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Wireless Power Transfer circuit for e-bike battery charging system

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Abstract: This work proposes a Series Series Resonant Inductive Power Transfer (SSRIPT) circuit as a means of supplying power to a wireless e-bike. System architecture is clearly outlined, and the widest possible range of viable aesthetic approaches is shown. To ensure the circuit is effective, a simulation model was created with the PSIM software. The simulation of an eighty watt device has been completed, with special focus placed on optimizing the design to reduce the final product's size and bulk. Further, it has two XBee-Pro S2 radios for simultaneous wireless communication between the primary and secondary sides. The efficiency of the planned method of management and aesthetic is verified by MATLAB simulation testing.

Search Terms: e-bike, battery, and Serie Series Resonant Inductive Power Transfer (SSRIPT)

I.INTRODUCTION

Wireless power transfer (WPT) is a well-known technique that allows energy to be transferred from a power source to an electrical load over an air gap using electromagnetic fields instead of wires. Radiative (or RF-based) and non-radiative (or coupling-based) WPT are the two most used approaches [1]. Because of the potential dangers associated with RF waves, the first technique is limited to low-power applications, whereas the second relies on the coupling of magnetic field between two coils to circumvent this limitation. Depending on the application, a WPT may use either a capacitive or inductive coupling mechanism. This second option is favored since its weaker electric field has less negative effects on humans. Inductive Power Transfer (IPT) is the name given to the wireless power transfer technology that relies on inductive coupling to transmit energy. This method has recently emerged as a major player in many industries, including medicine, consumer electronics (such as smartphones), clean manufacturing, and environmentally friendly transportation. There is little doubt that IPT uses can grow from low-power to medium-high power systems [4]. Therefore, researchers are now interested in maximizing power efficiency and extending transmission range [5]. In particular, if the operating frequency uses the resonant frequency, using a resonance circuit architecture on both the main and secondary sides of an IPT system may lead to improved performance for greater separation distance and for power transfer capabilities. RIPT (Resonant Inductive Power Transfer) is the name given to this circuit design, and it is widely regarded as a superior option for wireless powering across intermediate distances [5]. It's essentially a two-coil system, which is a loosely connected transformer [6], with two separate electrical circuits that are mutually coupled with one another (i.e., the primary and secondary sides). Since the latter produces a sizable leakage flow, it leads to a low coupling coefficient and thus low efficiency. To counteract this unfavorable influence, a compensation network is needed, and capacitors may be wired in series or parallel with the coils to do this. Topologies distinguishable by their use of series and/or parallel LC resonant circuit topology include the series-series (SS), series-parallel (SP), parallel-series (PS), and parallel-parallel (PP) configurations (PP). The main and/or secondary inductance [2] must be resonant with the compensating capacitor in order to fine-tune the system's performance. The power factor can be increased by using the main compensation network to reduce the VA rating of the power supply, and the secondary compensation network can improve the power transfer capabilities. With respect to efficiency, series-series circuits outperform the other three topologies (series-parallel, parallel-parallel, and parallel-series) [7]. At its resonant frequency 0, also known as the zero-phase angle

(ZPA) frequency, the SS-RIPT architecture is operationally equivalent to a double-tuned circuit (i.e., a resonant tank is present on either side of the circuit). However, in such a circuit, there may be more than one zero-phase-angle (ZPA) frequency, or rather several resonant frequencies. When the coupling coefficient k is larger than a critical value, kc, a transition occurs that is referred to as a bifurcation [8]. Special attention should be paid to the design of the magnetic components to ensure the circuit operates reliably and without bifurcation. Contactless battery charging, which is one kind of "near-field applications," is now the most promising usage of RIPT circuits. To promote the usage of a bike sharing service and improve the green inter-mobility in urban setting, a RIPT circuit for e-bike charging station is suggested in this study. In addition to guaranteeing a superior safety owing to the galvanic insulation between the primary (such as the charging station) and the secondary circuit, the lack of a plug-in makes this system more user-friendly than conventional ones (e.g., e-bike). Increased dependability, less maintenance, and a long lifespan are all guarantees thanks to this latter feature. Moreover, the system may be used in both ultraclean and ultradirty environments [9], because to the galvanic insulation and the concomitant lack of electrical lines and mechanical contacts, satisfying the needs of an outside service. This article focuses on the architecture and hardware implementation of an e-bike charger in order to provide a final product with reduced weight and dimensions that can be readily retrofitted to existing e-bikes and e-bike stations.

