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A Frequency-Modulated Wireless Power Drive for Electric Vehicles

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Executive Summary

This paper proposes a frequency-modulated wireless power drive (WPD) for electric vehicles. With the WPD, electric motors are allowed to work in a fully sealed environment without physical connections between the power source and the motors, avoiding potential risks of cable disconnection in the applications of electric vehicles, mobile robots, and automated guided vehicles. In particular, a three-phase switched reluctance motor (SRM) is artfully incorporated into the proposed WPD. Each motor phase is energized by an independent wireless power transfer channel, decoupled by magnetic couplers, thus, the motor can be powered and controlled with no microcontrollers at the motor side. To provide a wide speed range with higher efficiency, sigma-delta modulated pulse frequency modulation is incorporated into the proposed WPD, offering wide-range zero-voltage switching operation and precise speed control capability. Both theoretical analysis and computer simulations are conducted to verify the feasibility of the proposed WPD for SRMs.

Keywords: Inductive/Wireless Power Transfer, Power Electronic Systems, Electric Motor Drive, Drive & Propulsion Systems, Electric Vehicles

1 Introduction

After being pioneered by Nikola Tesla over a century ago [1], wireless power transfer (WPT) technology has drawn attention in industrial, domestic, and medical applications [2-3]. After years of research, it has been gradually applied and commercialized in charging applications of electric vehicles (EVs) [4-5], portable electronic devices [6], unmanned aerial vehicles [7], and medical implants [8]. Benefiting from the contactless power transmission, both the power supply and the equipment can be sealed separately with covers, offering characteristics of electrical spark protection, waterproofing, and better stability against complex outdoor environments [9-11]. Apart from transmitting electrical energy wirelessly, direct conversion between electricity and other types of energy can be also accomplished [12], such as thermal energy [13], optical energy [14], and mechanical energy [15]. Wireless motors convert electrical energy to mechanical energy without additional energy storage units and increase overall efficiency by reducing additional charging and discharging processes of energy storage. Due to the electrical isolation of WPT, power and signal cables can be totally eliminated, bringing fewer effects from cable abrasion, disconnection, and other environmental impacts [16]. These advantages promote the development of various types of wireless motors, including wireless DC motors [17], wireless induction motors [18-19], wireless stepper motors [20-21], wireless permanent-magnet brushless DC (PM-BLDC) motors [22-23], wireless permanent-magnet synchronous motors (PMSMs) [24-25], and wireless ultrasonic motors [26]. The wireless motor, together with other types of wireless energy conversion, can be generalized as a wireless power drive (WPD), for control and output power wirelessly.

The switched reluctance motor (SRM) is an attractive option for electric vehicle (EV) propulsion systems because of its low cost and simple structure and the research on wireless SRM has been carried out [27]. Due to its simple control strategy, it is possible to eliminate the microcontrollers and power switches at the receiver side for a simpler structure and improved reliability. Usually, multiple receivers are connected to each phase, feeding power to different motor windings independently. The one-to-many transmission requires a high-order compensation network at the transmitter side to maintain resonance at all frequencies, which increases the design complexity and system size. The wireless SRM revealed in [28-29] energizes three motor phases with a single transmitter and three receivers. The WPT frequency corresponding to each phase is different from the frequency to power only one phase at a time. Motor currents are equalized by changing the duty ratio. A wireless SRM using decoupled magnetic couplers is presented in [30]. The decoupled coupler creates independent power channels for energy transmission, thus the WPT frequencies for each phase can be the same. The wireless resolver is also proposed for motor commutation, however, the speed control is not discussed. Energy saving in freewheeling mode is also studied to charge the battery when the SRM works as a generator [31]. However, power converters and microcontrollers are essential for this complex control. For traction motors in electric propulsion systems, higher robustness is expected for fewer maintenance needs.

The performance of wireless motors highly depends on the WPT output regulation. Pulse width modulation (PWM) [32], pulse density modulation (PDM) [33], and pulse frequency modulation (PFM) [34] are the major approaches. PWM is the most commonly used method because of its simple control, however, the high-frequency hard switching loss is unavoidable unless implementing complex zero-voltage-switching (ZVS) control [32]. PFM modulates the switching frequency and maintains a wide range of soft switching during the regulation process, which reduces the loss of high-frequency hard switching, and makes it suitable for the proposed system [34].

In this paper, a frequency-modulated WPD is proposed for electric vehicles. By modulating switching frequency through PFM, ZVS operation is guaranteed in a wide operation range. A sigma-delta (Σ-Δ) modulator is designed to generate PFM sequences automatically with minimized harmonics. Particularly, a wireless three-phase SRM is developed based on the proposed WPD.

2 Wireless Power Drive for Electric Vehicles

2.1 System Configuration

The proposed WPD is depicted in Fig. 1, specifically, a 6/4 pole three-phase SRM is incorporated into the proposed WPD. Three separate magnetic coils transmit power to three motor stator windings and each transmitting coil is equipped with a half-bridge inverter to generate high-frequency current. For wireless transmission with multiple pairs of coils, cross-coupling brings energy to the untargeted motor phase, which affects the normal operation in speed, load capability, and efficiency. The proposed WPD design uses two orthogonal bipolar coils and one circular unipolar coil to form three magnetically decoupled power channels. Therefore, the transmitting frequency for each phase can be selected freely with no influence on selective transmission. In this design, the transmitting frequency in all three power channels is set as f_0=100 kHz. To simplify the structure, the proposed WPD adopts only capacitors connecting in series with the coils to form a series-series (SS) compensation. Under resonant frequency, the SS compensation behaves as a constant current source [35], and the variation of motor operation has no impact on motor currents, thus, motor control can be realized by manipulating the high-frequency inverter at the transmitter side.

