A review of multi-load radio energy transmission

Yigeng Song[1]

[1]School of Electrical Engineering, Southwest Jiaotong University, Chengdu, Sichuan Province, 610000, China

2539726717@qq.com

Abstract. In recent years, the multi-load magnetic coupling radio energy transmission technology has become a research focus, among which the system topology is a key research content, which determines whether the technology can meet the needs of different application scenarios. This paper uses literature analysis to sort out and analyze the topology of multi-load magnetically coupled radio energy transmission system An effective classification method is proposed, which is helpful to provide a reference for the related research on the topology of multi-load WPT systems. Firstly, the topologies of multi-load magnetically coupled radio energy transmission systems are classified. Then, the working principles, advantages and disadvantages of the main topologies are introduced. Finally, the problems faced by the topology of multi-load magnetically coupled radio energy transmission system are presented, and the future development trend is prospected.

Keywords: radio transmission, multi-load, topology, Magnetic coupling, impedance matching.

1. Introduction

In the field of multi-load WPT technology, scholars at home and abroad have conducted relevant basic research on coil structure, power distribution, system efficiency and frequency splitting, which is a hot research direction.In this paper, literature analysis will be used to discuss what are the classification of topologies of multi-load magnetically coupled radio energy transmission systems? What are the working principles of the main types of topologies? It is helpful to provide reference for the study of topology of multi-load WPT system.

Compared with single-load WPT technology, multi-load WPT technology has many advantages, such as higher power density, higher utilization rate of excitation source and freer spatial position of receiving load, which has become a research hotspot in recent years. However, due to the diversity of loads and the cross-coupling of magnetic fields between transmission coils, multi-load WPT technology is faced with many problems: (1) the cross-coupling between transmitting coils or receiving coils leads to system detuning and system performance deterioration; (2) Interference between receiving loads leads to complex control strategy; (3) The receiving power of each load is difficult to distribute on demand, which slows down the progress of practical application of the technology; (4) The output characteristics and transmission performance of the system are very sensitive to working conditions, which limits the application of the technology; (5) The increase of transmission coilleads to the increase of loss caused by parasitic resistance of the system, which makes the heating problem prominent. In this paper, the mechanism and characteristics of different types of

WPT topologies are described in detail, and then the problems of multi-load WPT topologies are pointed out. Finally, the development trend of multi-load WPT topologies is prospected.

2. Single-capacitor compensation multi-load WPT topology

2.1. Single Power Supply single Transmitter Coil (SSSTC)

SSSTC is the multi-load WPT topology with the simplest circuit structure, which is directly evolved from the single-capacitor compensation single-load WPT topology [1-2]. When all loops adopt series compensation, SSSTC multi-load WPT topology circuit is shown in Figure 1. In the figure, $\dot{U}_{in}$ is the voltage phasor of the high-frequency AC source. $\dot{I}_T$ and $\dot{I}_{Ri}$ are the phasor of current flowing through the transmitting coil and the ith receiving coil; L_T is the inductance of the transmitting coil, C_T and r_T are its compensation capacitance and parasitic resistance; L_{Ri} is the inductance of the ith receiving coil, C_{Ri} and r_{Ri} are its compensation capacitance and parasitic internal resistance. Z_{Leqi} is the equivalent load impedance connected to the ith receiving loop, and $\dot{U}_{oi}$ is the output voltage phasor at both ends. M_{Ti} is the magnetic coupling between the transmitting coil and the ith receiving coil, and M_{Rij} is the cross coupling between the ith receiving coil and the JTH receiving coil. Where, I, j=1, 2... , N and i ≠j.

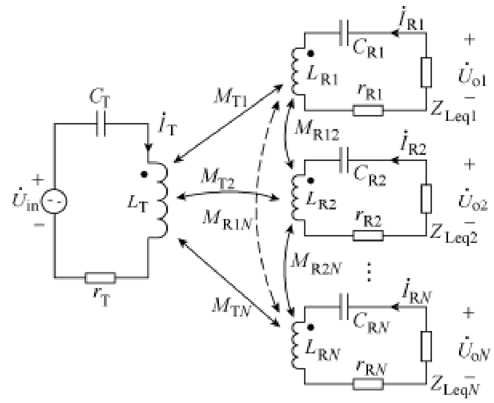

Figure 1. Circuit of the SSSTC multi-load WPT topology.

