



Load Independent Constant Current and Constant Voltage Modes for Static Wireless Charging System Using Reconfigurable Resonant Topology

Abstract: Wireless charging for electric vehicles is gaining attention as an alternative to plug-in systems because it removes physical connectors and simplifies day-to-day charging. Although the concept is promising, maintaining stable power transfer in a stationary wireless setup is not straightforward. Changes in the alignment between coils, fluctuations in coupling strength, and the natural variation in battery characteristics often lead to inconsistent charging performance. In this work, a static EV wireless charging system of 60 V, 2 KW is developed using an LCC-S resonant network that is tuned to operate at two carefully selected frequencies. At these operating points, the system naturally behaves like a current source or a voltage source, allowing the charger to move from CC to CV mode without relying on additional conversion stages. Both frequencies are designed to maintain nearly zero phase angle comply with the SAE J2954 frequency standards which helps the inverter operate under soft-switching conditions and reduces unnecessary reactive power. Overall, the proposed approach offers an efficient and compact wireless charging solution capable of delivering reliable CC/CV charging, even when coupling or load conditions change.

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Introduction

The move toward large-scale electrification of transportation has accelerated the development of reliable and user-friendly charging technologies for electric vehicles. As EVs become integrated into everyday mobility whether in homes, public charging zones, or commercial fleets the drawbacks of plug-in charging methods are becoming more evident. Cables and connectors not only wear out with repeated use but are also exposed to

environmental degradation, vandalism, and safety hazards. These issues create inconvenience for users and increase maintenance needs for operators. Wireless power transfer has therefore emerged as an attractive alternative because it removes the dependence on physical connectors and enables charging to occur automatically when a vehicle is positioned over a designated pad. The ability to charge vehicles seamlessly without user intervention offers clear advantages in both convenience and safety, making WPT a strong candidate for future EV charging infrastructure.

Among wireless charging techniques, resonant inductive coupling has gained particular interest because it can transfer energy efficiently across moderate air gaps while preserving electrical isolation between the power source and the vehicle. The typical static WPT arrangement consists of a transmitter coil embedded in the ground and a receiver coil mounted underneath the vehicle. Energy transfer between these coils depends heavily on magnetic coupling, which is strengthened by appropriately designed resonant compensation networks. Although these systems can achieve high efficiency, their



performance is affected by physical factors such as coil misalignment during parking, variation in vertical distance, and disturbances in the surrounding environment. Additionally, the electrical behavior of EV batteries changes continuously as they charge, causing the reflected load seen by the transmitter to shift. These variations make it difficult for traditional compensation topologies to maintain uniform charging performance. EV batteries must follow a well-defined charging pattern consisting of an initial constant-current stage, followed by a constant-voltage stage as the battery approaches full charge. Achieving both stages wirelessly through a single resonant network is challenging. Many existing wireless chargers incorporate additional DC-DC converters, communication links, and secondary-side controllers to regulate the output during CC and CV charging. While these solutions offer control flexibility, they also introduce additional components, increasing system size, power losses, and cost. Higher conduction and switching losses, additional cooling requirements, and reduced overall reliability are common outcomes. Moreover, when power flows through multiple conversion stages, the system often struggles to maintain the soft-switching conditions necessary for high-efficiency operation.

A major technical requirement for efficient wireless charging is maintaining zero-phase-angle (ZPA) switching across different loading conditions. When a resonant network operates at ZPA, the inverter sees a nearly resistive load, which minimizes reactive power and allows the switching devices to operate under favorable soft-switching conditions. This significantly reduces thermal stress and improves inverter lifespan. However, traditional series or parallel compensation structures achieve ZPA only over a limited operating window. As the battery's electrical characteristics evolve during charging, or when the coupling coefficient changes due to misalignment, these networks