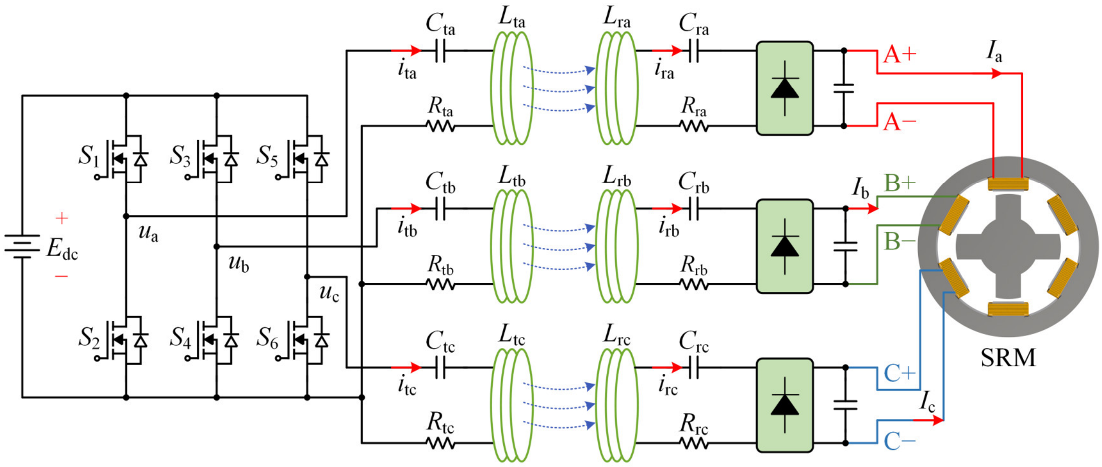


Figure 1: System topology of the proposed WPD for SRM.

In Fig. 1, A+, A-, B+, B-, C+, and C- represent the current input ports of the SRM. L_{ta}, L_{tb}, L_{tc}, L_{ra}, L_{rb}, and L_{rc} denote the transmitting and receiving coil inductances of power channels *A*, *B*, and *C* with subscripts *a*, *b*, and *c*. C_{ta}, C_{tb}, C_{tc}, C_{ra}, C_{rb}, and C_{tc} are the six compensation capacitors in channels *A*, *B*, and *C* with subscripts *a*, *b*, and *c*. R_{ta}, R_{tb}, R_{tc}, R_{ra}, R_{rb}, and R_{tc} are the overall internal resistances of compensation components on both sides of channels *A*, *B*, and *C* with subscripts *a*, *b*, and *c*. u_a, u_b, u_c, i_{ta}, i_{tb}, and i_{tc} represent the output voltages and currents of three half-bridge inverters. E_{dc} denotes the voltage of the DC power supply. I_a, I_b, and I_c are the motor currents of phases *A*, *B*, and *C*.

2.2 Circuit Analysis

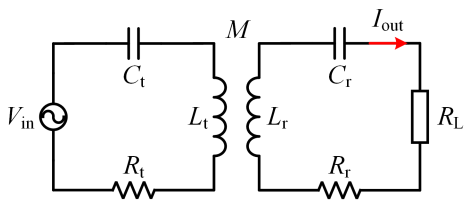


Figure 2: Equivalent circuit of SS compensation.

The compensation networks in the three power channels share the same structure, only channel *A* is analyzed to illustrate the characteristics of the compensation circuit. The SS compensation is one of the basic compensation structures in WPT. Fig. 2 shows the equivalent circuit model of the SS compensation circuit. When the system is under resonant condition, both the transmitter-side circuit and receiver-side circuit are under resonance. With a preset resonant frequency f_0, the primary capacitance and secondary capacitance are calculated as:

$$\begin{cases} C_t = \dfrac{1}{\omega_0^2 L_t} \\ C_r = \dfrac{1}{\omega_0^2 L_r} \end{cases}, \tag{1}$$

where $\omega_0=2\pi f_0$. Then, the input impedance at full resonance is derived as:

$$Z_{in}(f_0) = R_t + \frac{\omega_0^2 M^2}{R_r + R_L}, \tag{2}$$

where M is the mutual inductance between the coils and R_L is the equivalent resistive load. Therefore, the circuit shows pure resistance and it assists in achieving ZVS by bringing no reactive impedance in resonance. When neglecting all internal resistances of compensation components, the output current of SS compensation has no relationship with the load. The effective value of output current I_{out} is expressed as:

$$I_{out} = \frac{V_{in}}{\omega_0 M}. \tag{3}$$

2.3 Operating Principle

The whole control process is controlled by the primary controller installed at the transmitter side. By feeding power to three coils by turns, the motor phases draw power one by one to rotate in the corresponding direction. Fig. 3 shows the theoretical waveforms of transmitter currents (i_{ta}, i_{tb}, and i_{tc}) and motor currents (I_a, I_b, and I_c). For a 6/4 SRM, the motor commutates every 30 degrees, when the rotor is at the commutation point, the primary controller changes the power-delivering channel according to the commutation sequence and rotating direction, feeding power to the next motor phase. The whole commutation sequence repeats twice in a single round. Thanks to the decoupling design of magnetic coils, only the aim phase is energized. Fig. 4 explains the operating principle by showing the power path when driving motor phase *A* and motor phase *B*.

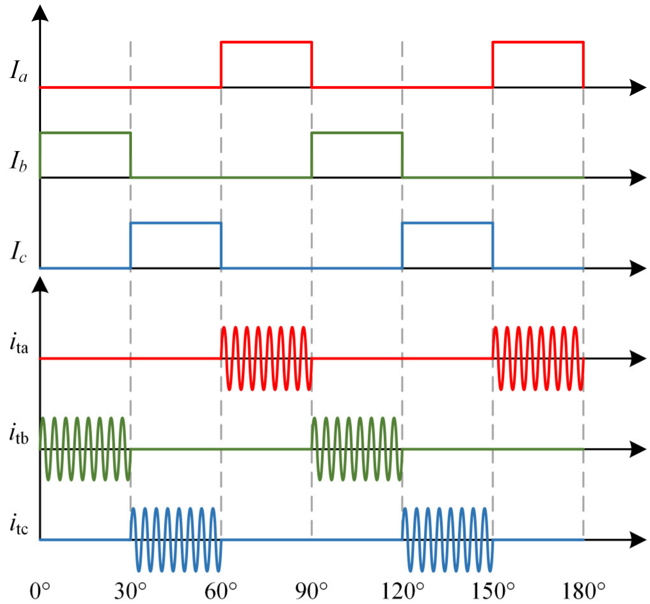


Figure 3: Theoretical waveforms of transmitter currents and motor currents.