2.2. Single Power Supply multiple Transmitting Coil (SSMTC)

Fig. 2 shows the WPT topological circuit with single power, multiple transmitting coils and multiple loads, and FIG. 3 shows the SCHEMATIC diagram of THREE-DIMENSIONAL WPT topology with three transmitting coils and three receiving coils. The transmitting side of the single-power multi-transmitting coil topology contains multiple transmitting coils but is only driven by a single high-frequency inverter [3-5]. Compared with the topological circuit shown in FIG. 1, the addition of multiple transmitting coils results in higher spatial freedom of the receiving coil. In order to suppress cross-coupling between receiving coils, transmitting coils can be placed vertically with each other, as shown in Figure 3. In the figure, T_{Xi} and R_{Xi} are corresponding transmitting coils and receiving coils respectively, and receiving coils are aligned with corresponding transmitting coils in turn. As the distance between each receiving coil is relatively far, the cross-coupling phenomenon can be effectively improved[5]. In practice, the system efficiency of SSMTC topology is easily affected by the amount of power supply load required by the receiving side at a certain moment, and its transmission efficiency is lower than other types of multi-load WPT topology, so there are few studies on SSMTC topology.

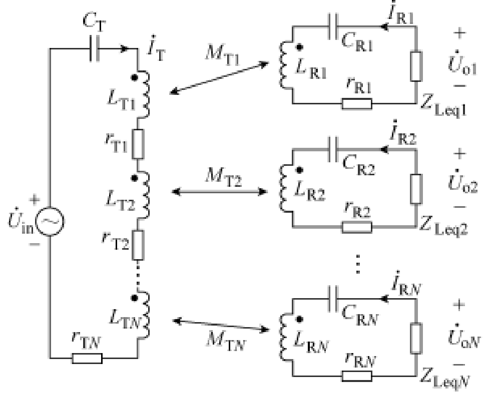

Figure 2. Circuit of the SSMTC multi-load WPT topology.

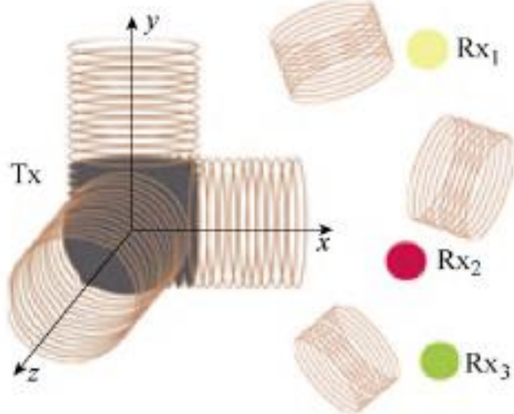

Figure 3. Diagram of a 3D WPT system with three transmitting coils and three receiving coils.

2.3. Multi-source multi-transmitter Coil (MSMTC)

Figure 4 is the MSMTC multi-load WPT topological circuit. In the figure, M_{iu} and M_{iv} are the direct coupling mutual inductance between the transmitting coil and the receiving coil, while M_{Tik} and M_{Ruv} are the cross-coupling mutual inductance between the transmitting coil and the receiving coil. The topology can further improve the spatial freedom of the receiving load by controlling different transmitting sources to generate different magnetic fields. Different from the above two topologies, this topology contains several transmitting loops, each of which is connected in series by high-frequency inverters, compensating capacitors and transmitting coils, and all transmission coils have magnetic field coupling, making the mathematical model more complex [6].

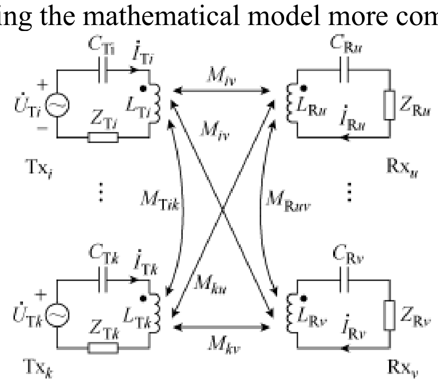

Figure 4. Circuit of MSMTC multi-load WPT topology.

