Dean&Francis

ISSN 2959-6157

Transfer Systems: Compensation Networks, Soft-Switching Techniques, and Future Trends

Miao Cheng

School of Computer Science and Engineering, Faculty of Innovation Engineering, Macau University of Science and Technology, Macau, 999078, China

*Corresponding author: 1230026851@student.must.edu.mo

Abstract:

This article carefully addressed the development of Wireless Energy transmission (WPT) systems using different types of compensation networks (CN), as well as the various soft-switching schemes employed. The major conclusions of the study are that suitable CN designs facilitate a feasible approach for power transmission when the operating conditions allow an optimal resonant match, which is true of several forms of CNs including those based on Inductor-Capacitor-Capacitor (LCC), SS-CN, etc., maximizing the power transfer capability. Soft-switching techniques help reduce reactive power loss and stray loss. They also lower switching loss, electromagnetic interference (EMI), and thermal stress. Reducing these losses and stresses improves system reliability, thereby indirectly extending the operating time. In other words, the fusion will allow us to have better performance on power transfer rate, less energy waste, greater work stability; It's not relevant to coupling state nor loading situations for real-world wireless power transmission.

Keywords: Wireless Power Transfer; Topological; Soft-Switching; Zero-voltage switch.

1. Introduction

Wireless Energy transmission (WPT) technology can transfer energy to a non-contact environment without relying on physical cables. This has always been a popular field with great market and research value, such as the current electronic devices that support wireless charging and electric vehicle (EV) charging power supplies. From an application perspective, compared with traditional wired methods, developing operation methods based on WPT can make it more convenient for people to utilize various types of electronic hardware items and avoid the potential risks and safety issues of wired charging. However, the practical application of Wireless Power Transfer (WPT) faces major obstacles, such as low efficiency, energy attenuation, strict alignment requirements, and high cost. These challenges have hindered the commercialization of WPT technology. Therefore, engineers must innovate in system design and transcend the conventional paradigm of wired charging.

The core of WPT systems is a number of elements,

ISSN 2959-6157

namely, high-frequency AC inverters, resonant compensator, primary and secondary coils for inductive coupling, and rectifiers [1]. These all play an important role in determining how well a WPT system converts power into usable electrical current, as well as its ability to stay operational and stable regardless of changes in external circumstances. But the ideal, certainly elegant, model is far from simple. Inverter losses along with loss induced through switching energy dissipate prohibitively large amounts of the available system power at higher power levels. Also, the system is extremely sensitive to the misalignment of coils, perturbations in the coupling coefficient, or deviations from the assumed characteristics of system components. This adds further challenges towards ensuring consistent functioning of the system.

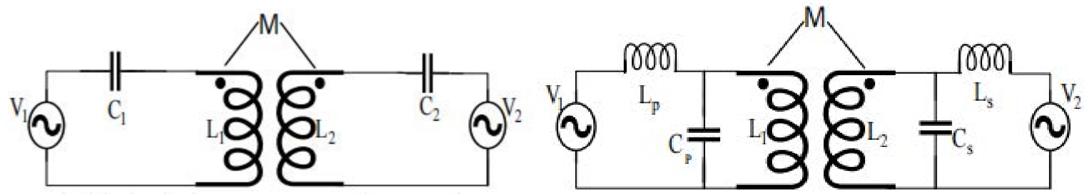

Figure. 1 Series-Series mono-resonant Compensation and LC based multi-resonant Compensation (Data from: [1])