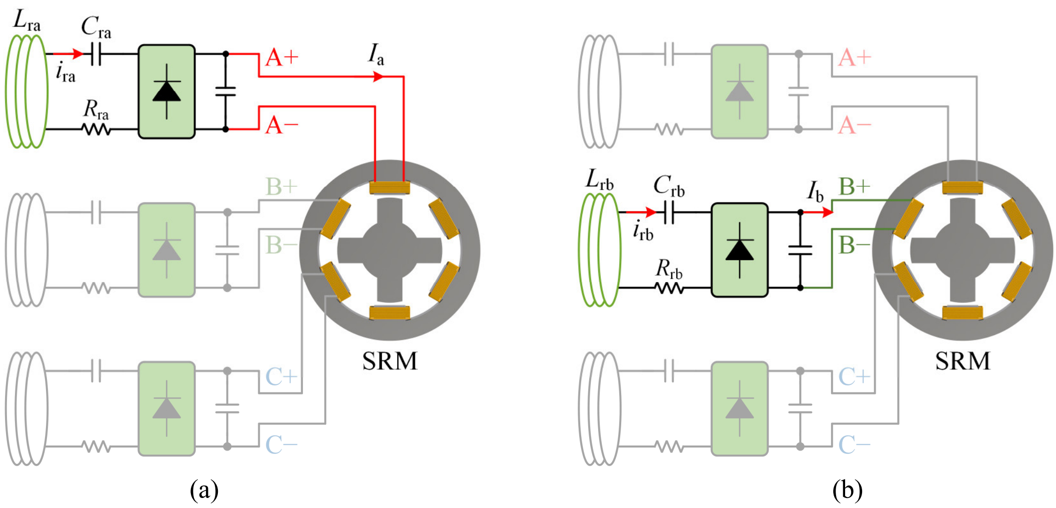


Figure 4: Selective power transmission in the proposed WPD: (a) Driving phase *A*; (b) Driving phase *B*.

2.4 Decoupled Magnetic Coupler Design

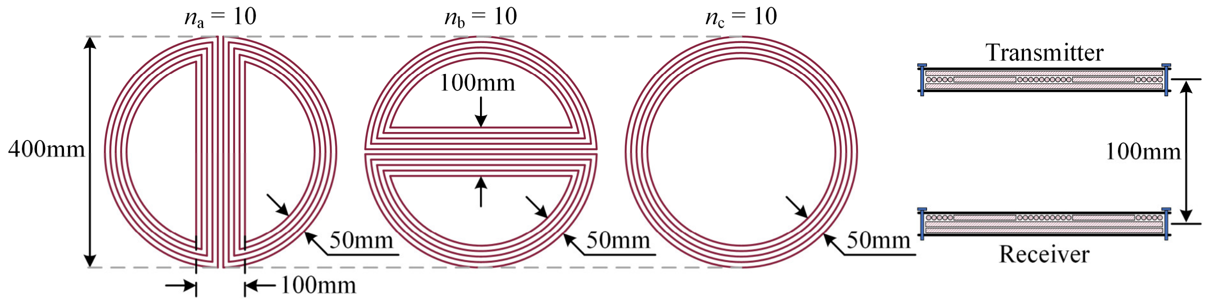
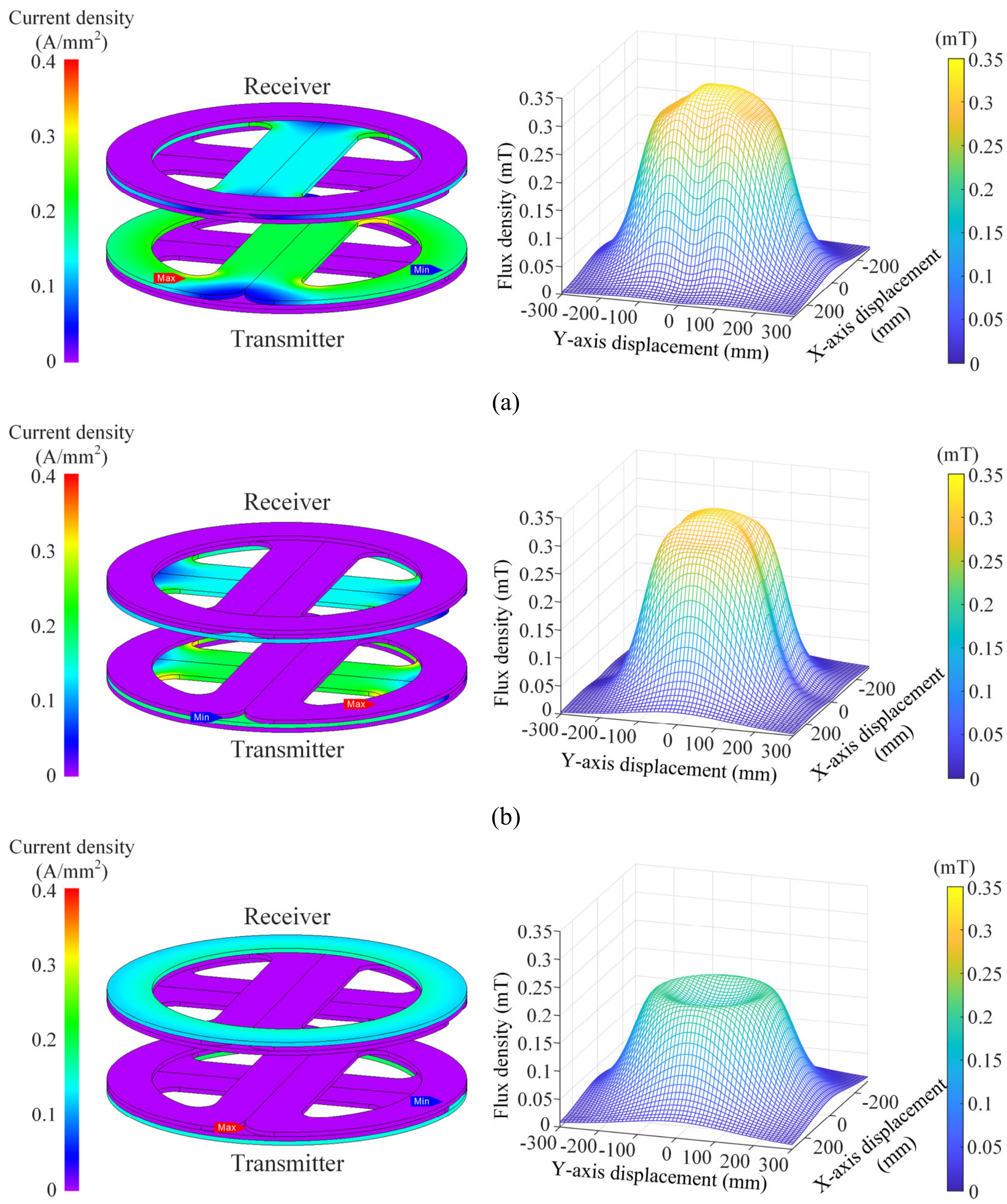