drift away from ZPA, causing increased losses and reduced efficiency. These limitations have led to the exploration of higher-order resonant networks particularly those based on LCC or hybrid compensation structures that provide more freedom to tailor voltage and current relationships at the receiver. Such networks can improve misalignment tolerance, reduce current stress on components, and maintain more stable performance under variable loads. The present work introduces reconfigurable LCC-S compensation network capable of supporting both constant-current and constant-voltage operation inherently, without adding converters or switches on the EV side. The core idea is to design the resonant tank so that it behaves like a current source at one resonant frequency and like a voltage source at another. Importantly, both operating points are chosen to maintain zero-phase-angle conditions, ensuring that the inverter continues to operate with soft-switching regardless of the mode. The compensation network uses a combination of series inductance, a series capacitor, and a parallel capacitor to create two distinct electrical responses, each corresponding to a specific charging requirement. By adjusting the switching frequency of the inverter, the system smoothly transitions between CC and CV modes while keeping the power transfer process stable. The proposed system incorporates a front-end rectifier, a boost converter with power factor correction, and a high-frequency inverter that drives the resonant network. The inclusion of a PFC stage ensures compliance with grid standards by shaping the input current waveform and reducing harmonic content. The inverter generates a high-frequency excitation signal that energizes the primary coil, while the resonant components shape the current and voltage profiles required for efficient inductive power transfer. This arrangement not only provides the electrical flexibility to realize CC and CV behavior but also reduces



electromagnetic interference and stabilizes output characteristics during transitions.

The motivation for adopting such a unified resonant architecture is closely tied to the long-term vision for EV charging infrastructure. As cities develop smart parking systems and public charging corridors, the equipment installed must be compact, efficient, and capable of meeting diverse operating conditions. A system that inherently supports both CC and CV charging while maintaining soft-switching and minimizing hardware overhead is well-suited for scalable deployment. Integrating resonant design principles with advanced control and simulation makes it possible to achieve consistent, high-quality charging performance in real-world scenarios. The work presented here proposes that a carefully engineered LCC-S resonant network, combined with digital control and optimized power electronics, can deliver a load-independent wireless charging system that transitions occur naturally between charging modes.

System Overview

Banu Mushtaq's *Heart Lamp* boldly dismantles the proposed wireless charging system has been developed around a unified and streamlined power conversion architecture that enables efficient power delivery from the electrical grid to the EV battery through a magnetically coupled inductive interface. The system is organized into several functional blocks that operate together to maintain stable charging conditions even as the load varies or coil alignment changes. As shown in Fig. 1 the process begins at the AC input, where the grid

supplies a sinusoidal voltage of 230V that must be conditioned before being used for high-frequency wireless transfer. A diode bridge rectifier is employed to convert the incoming AC signal into an unregulated DC waveform. Although simple, this stage alone is insufficient for maintaining grid standards, particularly when non-linear loads cause harmonic distortion. To overcome this limitation, a boost converter equipped with a power factor correction stage is placed immediately after the rectifier. The PFC unit reshapes the input current to follow the input voltage waveform more closely, thereby reducing harmonic content and ensuring near-unity power factor. This guarantees that the system adheres to power quality requirements while providing a stable DC link of 400V for subsequent stages.

The conditioned DC output from the PFC stage is then fed into a high-frequency half-bridge inverter. This inverter plays a crucial role because the resonant wireless power transfer network must be excited at a much higher frequency than the grid frequency to enable efficient magnetic coupling across the air gap. By switching between 85 KHz and 90 KHz, the inverter produces an alternating current waveform suitable for energizing the primary coil of the wireless charger. The amplitude and frequency of this high-frequency signal are not fixed; instead, they are controlled dynamically through the system's digital controller to achieve the desired output characteristics at the battery. The inverter's design ensures that switching transitions are clean and that device stress remains within acceptable limits, particularly during high-power operation.