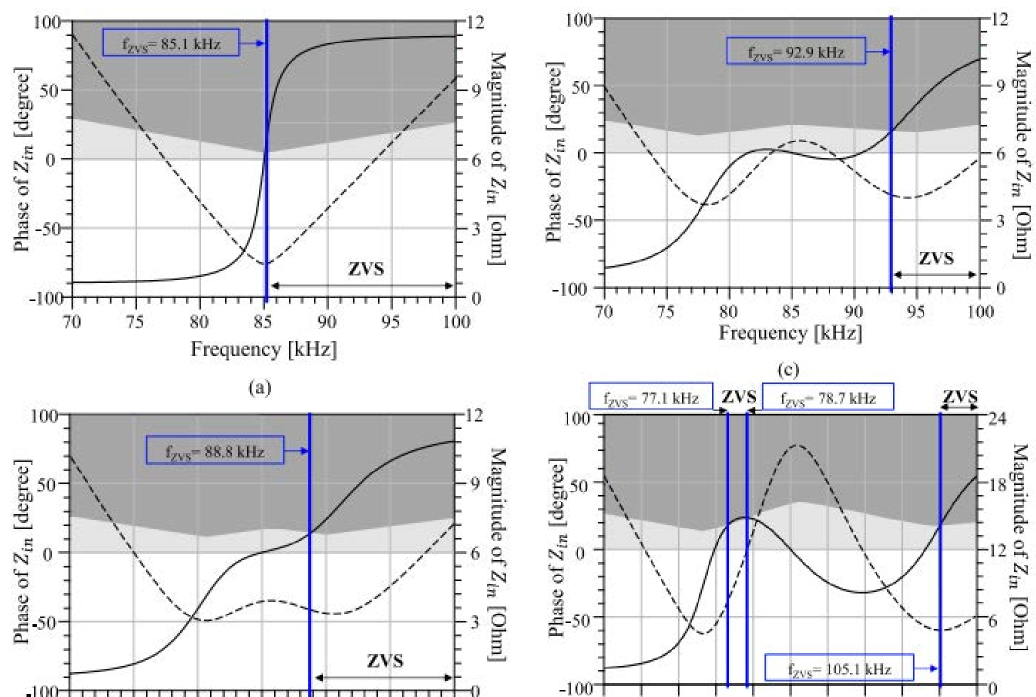

Figure. 2 Zero voltage implementation frequency range considering dead time. (a) For φ at k = 0.05, there is no bifurcation region. (b) For φ at k = 0.1, there is also no bifurcation region. (c) For φ at k = 0.2, there have bifurcation region. (d) φ at k = 0.35, have deep bifurcation region (Data from: [2])

One very promising way of overcoming these limitations is to develop and optimize compensation networks combined with soft-switching approaches. The compensation network, mainly Inductor-Capacitor-Capacitor (LCC) Compensation Network type. It is used to realize resonance, enhance power transfer, and minimize reactive power. It has an immediate effect on the system quality factor (Q) and load matching [3]. Accurate tuning is necessary to achieve maximum efficiency and low sensitivity to parameter variations [4]. It has been verified that the application of a multipoint resonant compensation topology and the proper use of capacitance or inductance based elements to control operating frequency will considerably improve voltage regulation as well as decreasing harmonics.

Currently, soft-switching technologies including ZVS (zero voltage switching) can be used to reduce switching losses, reduce electromagnetic interference (EMI), and decrease device stresses. All of the above are vital to ensure the reliable long-time operation of the inverter system.

Despite making progress, significant problems still need to be resolved. One challenge is that a high-efficiency power transfer in practical usage over diverse conditions such as different couplings caused by alignment or distance variation remains a hard nut to crack [3]. Another difficulty is obtaining better power transfer level with less energy loss. However, with the cost of rising voltage/ current stress on the circuit elements [5]. Also, the occurrence of harmonics affects both the power-level control and exacerbating EMI, thus harmonic analysis and control becomes essential. In addition, dynamic practical conditions force developers to create adaptive compensation and control mechanisms for optimal work in all circumstances without manual tuning.

To advance WPT technology further is to overcome its limitations in realizing better power transfer efficiency (PTE) through improvement of the compensation networks. Currently the technological weaknesses of the inferior PTE, higher harmonic distortion, weaker robustness hamper the large scale application of the systems. This research aiming to reach balance among those technical problems and match needs will pave the way to realizing maximum efficiency of WPT. In the second part of this research, the discussion is about the Fundamentals of Wireless Power Transfer. In the third part, the discussion is about Soft Switching and Zero Voltage Switching.

2. Fundamentals of Wireless Power Transfer

WPT Wireless power transfer (WPT) systems rely heavily on compensation networks for efficiency. control the power flow, and maintain stable operations under different loading and coupling situations. Thus, the design and analysis of them are still open problems caused by the complex electromagnetic interference, non-ideal characteristics of components, and dynamic environmental circumstances. In this part, we would like to provide comprehensive views about the performance and restrictions for each type of compensation topology, ways to achieve load insensitive outputs, and influences from parameters variation in WPT systems. Moreover, besides looking at some research efforts dealing with higher-level topologies such as multi-coil or dynamic compensation networks in order to improve their capabilities.