II.LITERATURE SURVEY

[1] X. Lu, P. Wang, D. Niyato, D. I. Kim and Z. Han, "Wireless Charging Technologies: Fundamentals, Standards, and Network Applications," in IEEE Communications Surveys & Tutorials, vol. 18, no. 2, pp. 1413-1452, Secondquarter 2016.

Power may be sent to electronic devices over an air gap using wireless charging technology. Recent innovations in wireless charging methods and the introduction of commercial goods provide a viable alternative to traditional portable battery power in resolving the energy bottleneck experienced by such gadgets. However, there are a number of challenges with scheduling, power management, and implementation that arise when integrating wireless charging into current wireless communication networks. In this article, we provide a thorough introduction to wireless charging methods, including their historical evolution, current state of technical standards, and emerging uses in the field of networking. In this article, we take a look at the various methods for deploying and scheduling static, mobile, and wireless chargers for use in network applications. Finally, we address some of the remaining questions and difficulties associated with putting wireless charging systems into practice. Last but not least, we speculate on potential wireless charging network uses in the future.

[2] WCZ and CCM, "Compensation Topologies of High-Power Wireless Power Transfer Systems," IEEE Transactions on Vehicular Technology, 65(6), pp. 4768-4778, June 2016.

Benefiting current automation systems, medical applications, consumer electronics, and more, wireless power transfer (WPT) is a relatively new technology that allows electric power to be sent over a specified distance without physical touch. This study surveys the many methods of compensation that have been proposed so far for the loosely coupled transformer. The fundamental and complex features of compensation topologies are analyzed and rated. Passive resonant networks are broken down into its component parts and evaluated to determine the best method for achieving a constant (load-independent) voltage or current output. Examples of common WPT compensation topologies are shown, each of which may be thought of as the union of many resonant network blocks. In addition, we analyze the input zero phase angle and the soft switching. The report also delves into the compensating needs for peak efficiency based on the various WPT deployment scenarios.

"Modern Trends in Inductive Power Transfer for Transportation Applications," by G. A. Covic and J. T. Boys, appeared in the March 2013 issue of IEEE's Journal of Emerging and Selected Topics in Power Electronics (volume 1, issue 1).

Modern automation systems, especially those operating in harsh conditions, may benefit greatly from inductive power transfer (IPT), which has evolved into a reliable power distribution technology in recent years. The same equipment may be employed in both a filthy factory and a clean one. This study explores the history of basic factory automation (FA) IPT systems, from their inception through their adaptation to today's sophisticated applications and beyond, including the much more formidable IPT highway. Power is transferred effectively between two highly linked coils working at resonance, which is at the heart of IPT technology. A lot of progress has been made throughout time in terms of air gap, efficiency, coupling factor, and power transmission capabilities. Misalignment is made possible by the introduction of new magnetic principles, which enable IPT systems to move from elevated monorails to the ground. However, there are major difficulties due to the requirements of an IPT highway. In this case, compared to the best FA practice, air-gaps must be one hundred times larger, power levels must be ten times higher, system losses must be ten times lower in order to meet efficiency requirements, and systems from different manufacturers must be interoperable across the entire range of operation. This article discusses the progress that has been made in addressing the obstacles associated with roadways, as well as the ongoing issues that have not yet been resolved by designers.