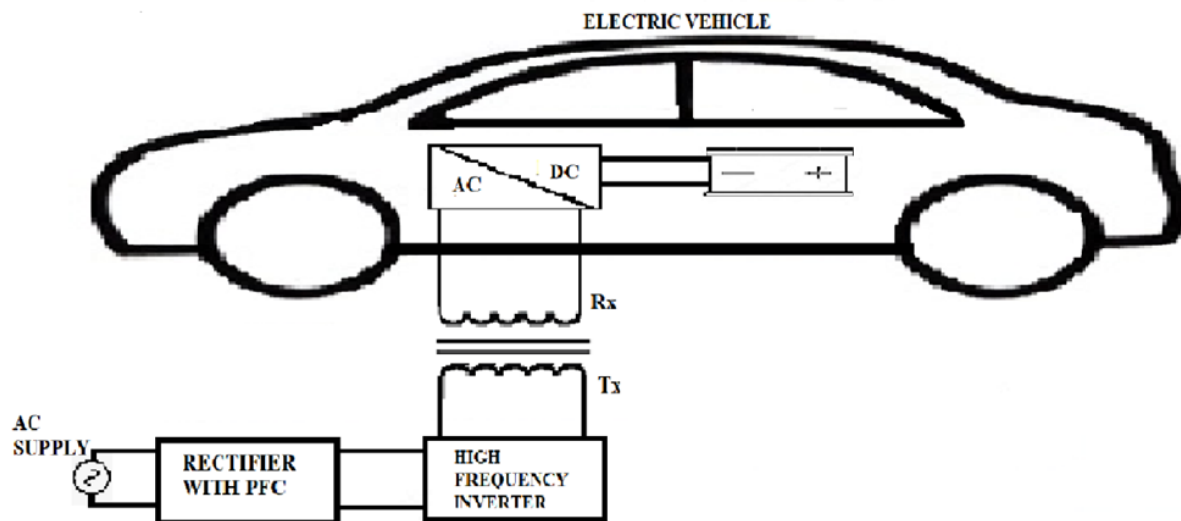


Fig. 1 Block Diagram

At the heart of the system lies the LCC-S resonant compensation network. This network is responsible for shaping the electrical characteristics of the system in such a way that the behavior of the power transfer link becomes nearly independent of the load. Traditional resonant networks often suffer from significant variations in output voltage or current when the coupling coefficient between the coils changes. Such variations are typical in practical charging scenarios where the EV may not be perfectly aligned with the charging pad. By contrast, the LCC-S structure provides more flexibility because it uses a combination of series and parallel reactive elements to create two different resonant frequencies, each corresponding to a specific output characteristic. The primary coil, compensated by the LCC elements, transfers power magnetically to the secondary coil located on the vehicle. The secondary coil is designed as part of an S-type compensation network, which helps maintain stable operation even when coupling conditions are not ideal.

Once the energy reaches the secondary coil, it must be converted into a usable DC form to charge the battery. This is achieved using a high-frequency rectifier, typically implemented with fast-recovery diodes. The rectified DC is

filtered to reduce ripple and supplied directly to the battery of 60 V, 2 KW. One significant

advantage of the proposed topology is that no additional DC-DC converter is needed on the vehicle side. In many existing wireless charging systems, an extra converter is required to achieve constant-current and constant-voltage charging.

A centralized digital control algorithm governs these transitions and ensures smooth operation at all times. The controller continuously monitors system signals, including output current, voltage, and battery state of charge. It then adjusts the inverter's operating frequency and modulation index accordingly. This form of frequency-based control is advantageous because it does not require mechanical relays or additional hardware on the vehicle side. The control logic, implemented in MATLAB/Simulink, provides a flexible and stable platform for testing different strategies and validating the robustness of the proposed wireless charging architecture. This methodology provides not only a theoretical framework but also a strong practical foundation for implementing reliable static wireless EV charging systems in everyday environments.

Design of the LCC-S Resonant Compensation Network

It represents one of the most critical aspects of the proposed wireless charging system as shown in Fig. 2 since the overall charging performance, power-transfer capability, and load-independent behavior are largely governed by the way the resonant tank is configured. Unlike simpler series or parallel structures, an LCC-S network provides additional degrees of freedom by incorporating both series and parallel reactive elements on the transmitter side, which can be strategically

tuned to achieve the current-source and voltage-source characteristics required for constant-current and constant-voltage charging. The objective of this design is not only to ensure efficient power transfer across an inductive air gap but also to maintain these characteristics consistently, even when the coupling coefficient varies due to misalignment or changes in coil separation. Achieving these performance goals requires a thorough understanding of how energy circulates within the resonant tank and how the primary compensation elements influence the reflected impedance seen by the inverter.

