

# Evaluation And Analysis of Harmonic Distortion and Reduction in Wireless Electric Vehicle Speed Control System

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**Abstract-** This paper evaluates harmonic distortion in a wireless PWM-based EV speed control system. RC low-pass filtering was implemented to suppress harmonics introduced by PWM switching and wireless coupling. Frequency and magnetic response analyses were performed using transfer functions and Bode plots. Harmonic distortion reduced from 6 dB to 0.85 dB, an 85.83% improvement, and the motor achieved 7,998 rpm with >90% wireless efficiency. These results validate the viability and stability of wireless PWM control when supported by harmonic mitigation.

**Keywords:** Bode Plot, Harmonics, Magnetic Coupling, PWM, RC Filter, Wireless EV.

## I. INTRODUCTION

Wireless electric vehicle speed control eliminates wiring complexity and improves modularity. However, PWM signals contain switching harmonics that distort motor performance. Wireless

transmission adds further distortion due to attenuation, electromagnetic interference (EMI), and magnetic coupling losses. This study applies a standard methodology to analyze and mitigate these distortions through RC filtering, frequency-response modeling, and performance evaluation.

## II. RESEARCH ELABORATIONS

Different researchers have proposed various wireless communication control technologies enabling simplified architecture, improved modularity, and reducing wears. Orike & Alase (2019) achieved 95 % wireless charging efficiency using Magnetic Resonance Wireless Power Transfer at a frequency of 10 MHZ. Daniel & Christian (2020) addressed over heating-related issues by reducing wiring. Zhang et.al (2024) applied Harmonic injection into SVPWM to suppress noise and improve waveform Quality.

| S/NO | AUTHOR & YEAR             | TOPIC   | DESIGN METHOD   | MAIN FINDINGS   |
|------|---------------------------|---|---|---|
| 1.   | Orike & Alase (2019)      | Wireless Power Transfer for Electric Vehicle  | Designed Magnetic Resonance Wireless Power Transfer (WPT) System at 10 MHZ; Analysed efficiency and misalignment effects. | The method achieved 95 % efficiency at 25cm; Suitable for Dynamic EV charging. Focussed on power transfer; Lacks control or harmonic scope. |
| 2.   | Daniel & Christian (2020) | IR-based Wireless Control of Induction Motor. | Used IR Transmitters and Phototransistors with a microcontroller to wirelessly control a 3-Ø motor via Auto transformers. | Enabled Wireless start/stop; Reduced wiring issues; Limited IR range; Lacks Harmonic analysis.  |
| 3.   | Zhang et.al (2024)        | Harmonic-Injected PWM for Servo Drivers.      | Applied Harmonic Injection into SVPWM to reduce Total Harmonic Distortion (THD) and Torque ripple in 3-Ø servo motors.    | Reduced Noise and Improved waveform quality. No wireless features.  |

### 2.1. Methodology

PWM is transmitted wirelessly through inductive coupling and filtered with a first-order RC low-pass network to reduce harmonics. MATLAB/Simulink and Fast Fourier Transforms are used to verify Harmonic attenuation and filter performance. The filter is applied to the Electric Vehicle control system, and Revolution per minute (RPM) is measured experimentally and further validation using the Bode magnetic and phasor response

### 2.2 System Overview

- The wireless EV control model consists of:
- PWM generator (20 kHz switching frequency)
- Inductive wireless transmission coils
- RC harmonic suppression filter

### 2.3 RC Filter Design

The RC filter was designed to attenuate high-frequency PWM harmonics thus optimizing the

maximum energy power transfer to drive the wireless Electric vehicle speed control system.

The filter is governed by:

$$H(j\omega) = \frac{1}{1+j\omega RC}$$

### 2.4 RC Filter Cutoff frequency

$$f_c = \frac{1}{2\pi RC}$$

Where  $f_c$  = Cutoff frequency

R = Resistance of the Resistor

C = Capacitance of the Capacitor

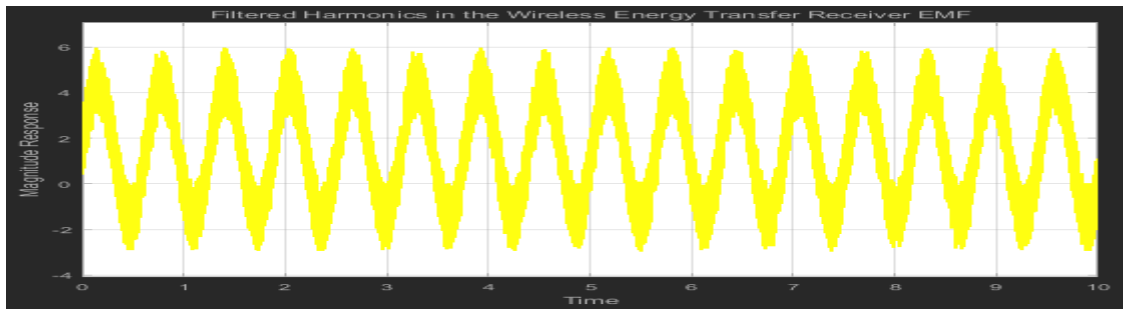
Substituting the selected component Resistor (R = 2.22k $\Omega$  and capacitor (C = 2.7nF) values:

