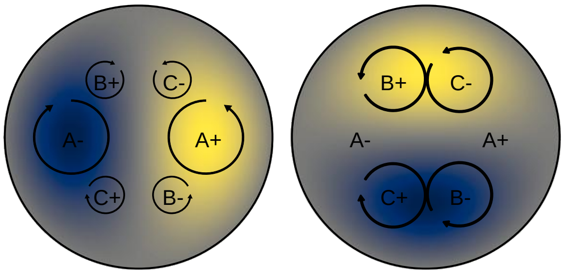
So, Receiver current $\bar{I}_R$ is given as:

$$\bar{I}_R = \frac{-(wM)\left(\frac{\bar{V}_S}{wL_P}\right)(R_1 + jwL_P)}{[Z_2R_1 + w^2M^2(1 + w^2{C_P}^2{R_1}^2)] + jwL_P}$$

Efficiency of parallel-series topology is given as:

$$\eta = \frac{({Q_T}^2 + 1)/Q_T}{Q_T + (\frac{1}{Q_T})(1 + K^2Q_R(1 + Q_T/Q_T))}$$

IV. RESONANCE CONDİTİONS



(a) α mode (b) β mode

Fig.3- Diagrammatic representation of α and β modes [16]

Low magnetic coupling develops between large air gap GAs and VAs. So, capacitive compensation improves the operating power factor. System efficiency is increased by achieving load-independent power factor correction through resonance tuning. In this section, a method for single-phase systems' tuning is developed as well as a quick overview of mathematical explanations of resonance [16].

Single Phase Resonance Condition:

On receiving side, a series of resonant forms and resonant frequencies are characterized as zero impedance. Let Z (w) be the impedance that varies with frequency. Consequently, the resonance conditions for single-phase systems can be written as

$$Z(\omega) = 0 \qquad (1)$$

Alternatively, we can conclude that a single-phase, unloaded series resonant network that requires no input voltage can maintain a sinusoidal current. Let I symbolize the series resonant networks steady-state current. Consequently, the above sentence can be stated as

$$I * Z(\omega) = 0 \qquad (2)$$

However, comprehending poly phase resonant circuits requires viewing resonance as a correlation between steady-state voltage and current.

V. RESULT

To ascertain the output average power, output voltage, output current, and transmitting current and receiving current of parallel-series resonant WPT, Simulation in MATLAB is used. Circuit parameter values are taken accordingly to the best suited. It is driven by a 220V single-phase sinusoidal voltage, and when the output power of an electric vehicle is calculated for charging purposes, the result is 32 kW. Output current is maintained at 32 A and Output DC voltage is 968 V.