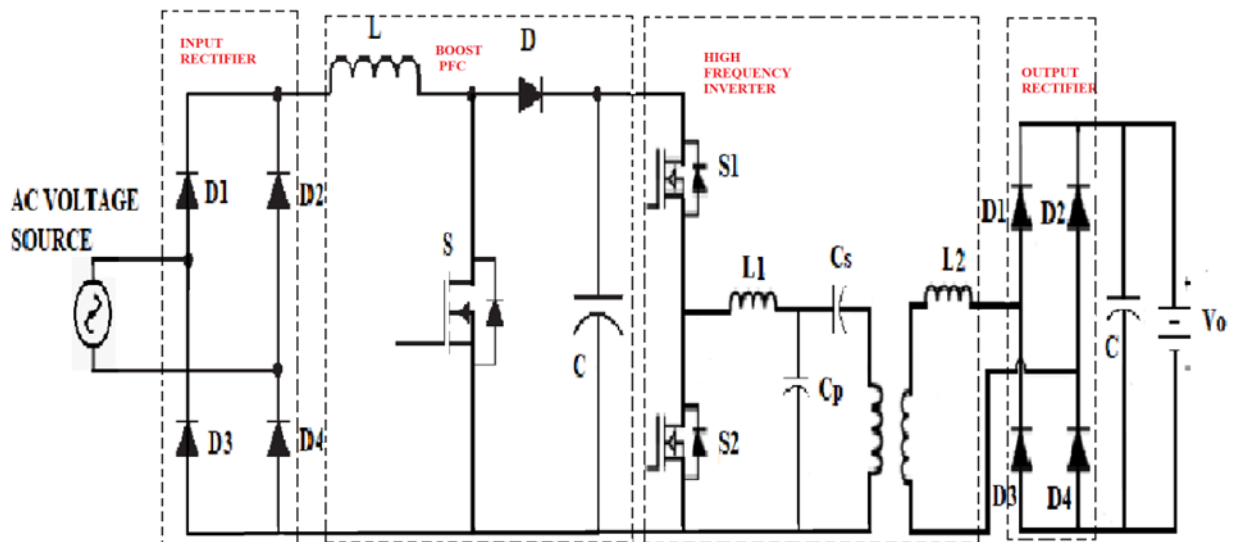


Fig. 2 Circuit Diagram

The design process begins by modeling the wireless power transfer system as a loosely coupled transformer with distinct primary and secondary inductances connected through mutual inductance. This model captures the essential behavior of the magnetic link and provides the basis for determining the required compensation. The LCC front end consists of a series inductor L_1 , a series capacitor C_s , and a parallel capacitor C_p arranged such that they generate two well-defined resonant frequencies. The first resonant point is selected to establish a current-source nature at the

output, enabling the system to maintain a nearly constant charging current despite variations in the reflected load. This is particularly useful in the initial charging phase, where the battery demands steady current to increase its state of charge efficiently. The second resonant point is chosen so the tank behaves more like a voltage source, ensuring that the battery terminal voltage remains well-regulated as it approaches full charge.

The resonant components are selected around a high operating frequency consistent

with the SAE J2954 wireless power transfer standard, which specifies typical values in the range of 85 kHz for light-duty EV wireless chargers as shown in equation (1).

$$f_0 = \frac{1}{2\pi\sqrt{L_1 C_s}} \quad (1)$$

where f_0 is the resonant frequency,

The series capacitor is computed using the resonance condition as shown in equation (2) involving the selected frequency and the coil inductances.

$$C_s = \frac{1}{(2\pi f_0)^2 L_1} \quad (2)$$

The parallel capacitor C_p ensures ZVS operation and shapes the primary tank's input impedance. Typical design guidelines suggest making C_p about 10–30% of C_s .

On the secondary side, the resonant design must match the behavior of the primary network. Although the compensation network on the receiver side is simpler typically consisting of a series inductor L_2 the value of this inductor is chosen so that the secondary coil resonates at the desired frequency in combination with the primary network as shown in equation (3).

$$L_2 = \frac{1}{(2\pi f_0)^2 C_p} \quad (3)$$

When the receiver coil resonates in harmony with the transmitter, the overall power transfer efficiency improves significantly.

Table 1 Specification of LCC-S Compensation Network

Parameters	Value
L_1	6.6 μ H
C_s	0.55 μ F
C_p	0.33 μ F
L_2	0.4 μ H
Operating Frequency	F1 = 85khz to F2 =90khz

For the CV point, the tank is tuned such that the combination of components creates a voltage amplification effect, allowing the output voltage to remain nearly constant even as the load varies. The Table 1 confirms that the selected parameters provide the required charging characteristics and meet the frequency, efficiency, and alignment-tolerance criteria essential for EV wireless charging applications. This structured design process ensures the system provides stable CC/CV charging without relying on additional secondary-side converters.