Figure 5: Geometric dimensions of the decoupled magnetic coupler.



(c)

Figure 6: FEA results of current densities and magnetic field distribution along the middle parallel plane between magnetic coils: (a) Channel *A*; (b) Channel *B*; (c) Channel *C*.

The magnetic coupler utilizes an orthogonal structure, consisting of two bipolar coils and one unipolar coil.

The two bipolar coils are placed orthogonally, and all the coils are coaxially attached tightly, eliminating the mutual inductance between the unrelated coils with a compact size. The geometric dimensions are shown in Fig. 5, each coil has 10 turns, and the distance is 100 mm between the transmitter and the receiver. Furthermore, a finite element analysis (FEA) model is built to estimate the magnetic field distribution, the coil models are built according to Fig. 5 and the loads in three channels are all set to 10 Ω. As shown in Fig. 6, when only one channel is energized, nearly no currents are induced in unrelated coils, which proves the decoupling of the proposed coupler.

3 System Control

The proposed WPD incorporates PFM to regulate the WPT output in each power channel. In the speed regulation process, the duty ratio of PFM is adjusted automatically to approach the aim speed with varied loads. Apart from speed regulation, PFM is also utilized in motor current equalization. According to (3), the output current of SS compensation is related to mutual inductance. The mutual inductance of the circular coil is different from the bipolar coil, and the bipolar coils also have varied coupling due to manufacture. The duty ratio in each power channel is tuned to offer an equalized motor current for smooth operation.

3.1 Pulse Frequency Modulation

PFM has been utilized in WPT output regulation due to its wide-range soft-switching capability [36]. As shown in Fig. 7, it modulates the pulse sequence between multiple switching frequencies, including the transmitting frequency and several orders of subharmonics. The modulated cycles contain high-order harmonics which have the same frequency as the transmitting frequency. Higher order leads to a lower amplitude of harmonics, therefore, the average output is reduced. Usually, the fundamental frequency is selected as WPT resonant frequency f_0, and the subharmonics are selected as $f_0/(2n+1)$. The proposed WPD uses f_0, $3f_0$, and $5f_0$. The regulated output against its maximum value is defined as the PFM duty ratio δ_{PFM}, which is expressed as [23]:

$$\delta_{\mathrm{PFM}} = \frac{\sum_{n=0}^{n} N_{2n+1}}{\sum_{n=0}^{n} (2n+1) N_{2n+1}}, \tag{4}$$

where N_{2n+1} is the number of half cycles under switching frequency $f_0/(2n+1)$. According to (4), the length of the modulated pulse sequence varies with control precision, a higher accuracy requires a longer sequence [37]. The uneven switching in PFM generation causes subharmonics and interharmonics in generated high-frequency current, with possible frequencies of

$$f_{\mathrm{h}} = \left(1 \pm \frac{j}{N}\right) f_0, \ j=1, 2, 3, \ldots, N-1, \tag{5}$$

where f_{h} is the harmonic frequency, $N=N_1+3N_3+5N_5$. Based on (5), more harmonics will be introduced with longer sequences for high accuracy. Research has revealed that an evenly distributed modulated sequence will reduce the harmonic amplitude around the fundamental frequency for easier filtering through the compensation network [38].

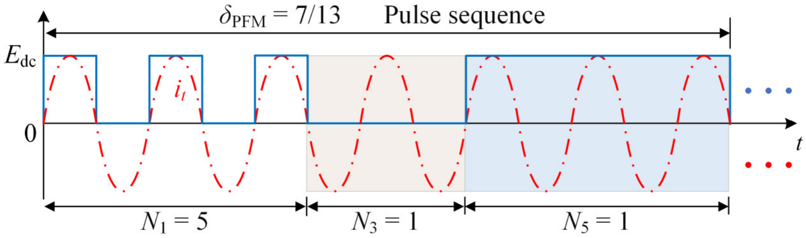


Figure 7: Theoretical waveform of PFM output of a half-bridge inverter.

Following the research in [38], the proposed system utilizes a Σ-Δ modulator to generate PFM sequences automatically based on feedback information. It distributes the modulated half-cycles evenly to reduce the current distortion. No complex computing is needed within the waveform generation, as depicted in Fig. 8. An example of the waveform generation process is illustrated in Fig. 9, where δ_{PFM}=19/29.

As the mutual inductance of the circular unipolar coil is different from the bipolar coils, the PFM duty ratio of each power channel is specially tuned to generate equalized motor currents. To better describe the current regulation, δ is defined as the output ratio of motor current.