2.1 Diverse Compensation Topologies

Writing compensators to achieve the best possible operating conditions has always been an arduous task. Classical compensation networks usually consist of the combination of series and parallel capacitors with coils to offset the inherent reactive power from the inductive coupling [6]. Common compensation networks are classical combinatorial groups containing SS, PP, SP, and PS, with their own performance characteristics [3].

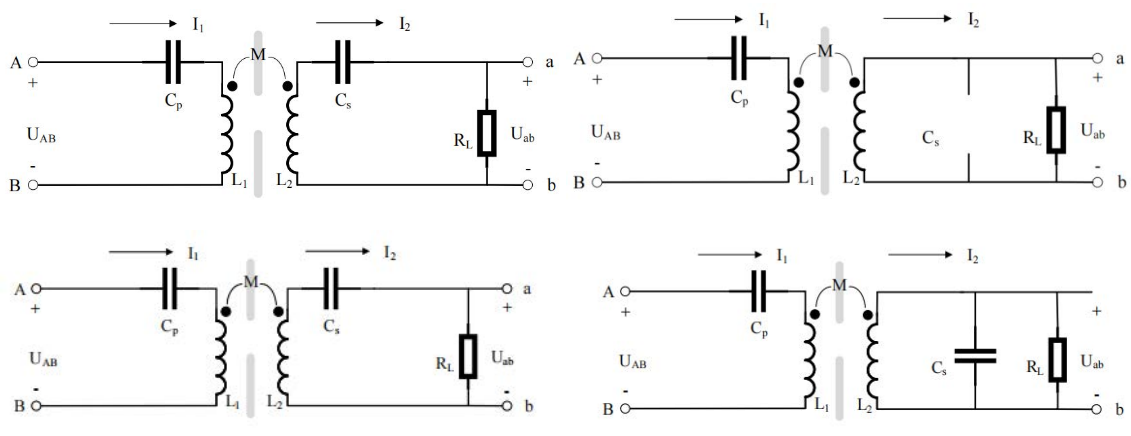

Figure. 3 SS, PP, SP, and PS Compensation network (Data from: [3])

The SS topology offers simplicity and strong power transfer ability with constant coupling coefficient. However, it has very poor immunity against coil position deviation or resistance mismatch especially when coil relative position is changing dynamically. Meanwhile, PP configuration has larger tolerance to resistive variations. But extra circuit nodes will reduce total power efficiency.

As a D-PS (Degenerate Push-Pull) topology combines the advantages of both previous topologies and offers some balanced voltages and currents. however, there is not a single topology that can optimally meet multiple criteria simultaneously like efficiency, range and stability [7]. For example, while using SP (symmetric push-pull) topologies allows for zero-voltage switching (ZVS) of transistors and

ISSN 2959-6157

lower inverter losses. But it is more sensitive to compensation capacitor tolerances and therefore requires precise component selection [8].

The observations show that the choice of compensation topology is naturally application specific. WPT designers have to make tradeoffs between efficiency, robustness, component cost, and complexity and no "one-size-fits-all" compensation network exists.

2.2 To design a constant voltage and current output independent of the load

Constant Voltage (CV) working hard to deliver Load-Independent Constant Voltage and Current Output The objective of producing load-independent outputs. CV and Constant Current (CC) is essential in ensuring that device performance does not change when the load changes.The latest compensating network designs break apart the relationship between output level and load changes with regards to the geometry and parameters of the scheme itself. For instance, carefully choosing networks such as S-S-S or S-S-P or N-S-S in a 3-coil WPT scheme can greatly extend the transmission distance while still retaining CV and CC capability [8]. The N-S-S system provides the ability to maintain CC even at differing load resistances, because it utilizes the intermediate coil to actively regulate magnetic coupling.

Further tuning of the compensation capacitance value is also a controllable knob to manipulate the working state to get a transition between CV mode and CC mode if desired [7]. Meanwhile, to obtain a load-independent output generally means more complicated design and control strategy, which must be compensated in real time, imposing difficulties on system integration and cost.

2.3 Impact of Compensation Parameter Variations on System Performance

The system's performance will be impacted when the values of the Compensation Parameters change. Due to the inductors and capacitors inside the Compensation Networks can be built of are manufactured with manufacturing tolerance, aging, variation of environmental temperatures, as well as parasitic components.