One of the most important features of the LCC-S network is its ability to maintain soft switching across both operating points. By designing the tank such that the inverter sees a predominantly resistive load at each resonant frequency, switching devices can operate under conditions close to zero voltage switching or zero current switching. This significantly reduces switching losses, suppresses voltage and current spikes, and improves the long-term reliability of the inverter. Maintaining soft switching is especially important in high-frequency applications such as wireless charging, where switching losses can quickly accumulate and cause excessive heating if not properly managed. The LCC-S network ensures that the inverter's operating environment remains favorable across a wide range of load conditions, which is essential for the practical deployment of WPT chargers in real-world settings.

Design Methodology

The design process for the proposed wireless EV charging system involves coordinated sizing of the power-processing stages of PFC-based boost converter. The objective is to ensure that the system provides a stable DC link for the inverter and supports regulated CC/CV charging at the 60V output. The DC-link voltage level is selected according to the

required battery charging voltage and the operating constraints of the inverter. The relationship between the input supply and the desired output charging voltage is established using the fundamental boost converter voltage-conversion expression, which defines how the duty cycle influences the DC-link level as shown in equation (4).

$$D = \frac{V_{out}-V_{in}}{V_{out}} \quad (4)$$

The boost inductor is then sized based on the input voltage range, duty ratio, switching frequency and allowable current ripple as shown in equation (5).

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{\Delta I_L \times f_s \times V_{out}} \quad (5)$$

The output capacitor is chosen from the voltage ripple specification at the DC-link and the expected load power as shown in the equation (6).

$$C = \frac{I_{out} \times (V_{out} - V_{in})}{\Delta V_C \times f_s \times V_{out}} \quad (6)$$

This ensures that the PFC stage maintains a consistent DC output even under dynamic EV battery charging conditions.

Table 2 Specification of Boost Converter

PARAMETERS	VALUES
Input Voltage	325 V
Output Voltage	400 V
Output Current	5 A
Inductor	0.3mH
Output Capacitor	2000 μ F

This Table 2 confirms that the selected parameters provide the required charging characteristics and meet the frequency, efficiency, and alignment-tolerance criteria essential for EV wireless charging applications. This structured design process ensures the system provides stable CC/CV charging

without relying on additional secondary-side converters.

Simulation Results and Discussion

The proposed LCC-S compensated wireless EV charging system was evaluated using a comprehensive MATLAB/Simulink simulation model representing the complete power conversion chain. The model includes the AC-DC rectifier, boost converter with power factor correction, high-frequency inverter, LCC-S resonant compensation network, secondary-side rectifier, and a digital constant-current-constant-voltage control scheme. The primary objective of the simulation study was to validate the capability of the proposed architecture to support constant-current operation and constant-voltage operation through frequency control while maintaining zero-phase-angle operation, without employing additional DC-DC conversion stages on the receiver side.

During the constant-current operating region, the inverter was driven at the resonant frequency corresponding to the current-source characteristic of the LCC-S network. The current battery waveform presented in Fig. 3 demonstrates stable and regulated delivery throughout the bulk charging interval. As the battery voltage increased during this stage, the charging current remained well regulated, indicating effective load-independent behavior of the resonant compensation network at the system level. This result confirms that the designed LCC-S parameters successfully isolate the primary current from secondary-side voltage variations while preserving zero-phase-angle operation at the inverter input.

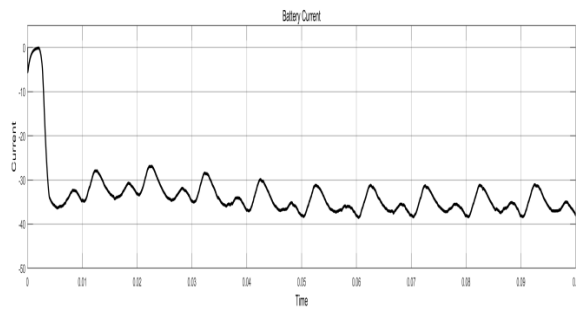


Fig. 3 Battery Current

Upon reaching the specified voltage reference, the control algorithm transitioned the inverter operation to the second resonant frequency associated with voltage-source behavior of the LCC-S network. In this operating region, the output voltage was tightly regulated, as shown in Fig. 4, confirming stable constant-voltage operation. The charging current followed a controlled profile consistent with voltage regulation, reflecting the characteristics of the resonant network under frequency-based control. The observed behavior verifies that the proposed topology can seamlessly transition between CC and CV operating regions while maintaining stable system performance.