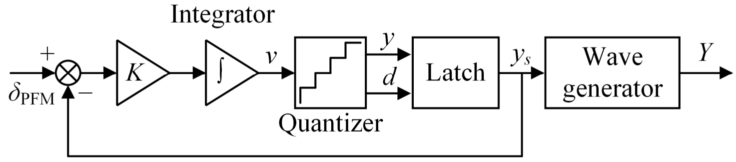


Figure 8: Σ-Δ modulator for PFM generation.

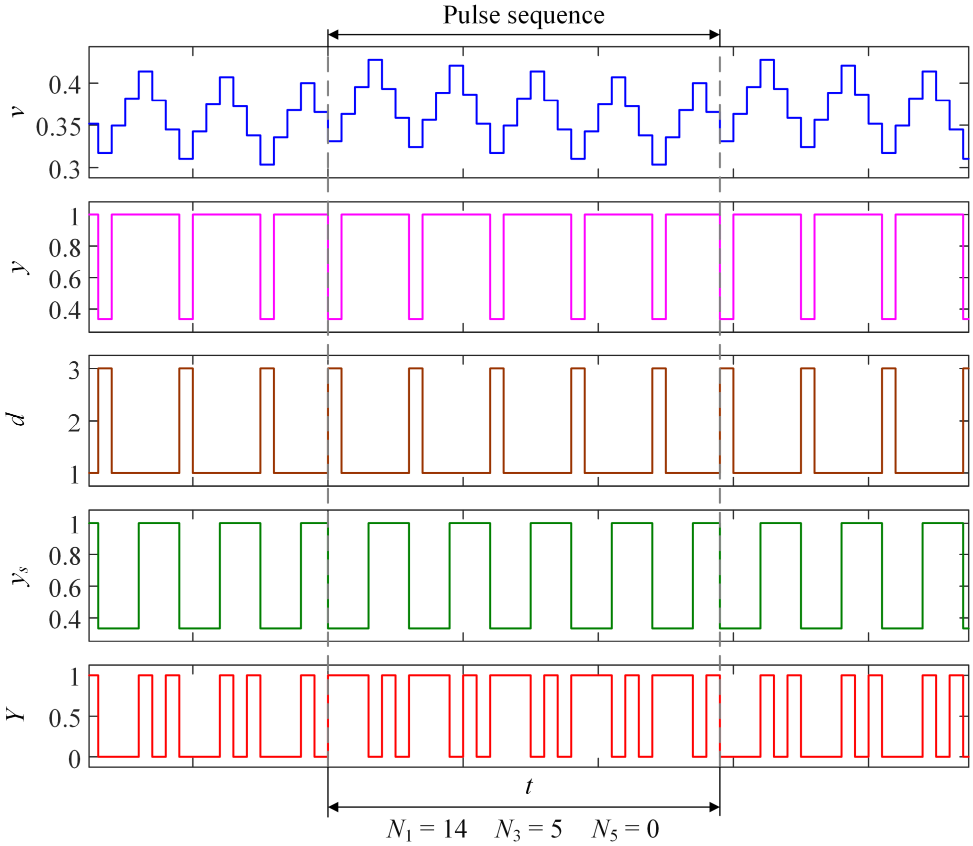


Figure 9: Waveforms of Σ-Δ PFM generation when δ_{PFM}=19/29 (N_1=14, N_3=5, N_5=0).

3.2 Closed-loop Speed Control

The proposed WPD realizes a closed-loop speed control based on rotor position feedback sampled by position sensors. Contactless feedback is not discussed in detail in this article, as several wireless feedback approaches have been proven to offer stable feedback operation wireless motors, such as Bluetooth [17], wireless resolver [30], amplitude-shift-keying modulated Hall effect sensor [23], and photoelectric encoder [25]. Fig. 10 shows the control diagram of the proposed WPD. The current motor speed calculated by the primary controller is compared with the aim speed, and then the difference is sent to a PI controller to generate the duty ratio δ and calculate the PFM duty ratios of three channels based on mutual inductances. After Σ-Δ modulator generates the PFM sequence, the primary controller outputs control signals to power switches of the transmitter-side power inverter based on the PFM sequence and rotor position.

In traditional closed-loop speed control, motor currents are also sampled together with position information. The current control forms an inner loop while the speed control forms an outer loop. However, in wireless schemes, real-time transmission of current information brings extra complexity and high requirements in communication speed and latency. In the proposed WPD, only rotor positions are sampled during the operation.

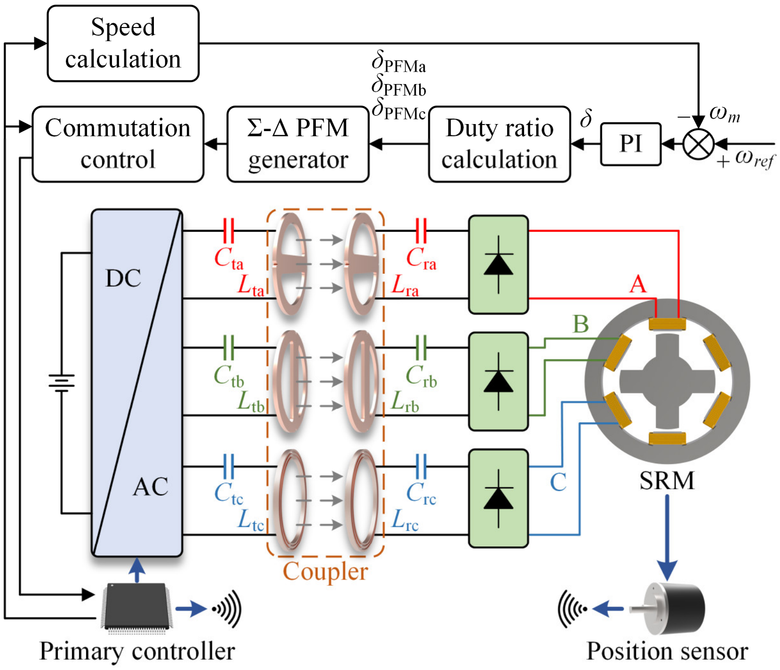


Figure 10: Control diagram of proposed WPD.