3. High-order impedance matching multi-load WPT topology

3.1. Multi-resonant Coil Type (MRCT)

Figure 5 shows two typical circuits of this topology. In Figure 5A, except for one or more transmitting loops [7-10] and multiple receiving loops [11-12], the topology shown only has one more relay loop than the MSMTC multi-load WPT topology. In FIG. 5b, the transmitting side consists of a source loop and a transmitting loop, while the receiving side consists of a receiving loop and a load loop respectively.

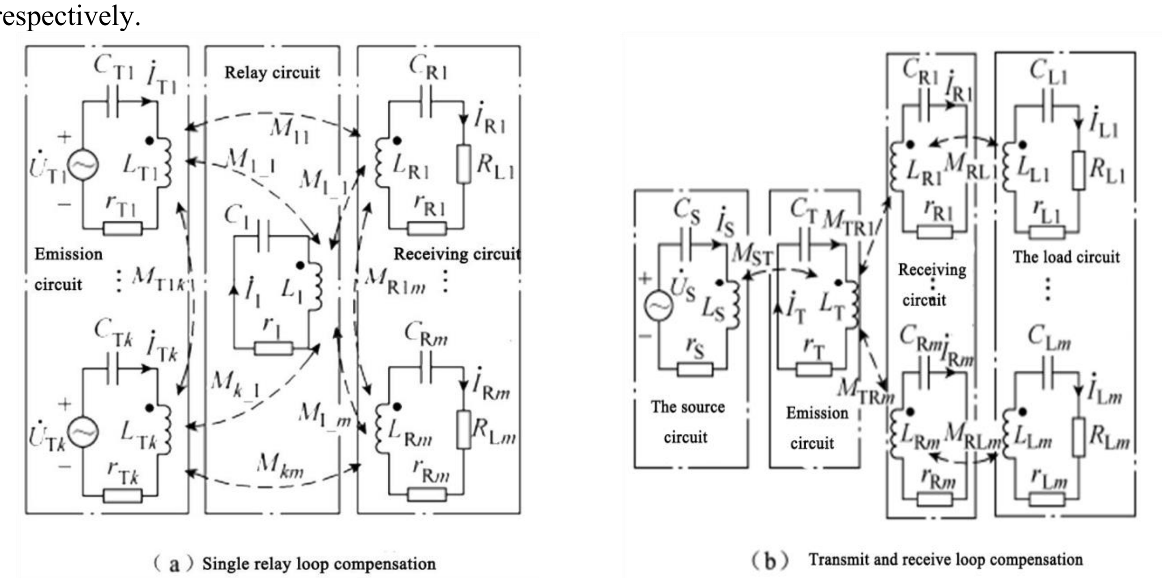

Figure 5. Circuit of MRCT multi-load WPT topology.

This topology is suitable for applications where the transmission coil position is fixed, but not for scenarios where the transmission distance and load conditions vary greatly.

3.2. Local passive compensation type (PPCT)

FIG. 6 shows the topology diagram of local passive compensation multi-load WPT. FIG. 6 shows that the transmitting side of PPCT multi-load WPT topology contains IMN and compensation on the transmitting side, and the receiving side contains receiving part and load part. At present, existing literatures mainly study this kind of topology, and the difference lies in whether the load part adopts parallel mode. When all the load parts are connected in parallel, they share a single receiving part, that is, all the input ends of the load parts are connected in parallel at the output end of the receiving part. When the load parts are electrically isolated from each other, the structure of all receiving sides is the same and contains the receiving part and the load part in sequence.

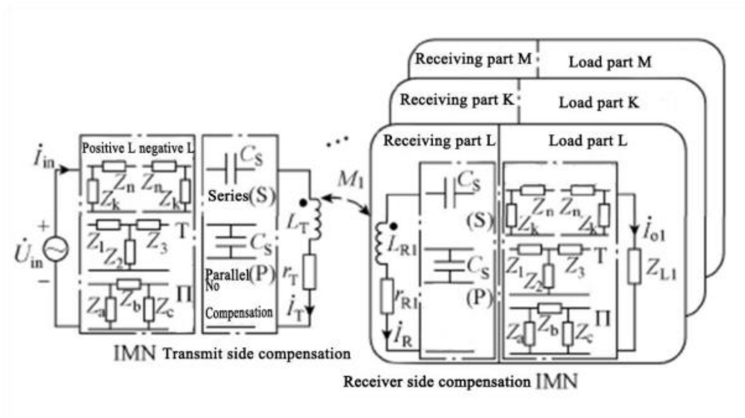

Figure 6. Circuit of PPCT multi-load WPT topology.