An Efficiency Optimization Scheme for Bidirectional Inductive Power Transfer Systems, B. X. Nguyen et al., IEEE Transactions on Power Electronics, volume 30, issue 11, pages 6310-6319, November 2015.

Bidirectional inductive power transfer (BIPT) systems are better suited for loads needing two-way power flow, such as vehicle-to-grid applications with electric cars, whereas unidirectional inductive power transfer (UDIPT) systems enable loads to consume electricity. There have been several initiatives to improve BIPT efficiency. The phase shift angle of the pickup converter governs the output power in a conventional BIPT system, whereas the main converter controls the input current. To reduce the coil losses in a series-series compensated BIPT system, this research suggests using an improved phase-shift modulation method. In addition, a thorough analysis of how power converters affect the system as a whole is provided. To maximize the BIPT system's effectiveness as a whole, a closed-loop controller is recommended. To demonstrate the value of the suggested approach, theoretical results are provided and compared to simulations and measurements of a 0.5 kW prototype. The results provide strong evidence for the viability of the suggested system, which provides excellent efficiency throughout a broad output power range.

[5] A Comprehensive Study on Composite Resonant Circuit-Based Wireless Power Transfer Systems, by J. Kim, G. Wei, M. Kim, J. Jong, and C. Zhu, IEEE Transactions on Industrial Electronics, vol. 65, no. 6, pages 4670-4680, June 2018.

Recent years have seen an increase in the use of magnetic resonant wireless power transfer (WPT) technology, with a number of different system topologies being implemented using a wide variety of composite resonant circuits to achieve a wide range of WPT properties. In this study, we examine the topologies and properties of the family of WPT systems that are based on composite resonant circuits and provide our findings. A calculation method of resonant frequency, current ratio, and quality factor of these circuits is presented, and the characteristics of these parameters are clarified. This leads to an examination of the characteristics of the composite resonant circuits, which are the fundamental circuits of transmitter and receiver of these systems. Second, this provides the foundation for research into WPT systems based on composite resonant circuits. We investigate potential configurations for these systems and provide a model for them that is functionally similar.

III.PROPOSED SYSTEM

SYSTEM DESCRIPTION

The SS-RIPT circuit's overall design may be seen in Fig. 1. The input DC voltage Vin is generated by an AC-DC converter using electricity drawn from the utility grid (i.e., 230 Vrms, 50 Hz). Using a half-bridge stage, the resulting DC voltage is transformed into a high-frequency AC voltage vp. So, the main compensation tank and primary coil of a power supply will resonantly vibrate at a frequency f0 matched to the switching frequency at which the power semiconductor devices are operated [6]. High-frequency alternating current (AC) travels through the main loop coil, creating a magnetic field that is then "generated" in the secondary loop coil. After a capacitive filter, Cout, is added to a diode-bridge rectifier, the resulting high-frequency AC voltage, vs, is converted to DC voltage. The battery pack receives the DC voltage Vo at its output. This is because there is insufficient coupling between the primary and secondary sides of the circuit, which results in a lower power output. To fix this problem, a capacitive tank with suitable leakage inductance correction should be used. To achieve unity power factor with a lower VA rating from the source, the main compensation network might be helpful.