4 Verification

Table 1: Simulation parameters

Items	Value	Unit
Transmitter coil inductance (L_{ta}, L_{tb}, L_{tc})	67.84, 67.84, 57.89	μH
Receiver coil inductance (L_{ra}, L_{rb}, L_{rc})	67.84, 67.84, 57.89	μH
Coil internal resistance (R_{ta}, R_{tb}, R_{tc}, R_{ra}, R_{ra}, R_{ra},)	0.075	Ω
Mutual inductance (M_a, M_b, M_c)	10.99, 10.99, 13.41	μH
Transmitting frequency (f_0)	100	kHz
Transmitter compensation capacitances (C_{ta}, C_{tb}, C_{tc})	37.34, 37.34, 43.76	nF
Receiver compensation capacitances (C_{ra}, C_{rb}, C_{rc})	37.34, 37.34, 43.76	nF
SRM rotor inertia	0.008	kg·m^2
SRM stator resistance (Ω)	3	Ω
SRM winding unaligned inductance (mH)	9.1	mH
SRM winding aligned inductance (mH)	52.7	mH

To further evaluate the feasibility of the proposed WPD for SRMs, a circuit model was built based on the circuit topology in Fig. 1 and the control diagram in Fig. 10 with detailed parameters in Table 1. As listed in Table 1, power channel *C* has stronger coupling due to coil structure, thus the output of channel *C* is set as a reference in output equalization, the duty ratios are calculated as:

$$\begin{cases} \delta_{\text{PFMa}} = \delta \dfrac{M_{\text{a}}}{M_{\text{c}}} \\ \delta_{\text{PFMb}} = \delta \dfrac{M_{\text{b}}}{M_{\text{c}}} \\ \delta_{\text{PFMc}} = \delta \end{cases} \tag{6}$$

First, three 10-Ω resistors were loaded to the WPT channels to test the PFM regulation. Fig. 11 (a) shows the waveforms of u_a, u_b, u_c, i_{ta}, i_{tb}, and i_{tc} when δ=1/2, as well as zoomed waveforms of u_a, i_{ta}, u_b, and i_{tb}. The outputs (I_a, I_b, and I_c) are shown in Fig. 11 (b). The Σ-Δ modulator generates the PFM sequence with the given duty ratio and also ensures a ZVS operation. Then, an SRM model replaces the resistive loads for further evaluation. The motor speeds up from 0 rpm to 200 rpm, and finally reaches 400 rpm, with a constant load of 0.4 N·m. The waveforms are recorded in Fig. 12, proving the feasibility of the proposed system.

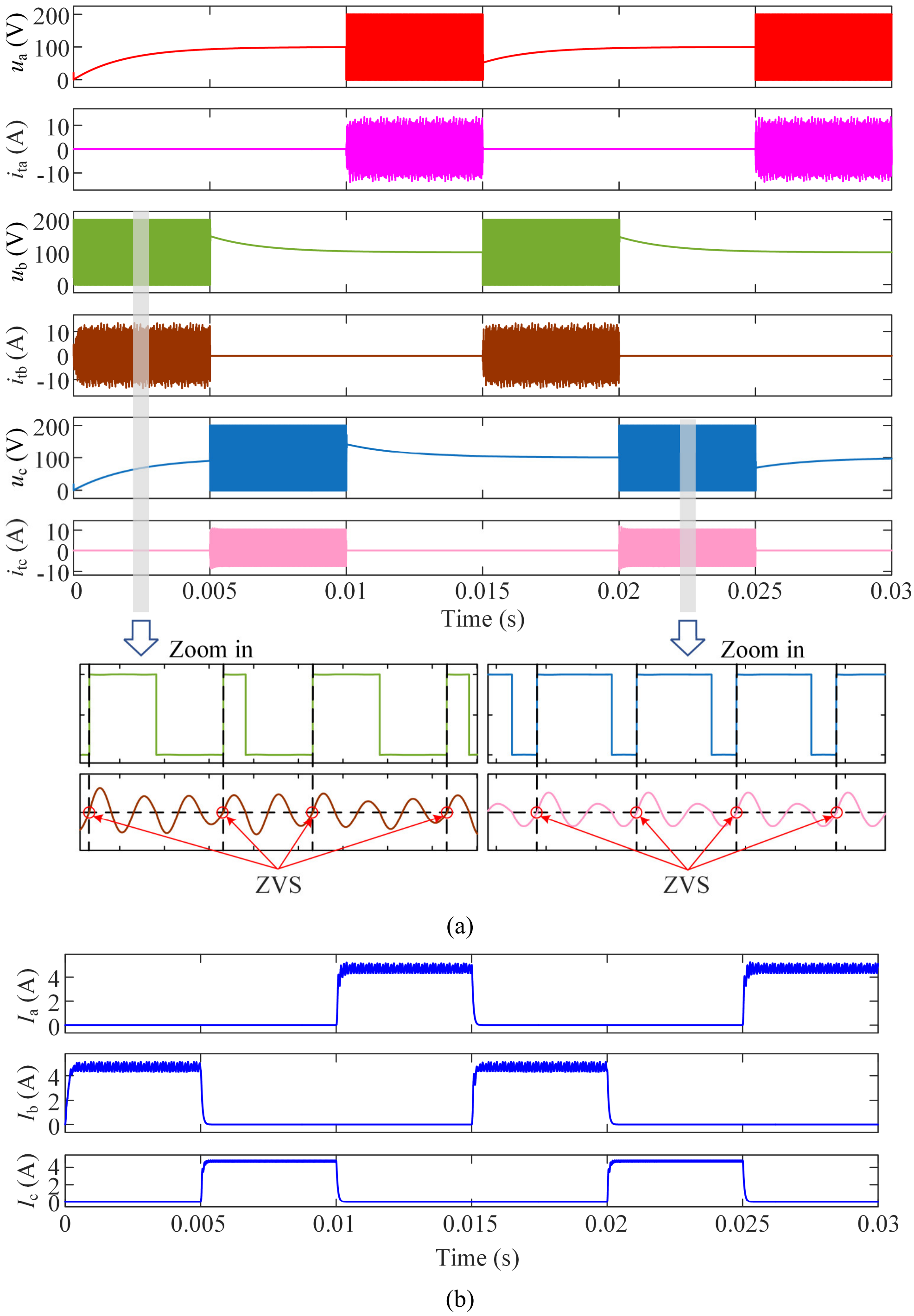


Figure 11: Simulated waveforms of proposed WPD using 10-Ω resistive loads. (a) Waveforms of inverter output voltage and current. (b) Waveforms of output currents.