Such deviations cause the changes of the resonant frequency, change the impedance matching condition, and deteriorate system efficiency and output stability, respectively. Sensitivity analyses have demonstrated that double-sided LCC compensation topologies exhibit strong robustness in transmission efficiency against parameter variation. But output power can be significantly affected by capacitive or inductive drift [3]. The parasitic junction capacitance of a full-bridge rectifier diode has a non-negligible impact on the optimal compensation capacitance size and the reactive power of the system. However, traditional design methods often overlook this aspect [6].

To put it into practice, should include tolerances within the design stage itself. And employ some sort of real-time adjustment methods or adaptive compensation networks to lower the degradation level. Emerging solutions involve real-time estimate of parameters from sensors which in turn is used as the feedback in order to change compensation elements online in order to account for capacitor aging or for environmental variation [7].

The most important thing to take away is that we cannot statically define compensation networks. Instead, they should be perceived from a dynamic, whole-system framework considering how the interaction of power electronics, magnetic coupling and load dynamics impact each other.

2.4 Effects of multiple coils and dynamic compensation networks on transmission range and error tolerance

To increase both transmission distance and misalignment tolerance in comparison to two-coil WPT systems, multi-coil and dynamic compensation networks, especially multi-coil configurations like 3-coil architecture, have been widely researched. When a relay coil or an intermediary coil is added, more magnetic coupling paths will be generated so that more flexible and efficient power transmission can be achieved over longer distance [8].

Three-coil compensation networks designed with appropriate topologies and tuning can maintain or even improve power transfer efficiency while substantially enhancing tolerance to spatial misalignments. For instance, the tradeoffs between S-S-S, S-S-P, and N-S-S compensation schemes illustrate potential pathways to optimize power and voltage stability in extended-range applications [8].

Dynamic compensators could adaptively update their parameter value by the variation of coupling coefficient. And be applied as a real-time adaptive element to energy system, either via adjustable-capacitor tuning or via the switching mechanism, to absorb the variable load pattern without losing much efficiency [9].

2.5 Critical Reflection

The WPT compensation network is affected by external factors such as topological structure, component changes and environmental dynamics. The static compensation network is mainly composed of the traditional WPT system and has some advantages in efficiency, but its disadvantages are significant, such as poor load independence, weak adaptability, and obvious sensitivity to parameter drift. Although multi-coil dynamic compensation networks can improve performance, they also have problems such as high complexity and high cost.

An efficient compensation network requires a shift from static and simple resonant models to a comprehensive integration of power electronics design, adaptive control technology, and overall system parameters. Only by taking such an approach will the different operating conditions that need to be addressed be satisfactorily covered. Leading to the robustness, efficiency and usability characteristics sought for deployment in WPT systems.

Further investigations can be made on the development of efficient and simple DCMs and parameter estimation techniques as well as low-cost tunable components, which will benefit many commercial applications later on. In addition, researchers can apply such research methods like hybrid topologies to increase transmission distance.

In a word, compensation networks are not simply reactive entities, instead they are vary inportant in the work ability of the WPT system. Hence, the design philosophy should have relatively complicated idea to balance between the high accuracy and the real time variation.

3. Soft-Switching and Zero-Voltage Switching (ZVS) Techniques

3.1 Introduction

ZVS Pursuing more efficient and reliable WPT systems necessitates focusing on the study of soft-switching technologies, especially the research for zero-voltage switching ZVS. Conventional hard-switching inverters suffer much bigger switching loss and EMI caused by the transition of both voltages and currents simultaneously. Therefore, WPT applications face a serious challenge: their feasibility has been restricted greatly due to thermal and reliability issues of power devices and smaller switching losses under ZVS [10]. Thus, adopting a soft switching scheme is crucial for the mitigation of such issues and ZVS technology allows switches to turn off and turn on at zero voltage condition so as to drastically reduce switching losses, making the circuit more robust.

Among various soft-switching methods, zero-voltage switching holds a unique position. Because it ensures that power metal-oxide-semiconductor field-effect transistors (MOSFETs) or other semiconductor switches only transition from one state to another when the drain-source voltage is zero. Therefore, there is almost no energy consumption during the switching process. This results in substantial reductions of both the switching losses and the resultant EMI, which directly enhances both the power transfer efficiency and the stability of the overall operation of the WPT system. Additionally, in real-world WPT implementations, ZVS makes feasible much higher operating frequencies than otherwise possible by mitigating the thermal and electrical stresses. Allow the use of smaller passive devices, thereby increasing power density.