$$f_c = \frac{1}{2\pi(2.2 \times 10^3)(2.7 \times 10^{-9})} \approx 26.8\text{KHZ}$$

## III. RESULTS / FINDING

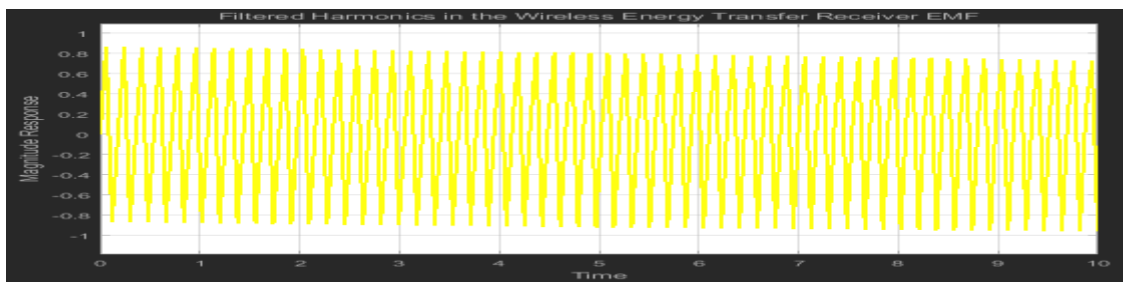
### 3.1 Unfiltered Harmonics

The diagram below shows an unfiltered Harmonics of 6 dB generated by the PWM.



### 3.2 Filter Harmonics (Smoothed waveform after low-pass attenuation)

As a result of the introduction of an RC low-pass filter, the high frequency components have been attenuated from 6 dB to 0.85 dB resulting in a reduction of 85.83 %.

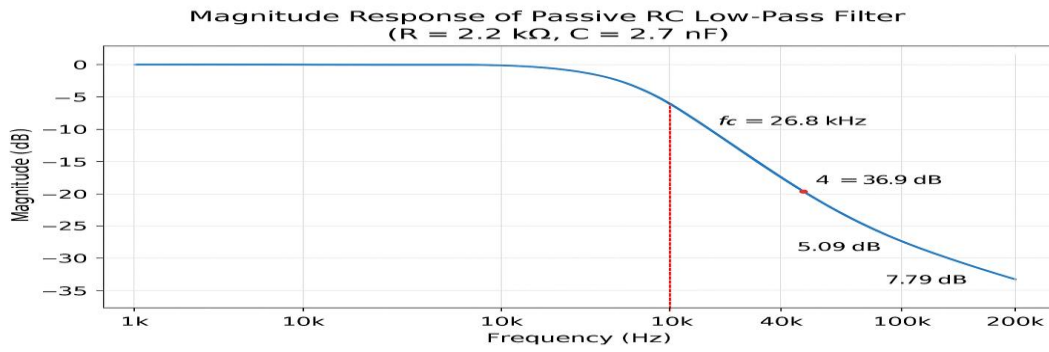


### 3.3 Bode Plot Analysis of RC Filter

The Bode plot is used to analyse the frequency response of the linear time-invariant (LTI) systems.