5 Conclusion

This paper proposes a WPD for electric vehicles, particularly, a wireless SRM is proposed. The system is fully controlled by the primary controller, and no active switches are adopted on the receiver side. Based on position feedback only, the system realizes a closed-loop speed control and the Σ-Δ PFM regulates the motor current while maintaining ZVS operation. With the proposed scheme, the motor has precise speed control capability. Both theoretical analysis and computer simulations are conducted to verify the feasibility of the proposed WPD for wireless SRM.

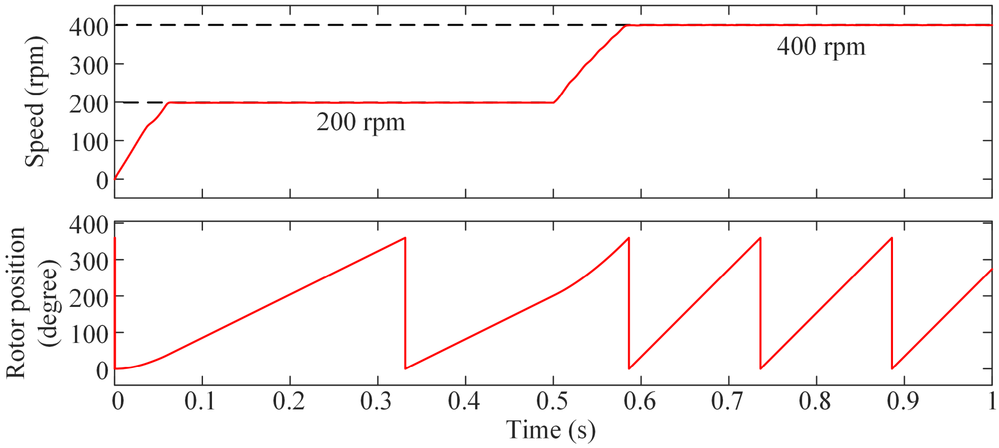


Figure 12: Motor speed and rotor position while accelerating with a constant load of 0.4 N·m.

Acknowledgments

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References

[1] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, *Wireless power transfer via strongly coupled magnetic resonances*, Science, ISSN 0036-8075, 317(2007), 83-86.

[2] Z. Zhang, K. T. Chau, C. Liu, F. Li, and T. W. Ching, *Quantitative analysis of mutual inductance for optimal wireless power transfer via magnetic resonant coupling*, IEEE Transactions on Magnetics, ISSN 1941-0069, 50(2014), 1-4.

[3] W. Liu, K. T. Chau, C. H. T. Lee, C. Jiang, W. Han, and W. H. Lam, *Multi-frequency multi-power one-to-many wireless power transfer system*, IEEE Transactions on Magnetics, ISSN 1941-0069, 55(2019), 1-9.

[4] M. Amjad, M. Farooq-i-Azam, Q. Ni, M. Dong, and E. A. Ansari, *Wireless charging systems for electric vehicles*, Renewable and Sustainable Energy Reviews, ISSN 1364-0321, 167(2022), 1-21, Art. no. 112730.

[5] C. Qiu, K. T. Chau, T.W. Ching, and C. Liu, *Overview of wireless charging technologies for electric vehicles*, Journal of Asian Electric Vehicles, ISSN 1883-6038, 12(2014), 1679-1685.

[6] Q. Huang, Z. Ma, S. Wang, and Y. Yang, *Integration of near-field communication (NFC) antenna and wireless charging coil for portable electronic products*, IEEE Journal of Emerging and Selected Topics in Power Electronics, ISSN 2168-6785, 12(2024), 3415-3425.

[7] W. Han, K. T. Chau, C. Jiang, W. Liu, and W. H. Lam, *Design and analysis of quasi-omnidirectional dynamic wireless power transfer for fly-and-charge*, ISSN 1941-0069, IEEE Transactions on Magnetics, 55(2019), 1-9.

[8] C. Liu, C. Jiang, J. Song and K. T. Chau, An effective sandwiched wireless power transfer system for charging implantable cardiac pacemaker, IEEE Transactions on Industrial Electronics, ISSN 1557-9948, 66(2019), 4108-4117.

[9] J. Ma, Z. Li, Y. Liu, M. Ban, and W. Song, *Thermal analysis and optimization of the magnetic coupler for wireless charging system*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 38(2023), 16269-16280.

[10] R. Lyu, W. Liu, Q. Li, and K. T. Chau, *Overview of superconducting wireless power transfer*, Energy Reports, ISSN: 2352-4847, 12(2024), 4055-4075.

[11] M. Song, P. Jayathurathnage, E. Zanganeh et al., Wireless power transfer based on novel physical concepts. Nature Electronics, ISSN 2520-1131, 4(2021), 707-716.

[12] W. Liu, K. T. Chau, X. Tian, H. Wang, and Z. Hua, *Smart wireless power transfer - opportunities and challenges*, Renewable and Sustainable Energy Reviews, ISSN 1364-0321, 180(2023), 1-22, Art. no. 113298.

[13] W. Han, K. T. Chau, Z. Zhang, and C. Jiang, *Single-source multiple-coil homogeneous induction heating*, IEEE Transactions on Magnetics, 53(2017), ISSN 1941-0069, pp. 1-6, Art. no. 7207706.

[14] C. Jiang, K. T. Chau, Y. Y. Leung, C. Liu, C. H. T. Lee, and W. Han, *Design and analysis of wireless ballastless fluorescent lighting*, IEEE Transactions on Industrial Electronics, ISSN 1557-9948, 66(2019), 4065-4074.