3.3. Active Impedance Matching type (AIMT)

The AIMT multi-load WPT topology adds active impedance matching networks at specific locations. The topology can be divided into three types: active equivalent load impedance transformation, active matching of compensating network on the receiving side and active matching of compensating network on the transmitting side. First type needs sampling active rectifier circuit or dc converter input and the output voltage or current signal, after compares to reference control on-off switch tube, in turn, changes the voltage current amplitude and phase, in order to bring into play the function of equivalent load impedance transformation, finally realizes the power allocation, system optimization and cross coupling efficiency. This type is focused on the design of the control strategy, and then two types are paying more attention to IMN topology optimization, the main use of active element (such as the switch tube, constant voltage source, etc.) and passive components (such as inductance, or resistance, etc.), the combination of ATMT, and by controlling the on-off of the switch tube and meeting the design requirements of the equivalent impedance.

4. Multi-channel multi-load WPT topology

4.1. Frequency Selective Transmission (STT)

The topology diagram of frequency-selective transmission multi-load WPT is shown in Figure 7. The transmitter side inverter of STT generally chooses to work at a certain frequency point, while the natural frequency of different receiving loops varies greatly. When the operating frequency of the starting inverter is a specific value, the closer the natural frequency and distance of the receiving circuit, the more power will be obtained, while the natural frequency and difference of the receiving circuit will obtain power. Through appropriate inverter frequency and natural frequency of each circuit, the smaller work can be adjusted, so as to realize reasonable distribution of power. Figure 7 shows the typical equivalent circuit. The transmitter side is equipped with an inverter and AN IMN with variable working frequency. The IMN can be set to an untunable or adjustable mode, and the adjustable mode IMN is usually realized by switching capacitor array. The receiving side generally needs to configure IMN and set it at different natural frequency points. The advantage of this topology is that it can supply power to devices of different standards without complex control policies, but the disadvantage is that it cannot supply power to multiple devices simultaneously.

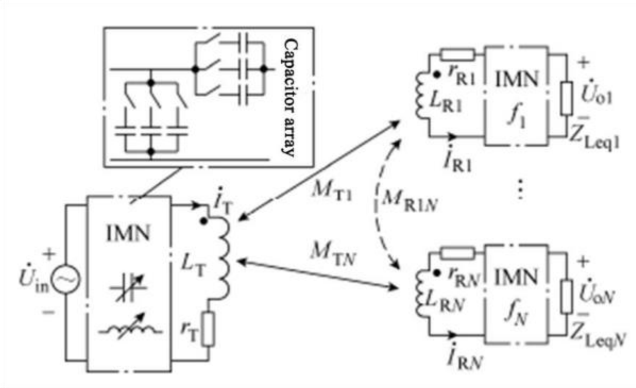

Figure 7. Circuit of STT multi-load WPT topology.

4.2. Multi-Heterofrequency Emission Source Class (MDFTST)

4.2.1. Single-source inverter multi-emission loop type. In order to solve the shortcomings of STT multi-load WPT topology, the optimization design of transmitter side has become the main research content. The most direct approach is to apply multiple transmitting loops with different operating frequencies to form the transmitting side. The resulting topology is called single-source inverter multi-transmitting loop [13-14] topology, which is similar to the MSMTC topology described in Section 1.3, but has significant differences. The natural frequencies of all transmitting loops and receiving loops in the MSMTC topology are the same, while the working frequencies of each transmitting loop in the ISI-MTLT topology are different, and the natural frequencies of each receiving loop are also different. The loops with different natural frequencies almost do not affect each other, thus reducing to eliminate cross-coupling interference.

4.2.2. MULTI-frequency PULSE width modulation multi-transmission loop type. On the basis of the multi-transmission loop topology shown in the common source inverter, the redundant inverters on the transmitting side are removed, leaving only multiple transmission loops with different natural frequencies, while the switch tube is driven by multi-frequency PULSE width modulation (MWHM). Its topological circuit is shown in Figure 8, which is called the multi-frequency PULSE width modulation (MWHM) multi-transmission loop topology.