However, making ZVS work consistently and reliably under the highly variable operating conditions encountered in most WPT systems is difficult. A WPT environment consists of varying couplings coefficients, varying loads that cause shifting load demands and parasitic elements that act as time-varying impedances for the inverter [11]. Any one or more of these factors can compromise the desired ZVS conditions, requiring an accurate model of these variations to generate the proper engineering compensation strategies and appropriate control techniques.

3.2 Multiple topologies

Several circuit topologies aiming at achieving ZVS have been proposed for WPT systems [7], which often contain deliberately designed compensation circuits like SS, SP, PS, and LCC circuit topologies [12]. Appropriate selection of these topics equivalently achieves two key effects: providing a favorable inductive load characteristic and realizing resonance. The advantage of these circuits comes from two aspects: shaping system impedance so that there is some excess inductance which facilitates ZVS. And also offering resonance so that there will be an appropriate reactive current flow to avoid over-voltage and excessive reactive power. LCC-S topology not only supports zero phase angle operating mode all along but also facilitates ZVS through wide-ranging load and coupling variation. Clamping diodes, together with reactive elements, aid in shaping the switching waveform for facilitating ZVS [13]. Different variants of the soft-switching strategies adjust their adaptation style to different conditions, such as compensation networks and load. Class-E inverter topologies utilize ZVS of secondary-side compensation capacitors to achieve load-independent ZVS, but only if they meet certain coupling coefficient range requirements. This allows a simpler inverter design and also lessens switching losses where the coupling coefficient is high.

These designs require a detailed analysis of compensation capacitor, inductor and also diode duty cycle to achieve the very tight control over the required operating conditions. So that it can be compatible with both ZVDS and ZVS. A critical factor in the realization of ZVS in practical WPT systems is the management of dead time, the interval during which both upper and lower switches of an inverter leg are turned off to prevent shoot-through. While dead time is essential for device protection, incorrect dead

ISSN 2959-6157

time setting can offset the inverter's input impedance from the inductive region required for ZVS, resulting in increased switching losses and compromised efficiency.

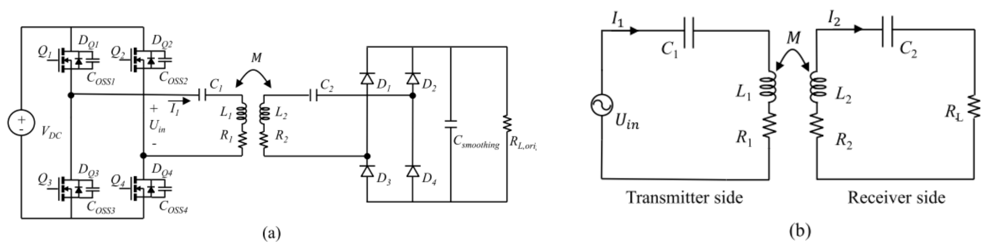

Figure.4 (a) The simplified circuit structure of ZVDS class de current-driven full-bridge rectifier is presented, including four diodes, junction capacitance and load. (b) shows the corresponding equivalent circuit model. (Data from: [3])

Therefore, compensation capacitor values must be carefully calculated considering dead time characteristics to ensure minimum dead time suffices for ZVS realization without excessive power loss [2]. The interaction of dead time with the compensation network and system operating conditions demands sophisticated modeling and adaptive control strategies.

3.2 Active rectifiers

Active rectifiers, especially semi-bridgeless active rectifiers, have also started to be used for ZVS in the receive-side implementation, which has further extended its operational range. While simultaneously decreasing the loss level during conduction and switching phases. They adaptively adjust the load impedance seen from the inverter and provide the phase-aligned equivalent of ZVS. Their buck-boost characteristics allow systems to run efficiently over highly varying loads, such as the car loading/discharging fluctuation experienced when using vehicles as power plants in EV chargers, as well as grid switching fluctuations [12].