[15] C. Jiang, K. T. Chau, C. H. T. Lee, W. Han, W. Liu, and W. H. Lam, *A wireless servo motor drive with bidirectional motion capability*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 34(2019), 12001-12010.

[16] Z. Zhang, H. Pang, A. Georgiadis, and C. Cecati, *Wireless power transfer—An overview*, IEEE Transactions on Industrial Electronics, ISSN 1557-9948, 66(2019), 1044-1058.

[17] C. Jiang, K. T. Chau, C. H. T. Lee, W. Han, W. Liu, and W. H. Lam, *A wireless servo motor drive with bidirectional motion capability*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 34(2019), 12001-12010.

[18] A. Babaki, S. Vaez-Zadeh, A. Zakerian, and A. Jafari Natanzi, *Analysis and control of wireless motor drives with a single inverter in primary side*, IEEE Transactions on Energy Conversion, ISSN 1558-0059, 36(2021), 930-939.

[19] H. Wang, K. T. Chau, C. H. T. Lee, and C. Jiang, *Wireless shaded-pole induction motor with half-bridge inverter and dual-frequency resonant network*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 36(2021), 13536-13545.

[20] S. Li, K. T. Chau, W. Liu, C. Liu, and C.K. Lee, *Design and control of wireless hybrid stepper motor system*, IEEE Transactions on Power Electronics, ISSN: 1941-0107, 39(2024), 10518-10531.

[21] L. Fang et al., *Design of wireless individual-drive system for variable-reluctance stepping motor*, IEEE Transactions on Circuits and Systems II: Express Briefs, ISSN 1558-3791, 69(2022), 2141-2145.

[22] H. Wang, K. T. Chau, W. Liu, and S. M. Goetz, *Design and control of wireless permanent-magnet brushless DC motors*, IEEE Transactions on Energy Conversion, ISSN 1558-0059, 38(2023), 2969-2979.

[23] S. Li, K. T. Chau, W. Liu, J. Guo, C. Liu, and Y. Hou, *A wireless permanent-magnet brushless DC motor using contactless feedback and autonomous commutation*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 40(2025), 10140-10153.

[24] Y. Chen, C. Gan, H. Shi, K. Ni, Z. Yang, and R. Qu, *Auxiliary circuit free maximum power efficiency tracking scheme for wireless motor system with source-load coupling*, IEEE Transactions on Industrial Electronics, 70(2023), 3414-3425.

[25] Y. Liu, W. Wang, S. Liu and C. Liu, "*A compact wireless permanent magnet synchronous motor system with precise speed and position control*," IEEE Transactions on Industrial Electronics, ISSN 1557-9948, 71(2024), 11852-11863.

[26] Z. Xue, K. T. Chau, W. Liu, and Z. Hua, *Magnetic-free wireless self-direct drive motor system for biomedical*

applications with high-robustness, IEEE Transactions on Power Electronics, ISSN 1941-0107, 39(2024), 2882-2891.

[27]K. T. Chau, *Pure electric vehicles*. In Alternative fuels and advanced vehicle technologies for improved environmental performance – Towards zero carbon transportation, (Ed.) R. Folkson, Woodhead Publishing, ISBN 978-0-85709-522-0, 2014, 655-684.

[28]C. Jiang, K. T. Chau, W. Liu, C. Liu, W. Han, and W.H. Lam, *An LCC-compensated multiple-frequency wireless motor system*, IEEE Transactions on Industrial Informatics, ISSN 1941-0050, 15(2019), 6023-6034.

[29]J. Cai, B. Li, A. D. Cheok, Y. Yan, and X. Zhang, *Optimal design and control of a decoupled multifrequency multiphase wireless switched reluctance motor drive system*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 39(2024), 10152-10165.

[30]H. Wang, K. T. Chau, C. H. T. Lee and X. Tian, *Design and analysis of wireless resolver for wireless switched reluctance motors*, IEEE Transactions on Industrial Electronics, ISSN 1557-9948, 70(2023), 2221-2230.

[31]W. Ding, K. Li, J. Yuan, J. Li, and C. Du, *Wireless power transmission-based in-wheel switched reluctance motor drive system with an x-type converter*, IEEE Transactions on Energy Conversion, ISSN 1558-0059, 38(2023), 450-462.

[32]Y. Jiang, L. Wang, Y. Wang, J. Liu, X. Li, and G. Ning, *Analysis, design, and implementation of accurate ZVS angle control for EV battery charging in wireless high-power transfer*, IEEE Transactions on Industrial Electronics, ISSN 1557-9948, 66(2019), 4075-4085.

[33]H. Li, J. Fang, S. Chen, K. Wang, and Y. Tang, *Pulse density modulation for maximum efficiency point tracking of wireless power transfer systems*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 33(2018), 5492-5501.

[34]W. Liu, K. T. Chau, C. H. T. Lee, W. Han, X. Tian, and W. H. Lam, *Full-range soft-switching pulse frequency modulated wireless power transfer*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 35(2020), 6533-6547.

[35]W. Li, H. Zhao, J. Deng, S. Li, and C. C. Mi, *Comparison study on SS and double-sided LCC compensation topologies for EV/PHEV wireless chargers*, IEEE Transactions on Vehicular Technology, ISSN 1939-9359, 65(2016), 4429-4439.

[36]W. Liu, K. T. Chau, C. H. T. Lee, X. Tian, and C. Jiang, *Hybrid frequency pacing for high-order transformed wireless power transfer*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 36(2021), 1157-1170.

[37]X. Wang et al., *Synthesis and analysis of primary high-order compensation topologies for wireless charging system applying sub-harmonic control*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 38(2023), 9173-9182.

[38]J. Tang, Q. Zhang, C. Cui, T. Na, and T. Hu, *An improved hybrid frequency pacing modulation for wireless power transfer systems*, IEEE Transactions on Power Electronics, ISSN 1941-0107, 36(2021), 12365-12374.

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