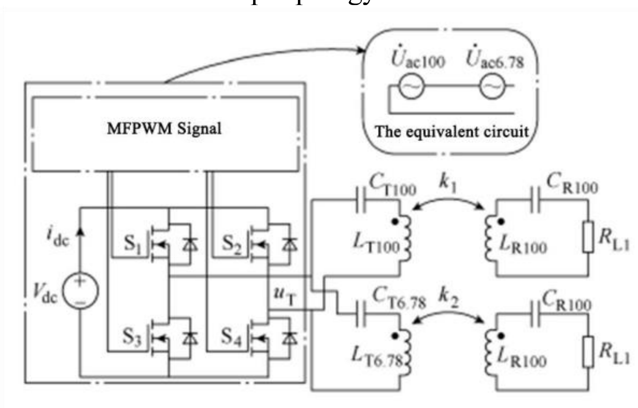

Figure 8. Circuit of three-phase MFPWM-MTLT WPT topology.

4.2.3. Mixing single transmitting loop type. The new topology with multi-frequency excitation sources and few emission loops is called the mixed-frequency single-emission loop topology. The mixed-frequency single-emission loop WPT topology circuit is shown in FIG. 9. It can be seen that the topology is mainly composed of four parts, namely, mixed-frequency AC source, compensation network, single transmitting loop and multiple receiving loop. Among them, there are mainly three construction modes of mixed-frequency AC source, as shown in the upper part of the figure, and multiple compensation networks, as shown in the lower part of Figure 9.

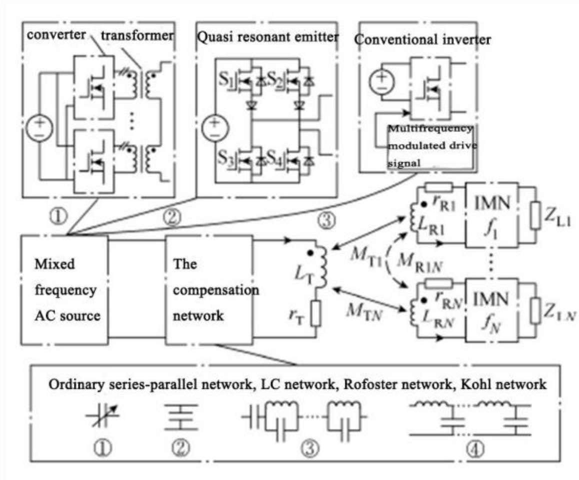

Figure 9. Circuit of MF-STLT WPT topology.

5. Conclusion

The wide popularity of electronic devices and the development of smart home have promoted the progress of multi-load WPT technology. At present, the technology has made some achievements and has been applied in the fields of consumer electronics, transportation and medical devices. In this paper, the existing research results are sorted and analyzed from the perspective of system topology, and an effective classification method is proposed, which is helpful for the related research of multi-load WPT system topology. In terms of topology, researchers mainly improve the multi-load magnetically coupled WPT topology from the aspects of impedance matching network/compensation network, the circuit relationship between the transmitting side and the receiving side, and the transmitting source, so as to improve or solve specific problems.

Although there are many research results, there are still some problems in multi-load WPT topology, such as low overall efficiency, serious heating, too much space, limited transmission distance, insufficient freedom of receiving load position, unreasonable power distribution, interference of receiving side and sensitivity of output to load conditions. The development of multi-load WPT topology requires further improvement in the following aspects:

1) Innovation and improvement of active impedance matching network. It is one of the future development trends to further explore active IMN, give full play to its advantages of continuous regulation, and tap its potential ability of "holding multiple jobs", that is, to satisfy multiple demands simultaneously.

2) Further improvement of system compatibility. The use of mixed-frequency ac sources is helpful for the compatibility of these standards, but the existing research results still have the problem that the number of system frequencies is small and can only cover individual standards. Further research on mixed ac sources and transmitters is needed.

3) The degree of freedom of receiving load position is improved. The invention of a new transmitting coil structure that can combine the advantages of existing technology and the positioning function of control algorithm, or based on the new WPT mechanism (such as the millimeter wave technology in recent years), and then achieve all-round rapid charging of receiving load, will be one of the future development trends.

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