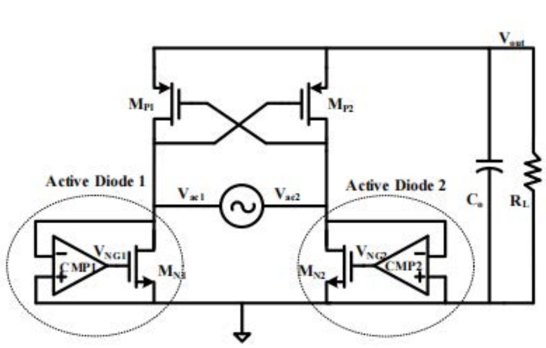

Figure. 5 A conventional Active rectifier circuit diagram showing a structure containing two Active Diodes, a compensation capacitor, and a load. (Data from: [14])

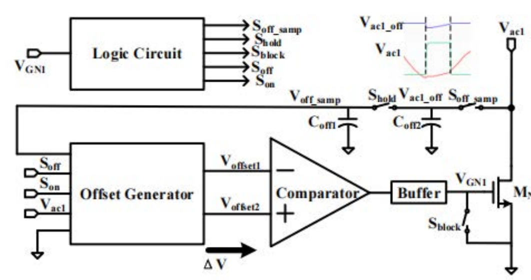

Figure.6 Adaptive compensation active rectifier system architecture diagram, only showing an active diode and its control circuit block diagram. (Data from: [14])

In addition to improving the switching performance of the input device, advanced control schemes adjust compensation capacitors via active dead-time compensation to ensure ZVS is maintained. The values and switching timings of the capacitance are dynamically adjusted based on measured coil coupling coefficient (C, C couple), load impedance, and inverter current waveform data (Inverter currents) [7]. The proposed control scheme can maintain operation close to the ZVS condition despite system disturbances. [2]. In comparison to fixed parameter design method which is often not optimal in a variable environment and may fail when it comes to performance or even reliability [8].

Although significant progress has been made in recent years, challenges still exist [7]. Achieving good ZVS under wide range of the coupling factor and load variation requires a good system modeling including harmonic analysis, parasitic effects, nonlinear device characteristics etc. [11]. Ensuring stable operation and avoid voltage/current bifurcations during the over coupled region is challenging [10]. The complexity and expense associated with implementing active rectifiers/controllers to improve efficiencies need to be balanced to maintain a cost-effective solution.

In summary, the improvement of WPT system efficiency and stability are related to the soft-switching technique. Especially ZVS (Zero-Voltage-Switch) technique. Through appropriate compensation network design, supplemented with active rectification, dead time compensation can play an important role in the application of WPT system to hard requirement scenarios. Furthermore, more research efforts need to be exerted on adaptive control, precise capacitor parameter tuning and complete system modeling to obtain the advantages of ZVS technique. And to cater for the evolutionary needs of WPT applications.

4. Challenges and Future Perspectives

4.1 Challenges

Though significant improvement of soft-switching techniques and compensation networks design have been made for wireless power transfer (WPT), many major issues and technical bottlenecks still exist to fully realize its potential, especially in variable practical environments. Solutions should be developed to address these challenges for strong, efficient, and scalable WPTs for different applications.

A primary limitation lies in existing compensation networks and soft-switching implementations that often assume fixed or narrowly varying operating conditions. Traditional compensation topologies, such as LCC, series, and series-parallel, typically implement zero-voltage switching (ZVS) on the nominal coupling coefficient and load resistance to match the impedance. However, WPT systems will encounter problems such as dynamic changes in coupling strength (due to fluctuations in coil alignment and distance) and considerable load transfer [2]. These issues can cause the input impedance of the inverter to deviate from the conditions required by the zero-voltage switch. This leads to problems such as the decline in the performance of soft switches, increased switching losses, reduced efficiency, and damage to hard switches [11]. In addition, the working bandwidth of some compensation configurations is limited, making them vulnerable to frequency bifurcations and unstable when over-coupled or out of balance [2].

Another issue is the difficulty in coordinating dead zone time control and compensation element Settings. Dead time can prevent penetration, but excessive dead time or mismatched compensation elements may confine the zero emitter to an extremely limited operating area. Even without a zero-voltage switch, this will still lead to switching losses. When the compensating element fails to keep up with the changes in the rapidly coupled current waveform, zero voltage loss will occur, and at this point, all soft-switching advantages will be lost [11]. However, adaptive dead time and capacitance tuning show great potential, but their reliance on complex circuits and real-time control increases costs and implementation difficulty [12].

Stability under actual conditions is also a major design challenge. Over-coupling can lead to resonant frequency division and zero-phase Angle bifurcation, thereby disrupting the waveforms required for ZVS and system stability [2]. Solving this problem requires advanced modeling, harmonic analysis and feedback control [5]. However, these methods lack reliable standardization and are also quite complex, thus posing a significant challenge, especially for small interconnected WPT modules.