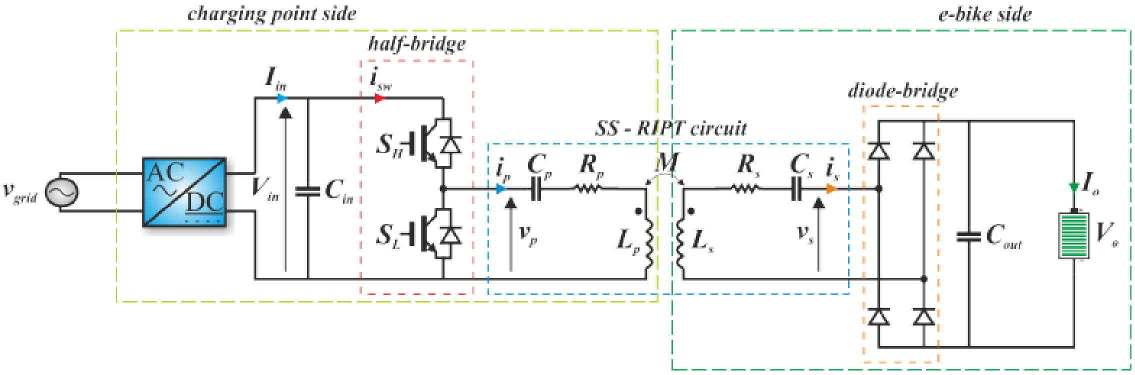


Fig. 1. Wireless charger for e-bike battery pack

In reality, the power factor is affected by the reactive nature of the impedance encountered by the source [10]. As a corollary, the efficiency of the system drops due to the resistive losses created by the circulation of reactive power. Adding an additional compensating circuit helps boost the system's power transfer efficiency. Secondary compensating capacitance is selected to enable resonance and achieve maximum performance when the secondary is tuned to the resonant frequency. The primary capacitance Cp is independent of mutual inductance M and load, and the reflected reactance is zero, two of the fundamental benefits of the SS-RIPT circuit topology that have been widely discussed [8, 11]. Suitable design procedures are reported in [12], with the primary goal being the determination of the values of electrical and electromagnetic circuit parameters, for an SS-RIPT configuration, that would satisfy the aforementioned power transfer capability requirements while also avoiding the bifurcation phenomenon. Table I displays the results of the measurements taken.

The e-bike charger's circuit specs are laid forth in Table I.

Symbol	Description	Value
L_p, L_s	Primary, secondary self-inductance	$91.3\ \mu H$
R_p, R_s	Equivalent primary, secondary resistance	$61.8\ m\Omega$
M	Mutual inductance	$30\ \mu H$
C_p, C_s	Primary, secondary compensation capacitance	$180\ nF$
f_0	Resonant frequency	$40\ kHz$
V_{in}	Rated input DC voltage	$48\ V$
V_o	Rated output DC voltage	$42\ V$
P_o	Rated output power	$80\ W$
R_o	Rated output resistance	$22\ \Omega$

Because of their superior mutual coupling and lower leakage flux, EE cores are the shape of choice for the planned magnetic pads [12]. A ferrite material with a relative permeability of 2300 and a flux density saturation threshold of 0.42 T forms the core. The input capacitor Cin=4-330 F=1.32 mF has such a high value because it is possible to get the required current from the power source while keeping the dc-link input voltage constant. The output filter capacitor has a value of Cout=3-680 F2 mF, which ensures a constant voltage at the output. Additionally, the output RC circuit governs the system dynamics, which in turn influences the size of Cout. Therefore, there is a limit on the time response of the system due to the constant =RoCout. In addition, the digital controller only takes action whenever fresh data is received, therefore the necessary time delay for ZigBee protocol wireless connection between the main and secondary side must be considered.

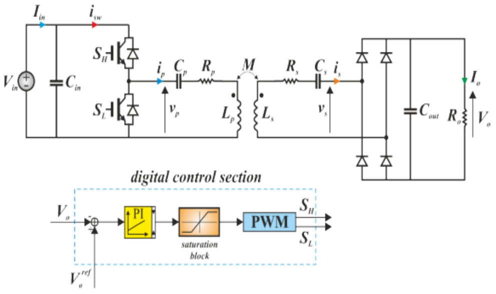


Fig. 2. Digital control circuit simulation

Figure 2 depicts the control method, whereas Table I lists the identical values for the circuit parameters employed. By subtracting the actual battery voltage from the target reference voltage, we can calculate the voltage error, which may then be used as an input to a digital proportional-integral (PI) controller. A saturation block thus keeps the duty cycle where it ought to be [0; 0.5]. The gate signals for the half-bridge converter are finally produced by the PWM (Pulse Width Modulation) block. With the intention of maximizing power transmission, the operating frequency is locked in at the resonance frequency (i.e. 40 kHz). Since no dynamic changes to the circuit parameters take place in an SS-RIPT based static charging system, the chosen control approach belongs to the category of fixed frequency methods.