A. *Simulation of output voltage*

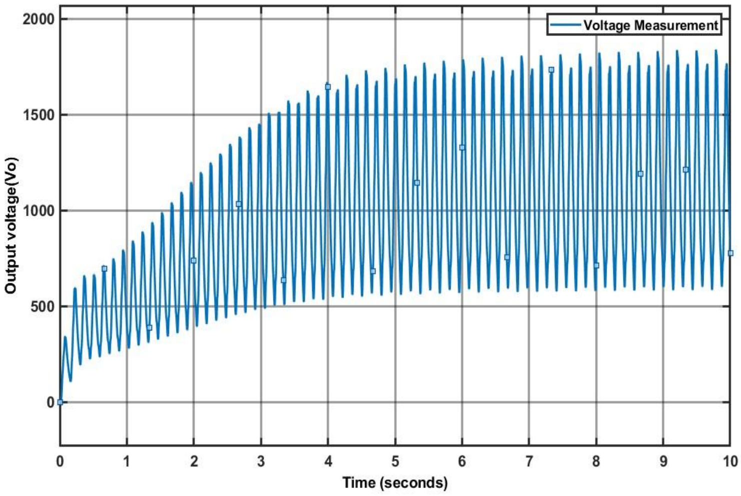


Fig.5- Output voltage (V) in MATLAB

B. *Simulation of output current*

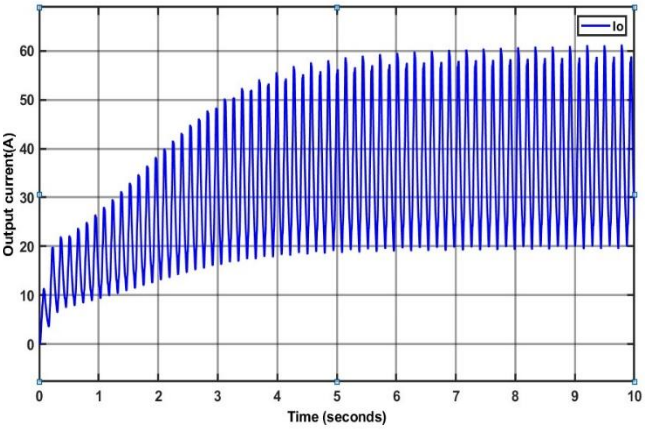


Fig.6- Output current (A) waveform in MATLAB

C. Simulation of Transmitting and Receiving Current

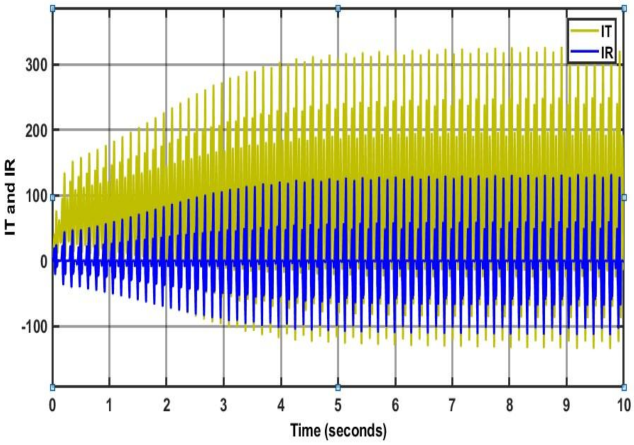


Fig.7- IT (A) and IR (A) waveform

D. Simulation of Output Average Power

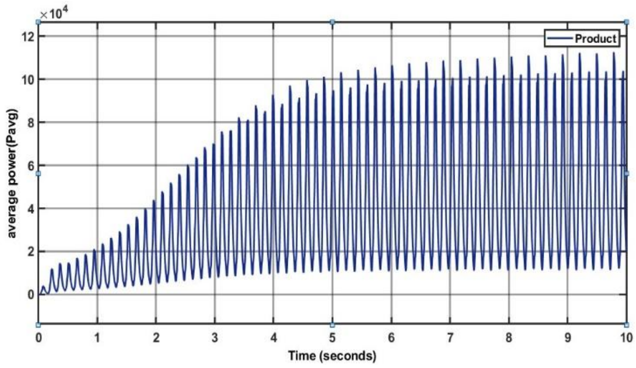


Fig.8- The waveform of Output power (W)

VI. CONCLUSION

The parallel–series resonant compensation of the circuit of wireless power transfer has been analyzed in this paper for the electric vehicle. The mathematical model of parallel—series compensation topology of the WPT system is established. The expressions of supply current, transmitting current, receiving current, efficiency, and output voltage are derived.

The relationship between transmitting current, receiving current, output voltage, and the complete set of WPT technology along with parallel—series compensation topology are analyzed in MATLAB/SIMULINK simulation. In addition, in the WPT system of parallel—series compensation topology, the transmission power is very sensitive to changes in load resistance, change in quality factor, and change in effective coupling factor also. In this paper PFC- converter is used that helps in less input VA is required from the source side and input power factor is improved. It needs to be studied in future works since the great significance of compensation of parallel-series topology has greater transmission efficiency among all topology available till now.

REFERENCES

[1] Shuxuan song, Weifeng Zhang, Qichen Geng, “Analysis of S-S resonance compensation circuit of electric vehicle wireless power transfer systems,” vol. 978, no. 1, pp. 7281-9606, June 2020.

[2] W. Zhang and C. C. Mi, “compensation topologies of high power wireless power transfer systems,” vol. 65, no. 6, pp. 4768 – 4778, June 2016.

[3] K. N. Mude and K. Aditya, “ comprehensive review and analysis of two–element resonant compensation topologies for wireless inductive power transfer system,” in Chinese journal of electrical engineering, vol. 5, no. 2, pp. 14-31, June 2019.

[4] G. A. Covic, J. T. Boys, “inductive power transfer systems,” *Proceedings of the IEEE*, vol. 101, no. 6, pp. 1276-1289, June 2013.

[5] 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, vol. 1, no. 1, pp. 28-41, March 2013.

[6] Akhil A. G., Harisankar S., Jishnu K., Sreenand S., Vivek Vijay, Asha C. A., Dr. Preetha P. K., “ Coupled wireless charging systems for Electric vehicle,” Third international conference on Intelligent communications technologies and Virtual Mobile Networks(ICICV), vol. 978, no. 1, pp. 6654-1960/4, 2021.

[7] S. Choi, B. Gu, S. Jeong, and C.Rim, ” Advances in wireless power transfer systems for roadway-powered electric vehicles,” IEEE Journal of emerging and selected topics in power electronics, vol. 3, no. 1, pp. 18-36, March 2015.

[8] S. Hui, W. Zhong, and C. Lee, ” A critical review of recent progress in mid-range wireless power transfer,” IEEE transactions on power electronics, vol. 29, no. 9, pp. 4500-4511, Sep 2014.

[9] S. Y. R. Hui, ” Magnetic resonance for wireless power transfer,” IEEE power electronics magazine, vol. 3, no. 1, pp. 14-31, March 2016.

[10] Seho Kim, Grant A. Covic, and John T. Boys, ” IEEE Journal accepted for future issue,” 2016.

[11] P. Sregeant and A. Van den Bossche, ”Inductive coupler for contactless power transmission,” Electric power applications, IET, vol. 2, no. 1, pp. 1-7, Jan 2008.

[12] J. Hirai, T. W. Kim, and A. Kawamura, “Study on intelligent battery charging using inductive transmission of power and information,” IEEE Transactions on Power electronics, vol. 15, no. 2, pp. 335-345, March 2000.

[13] Y. Wang, Y. Yao, X. Liu, D. Xu, and L. Cai, ” An LC/S compensation topology and coil design for wireless power transfer,” in IEEE transaction on power electronics, vol. 33, no. 3, pp. 2007-2025, March 2018.

[14] Y. Yao, Y. Wang, X. Liu, D. Xu, and L. Cai, ” Analysis, Design, and Optimization of LC/S compensation topology with excellent load-independent voltage output for the inductive power transfer,” in IEEE transactions on transportation electrification, vol. 4, no. 3, pp. 767-777, Sept. 2018.

[15] A .P. Hu, G. A. Covic and J. T. Boys, ”Direct ZVS start-up of a current- fed resonant inverter,” IEEE Transactions on power electronics, vol. 21, pp. 809-812, 2006.

[16] Jason Pries, Veda P. Galigekere, Omer C. Onar, Gui-Jia Su, ”Journal of IEEE on 50kW three phase Wireless power transfer system using Bipolar Winding and Series resonant networks for rotating magnetic field,” 2019.