4.2 Some Solutions and Future Perspectives

Resolving these issues demands innovative solutions that target an advanced, adaptable, and standard method for developing WPT. Compensation networks combined with self-tuning soft-switching architectures ought to have capabilities that constantly suit changing load conditions, coupling states, and various working atmospheres; moreover, employing dynamic control systems using real-time sensing techniques together with machine-learning methods in tandem makes it possible to forecast compensation capacitance, dead-time parameters, and inverter switching modes to achieve the best-zero voltage switch (ZVS) performance and best efficiency based on different operating conditions of the system [12].

Standardization plays an important role in establishing common approaches and benchmarks of methods and standards for WPT systems. Defining common standards for modules, components, and the corresponding benchmark values (efficiency, stability, ZVS robustness, etc., compensation parameters) can facilitate faster commercialization [14]. Meanwhile, the modularity and reconfigurability of compensation networks can ease the implementation difficulty for PNPW applications and minimize unneeded system errors as well as improve fault tolerance [14,15].

The future development of Wireless Power Transfer (WPT) can benefit from advances in wide-bandgap semiconductors like SiC and GaN. These devices enable converters to operate at higher switching frequencies with better thermal stability, while avoiding associated losses [16]. As a result, WPT systems can become smaller, lighter, and more compact, while still maintaining high soft-switching efficiency [16]. Additionally, there has been some attention towards developing modular and configurable compensation network designs that improve scalability and real life fault tolerance.

Solve current issues by bringing together advance adaptive control, real-time parametric prediction, intelligent

ISSN 2959-6157

compensation network, and comprehensive standardized framework to reduce the influence of load and coupling fluctuation onto ZVS and efficiency and improve WPT flexibility under the disturbance of uncertain factors. Then this step forward would help bridge the gap between traditional PWM (Pulse Width Modulation)-based approach, like soft PWM switched method, smart control scheme, device innovating solution and standardizing architecture. And it will bring a brand new tech into next generation soft-switching wireless power transfer.

5. Conclusion

This paper studies the compensation network and soft-switching technology. Through the compensation network, the inverter provides the coil load and ensures that the switching devices can switch in a nearly lossless transition, which is necessary for zero-voltage switching. Compared with traditional hard-switching inverters, the synergistic coupling of these advantages enables us to reduce power loss, lower electromagnetic radiation, and suppress current drift. In addition, the flexibility introduced through compensation element tuning and the higher efficiency achieved through dead time optimization help maintain the soft-switching advantage in a wide range of operating environments.

This paper also covers that the current compensation and soft-switching methods still have some serious problems: poor flexibility, low bandwidth, sensitivity to coil alignment deviation, load changes and environmental disturbances. In addition, the technical bottlenecks brought about by the static compensation element values and fixed dead time parameters can also lead to unsatisfactory soft switching during dynamic processes, resulting in efficiency loss or transient instability. Meanwhile, due to the high complexity and cost of implementing adaptive control and parameter estimation techniques. These solutions have certain limitations for large-scale market application, that is, large-scale production.

Looking ahead, the development of WPT should focus on an intelligent real-time adaptive compensation network architecture that integrates sensing and machine learning-based control algorithms. The system aims to self-configure, continuously meeting optimal resonance and switching conditions across the entire operating range. This preserves high efficiency and stable zero-voltage switching at all times, even when subjected to major external disturbances. By leveraging intelligent adaptive algorithms and unified standards to overcome current technical limitations, WPT will be widely applied in fields such as electric vehicles, consumer electronics, and medical implants. Progress in this direction not only contributes to the efficient application of wireless energy transmission devices. Meanwhile, the maintenance-free and widely used WiTR system can also meet more stringent power demands to adapt to the constantly changing world.

References

[1] Akshay, G. Yadav and M. Singh, "Validation of a Parameter Design methodology for Air-core two-coil WPT system with multi-resonant LC compensation," 2023 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE), Trivandrum, India, 2023, pp. 1-6.

[2] H. Kim et al., "Determination of Compensation Capacitor Considering the Dead-Time Characteristics for ZVS in Wireless Power Transfer System," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 11, no. 3, pp. 2501-2513, June 2023.