IV.SIMULATION RESULTS

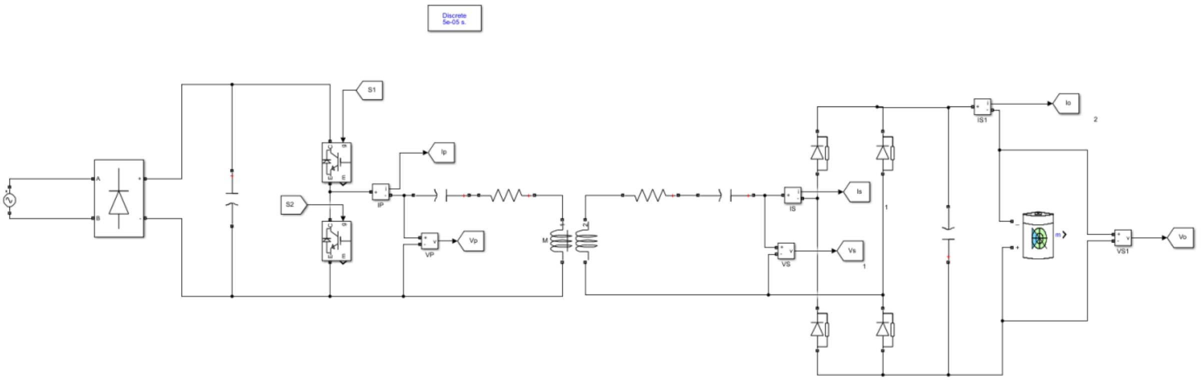


Fig.3 MATLAB/SIMULINK circuit diagram of the proposed system

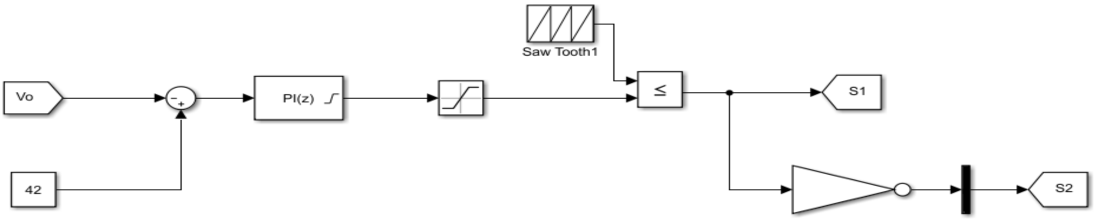
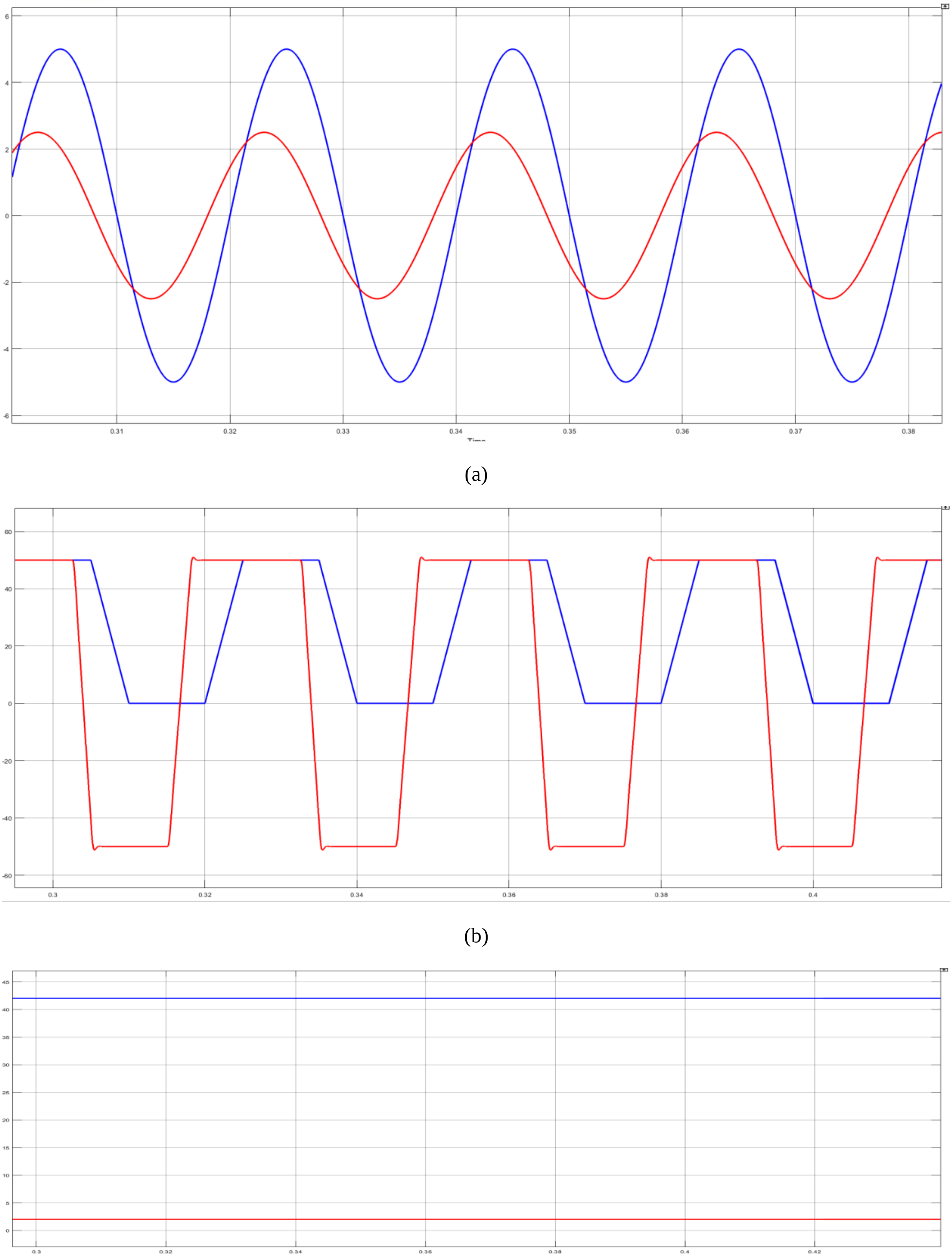


Fig.4 Control system

Fig. 3 illustrates the PSim simulator's steady-state results for the circuit's primary voltages and currents. Both the main and secondary currents exhibit nearly sinusoidal waveforms, as seen in Fig. 5.a). As demonstrated in Fig. 5.b), high-frequency (i.e., resonance frequency) square-waves are produced by the main and secondary voltages. In specifically, the half-bridge connection specifies that the principal voltage is a positive amount from zero to Vin. Fig. 5.c) shows that the output voltage behaves reliably and meets the target value of 42 V.



(a)

(b)

(c)

Fig.5 Simulated performance: a) primary and secondary currents; b) primary and secondary voltages; c) load voltage and current.

CONCLUSION

This work focuses on the design and regulation of a wireless power transfer circuit architecture for charging an electric bike's battery. In particular, an SS-RIPT circuit for e-bike charging station is planned to encourage people to utilize a bike-sharing service since it is easier to operate than older models. The appropriate design approach may then be established thanks to the detailed description of the system that has been supplied, which highlights the key elements of the selected circuit architecture. To validate the aforementioned design process and put the control approach to the test, a numerical analysis was performed. Successful simulation results validate the efficiency of the suggested design and control strategy for the 80 W e-bike battery charger.

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