### 3.4 Magnetic Plot

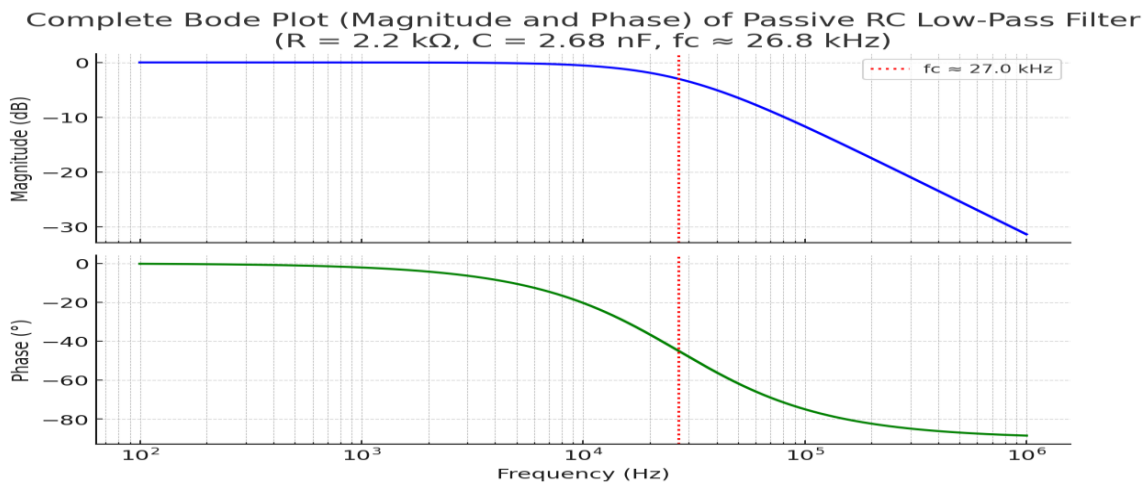
Shows a -20 dB/decade roll-off beyond cutoff, confirming low-pass behaviour.



above represents the Bode plot which shows a cutoff frequency of approximately 26.8 KHZ, beyond which the gain decreases at a rate of approximately -20dB per decade which is characteristic of a first-order RC filter. The filter passes the fundamental 25KHZ signal with minimal attenuation (around -2.8dB) while effectively rejecting higher-frequency harmonics and switching noise components.

The plot indicates that attenuation increases at a slope of roughly -20dB per decade beyond the cutoff frequency, demonstrating the expected first-order behavior. This means that for every tenfold increase in frequency beyond the cutoff point, the output voltage decreases by a factor of ten.

### 3.5 Bode Magnetic and Phasor Response



At frequencies well below the cutoff ( $< f_c$ ), the phase shift is negligible (approximately  $0^\circ$ ), indicating that the output signal is nearly in phase with the input. As the frequency approaches the cutoff frequency point ( $f_c \approx 26.8\text{KHZ}$ ), the phase lag increases to approximately  $-45^\circ$ , which is a theoretical characteristic of a first-order RC filter. Beyond the cutoff, the phase continues to shift towards  $90^\circ$ , indicating that the output increasingly lags behind the output signal as the frequency rises.

While the magnitude response validates the attenuation of high-frequency harmonics, the phase response provides insight into the signal time delay introduced by the filter. This confirms the expected dynamic behavior of a first-order low-pass filter, thus validating both the theoretical and simulated frequency domain performance.

3.6 Table 1

| S/NO | Metrics   | Metric Before Filtering | Metric After Filtering |
|------|-----------|-------------------------|------------------------|
| 1.   | Harmonics | 6.0 dB                  | 0.85 dB                |

|    |            |          |           |
|----|------------|----------|-----------|
| 2. | RPM        | Unstable | 7,998 rpm |
| 3. | Torque     | Rippled  | Smooth    |
| 4. | Efficiency | ~70 %    | >80%      |

The table 3.6 above demonstrates the Wireless Electric vehicle speed control system Motor Performance  
 Maximum stable speed: 7,998 rpm  
 Torque output: 158.47 Nm  
 Wireless efficiency: > 80%

3.6 Table 2

| S/NO. | FREQUENCY (KHZ) | RESPONSES (dB) |
|-------|-----------------|----------------|
| 1     | 25.00           | -2.80          |
| 2     | 40.00           | -13.0          |
| 3     | 60.00           | -18.0          |
| 4     | 100.00          | -24.0          |

25KHZ is the fundamental frequency component which corresponds to the minimal loss. These results indicate that harmonic and switching frequency components above the cutoff frequency ( $f_c = 26.8$  KHZ) are significantly attenuated, while the desired low-frequency component is preserved. The observed responses match the theoretical model for a first-order passive low-pass filter, thus validating the accuracy of the selected design parameters. In conclusion, the designed RC low-pass filter with  $f_c \approx 26.8$  KHZ successfully meets the design objective of suppressing high-frequency distortions while maintaining optimal signal quality at the receiver output. This ensures improved waveform integrity and efficient power transfer to the induction motor drive.

#### IV. APPENDICES

##### Appendix A - Filter Calculations

Given  $R = 2.2 \text{ k}\Omega$ ,  $C = 2.7 \text{ nF}$ :

$f_c \approx 26.8 \text{ Hz}$

##### Appendix B - Simulation Parameters

Switching: 20 kHz

Coupling coefficient: 0.41

Coil inductance: 1.2 mH

Load: 3-phase induction motor, 15 kW

##### Appendix C - Raw Data Summary

Pre-filter distortion: 6 dB

Post-filter distortion: 0.85 dB

Speed range: 0–7,998 rpm

#### V. ACKNOWLEDGMENT

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