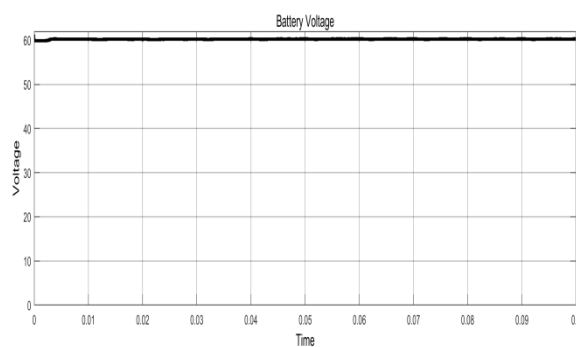


Fig. 4 Battery Voltage

A notable outcome observed during both operating regions is the preservation of zero-phase-angle operation. The inverter voltage and current remained closely aligned in phase during both CC and CV modes, enabling soft-switching conditions across the entire charging process. This characteristic significantly

reduces reactive power circulation and switching losses, thereby improving overall efficiency and ensuring reliable operation of the power electronic devices. Additionally, the impedance characteristics of the LCC-S network remained stable under variations in coupling conditions, demonstrating robustness against misalignment effects commonly encountered in wireless EV charging environments.

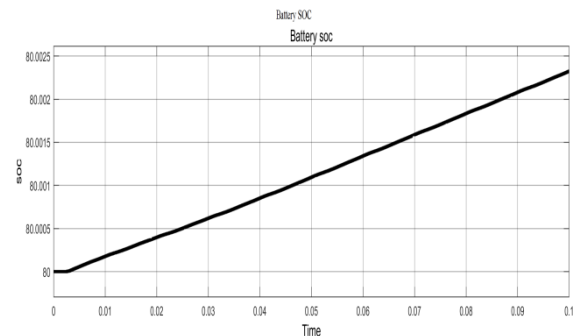


Fig. 5 Battery SOC

The state-of-charge profile illustrated in Fig. 5 exhibits a smooth and continuous increase throughout the charging cycle, confirming uninterrupted power delivery and seamless transitions between operating modes. Although the SOC evolution is obtained using a simplified battery representation, it clearly demonstrates the stability of the proposed resonant control strategy and the consistency of power transfer.

Overall, the simulation results validate that the proposed LCC-S-based wireless charging system inherently supports regulated constant-current and voltage-regulated constant-voltage operation at the resonant network level through frequency control while maintaining zero-phase-angle switching. The results confirm the effectiveness of the compensation design and control strategy in achieving stable, efficient, and load-independent charging behavior suitable for static wireless EV charging applications.



Conclusion

This paper presented a load-independent wireless EV charging system based on an LCC-S resonant compensation topology capable of supporting regulated constant-current and constant-voltage operation through resonant frequency control. By designing the resonant tank to operate at two carefully selected zero-phase-angle frequencies, smooth transitions between CC and CV operating regions are achieved without requiring additional DC-DC converters on the vehicle side. This approach simplifies the overall system architecture while ensuring soft-switching operation and improved efficiency.

The integration of a power-factor-corrected front-end converter provides a stable DC link and ensures compliance with grid power-quality standards. The high-frequency inverter and optimized LCC-S network enable reliable inductive power transfer under coupling variations, while the digital control strategy effectively regulates charging behavior using frequency modulation. The simulation results confirm stable system-level performance, seamless mode transitions, and consistent charging characteristics.

Overall, the proposed LCC-S-based wireless charging architecture offers a compact, efficient, and scalable solution for static EV charging applications. The results demonstrate the feasibility of achieving CC and voltage-regulated CV operation through resonant control while maintaining zero-phase-angle operation. With future extensions incorporating detailed battery dynamics and experimental validation, the proposed system can be further developed to support advanced wireless EV charging infrastructures.

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