[3] H. Niu, F. Gao, X. Liu and B. Zhang, "Parameter Sensitivity Analysis of Dual-Sided LCC Compensation Networks for Wireless Power Transfer Systems: Participation factor Analysis Approach," 2024 IEEE 10th International Power Electronics and Motion Control Conference (IPEMC2024-ECCE Asia), Chengdu, China, 2024, pp. 893-897.

[4] Y. Liu, F. Gao, H. Liu and H. Li, "Harmonic Analysis and ZVS Implementation in Double-Side LCC WPT System," 2021 IEEE Sustainable Power and Energy Conference (iSPEC), Nanjing, China, 2021, pp. 3619-3624.

[5] C. Tao, L. Wang, Y. Zhang, S. Li and C. Da, "Research on Three-Phase Hybrid Compensation WPT System with High Misalignment Tolerance and Its ZVS Control Strategy," in IEEE Transactions on Power Electronics, vol. 38, no. 12, pp. 14847-14860, Dec. 2023.

[6] S. Feungkeaw, C. Ekkaravarodome, K. Jirasereeamornkul and Y. Kumsuwan, "Analysis of a ZVDS Class-DE Current-Driven Full-Bridge Rectifier to Compensation Network Capacitance Design for WPT System," 2024 21st International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), Khon Kaen, Thailand, 2024, pp. 1-6.

[7] Y. Lan, Q. He, J. Wang, W. Chen, Q. Chen and X. Zeng, "Sensitivity Analysis of S/SP Compensation Capacitance Parameters and ZVS Implementation in Wireless Power Transfer System," 2023 IEEE 2nd International Power Electronics and Application Symposium (PEAS), Guangzhou, China, 2023, pp. 598-603.

[8] H. S. Wang, K. W. E. Cheng and J. F. Hu, "An Investigation of Compensation Networks for Three-coil Wireless Power Transfer," 2020 8th International Conference on Power Electronics Systems and Applications (PESA), Hong Kong, China, 2020, pp. 1-6.

[9] M. Bertoluzzo, M. Forato and E. Sieni, "Optimization of the Compensation Networks for WPT Systems," IECON 2018 - 44th

Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, USA, 2018, pp. 4828-4833.
[10] J. Zhang, J. Zhao, L. Mao, J. Zhao, Z. Jiang and K. Qu, "ZVS Operation of Class-E Inverter Based on Secondary Side Zero Compensation Switching at Variable Coupling Coefficient in WPT," in IEEE Transactions on Industry Applications, vol. 58, no. 1, pp. 1022-1031, Jan.-Feb. 2022.
[11] H. Kim, J. Ahn, J. Rhee and S. Ahn, "Compensation Capacitor Tuning Method of LCC-S Topology Wireless Power Transfer System to Implement ZVS under Various Conditions," 2023 XXXVth General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS), Sapporo, Japan, 2023, pp. 1-4.
[12] M. Li, J. Deng, D. Chen, W. Wang, Z. Wang and Y. Li, "A Control Strategy for ZVS Realization in LCC-S Compensated WPT System with Semi Bridgeless Active Rectifier for Wireless EV Charging," 2021 IEEE Energy Conversion Congress and Exposition (ECCE), Vancouver, BC, Canada, 2021, pp. 5823-5827.
[13] H. -C. Hsieh and J. -S. Lai, "A Half-Bridge CLC-Series Wireless Power Transfer System with Clamping Diodes," 2021 IEEE International Future Energy Electronics Conference (IFEEC), Taipei, Taiwan, 2021, pp. 1-6.
[14] Y. Ma, K. Cui, Z. Ye, S. Fang and X. Fan, "A ZVS Active Rectifier with Adaptive On/Off Delay Compensation for WPT Systems," 2018 IEEE Asia Pacific Conference on Circuits and Systems (APCCAS), Chengdu, China, 2018, pp. 167-170.
[15] K. Li and W. Ding, "An Improved One-to-Three WPT System with Tunable Compensation Network and Enhanced Pulse Density Voltage Control," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 11, no. 3, pp. 3586-3596, June 2023.
[16] R. Carvalho, E. Gomes, P. Rao, L. Pereira, A. Kotrashetti and S. Gupte, "A Comparison of Compensation Networks for Wireless Charger for Electric Vehicles," 2021 IEEE Bombay Section Signature Conference (IBSSC), Gwalior, India, 2021, pp. 1-6.