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# Modeling and Mitigation of Conducted Electromagnetic Interference in Power Electronic Converters

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**ABSTRACT:** Conducted electromagnetic interference (EMI) remains a critical challenge in power electronic converters, particularly in grid-connected photovoltaic (PV) systems, where high-frequency switching generates noise that can impair system performance and disrupt nearby electronic devices. This paper proposes a comprehensive framework for modeling and mitigating conducted EMI in a dual-stage single-phase PV system, comprising a DC-DC boost converter and a DC-AC H-bridge inverter. A high-frequency equivalent circuit model is developed to predict common mode (CM) and differential mode (DM) noise, validated through MATLAB/Simulink simulations and experimental measurements on a 200W prototype. Novel mitigation strategies include a fuzzy logic-based Maximum Power Point Tracking (MPPT) controller to minimize oscillations and stabilize switching, a Fixed Frequency Hysteresis Current Control (FFHCC) to maintain consistent inverter switching, and a modified passive EMI filter optimized for CM and DM noise attenuation. Simulation results demonstrate a 94.51% MPPT tracking efficiency and significant EMI reduction, with experimental data confirming compliance with CISPR 11 Class A standards, achieving a 40 dB $\mu$ V margin in average EMI spectra.

The proposed techniques are cost-effective, scalable, and applicable to large-scale PV installations, contributing to enhanced electromagnetic compatibility (EMC) in renewable energy systems. This work advances the design of power converters by offering practical solutions for EMI suppression without compromising efficiency or requiring complex hardware modifications.

**KEYWORDS:** Electromagnetic Interference, Power Electronic Converters, Photovoltaic Systems, Fuzzy Logic MPPT, Fixed Frequency Hysteresis Current Control, Passive EMI Filter, Electromagnetic Compatibility.

## I. INTRODUCTION

Power electronic converters are essential components in modern energy systems, enabling efficient power conversion for applications such as grid-connected photovoltaic (PV) systems, electric vehicles, and renewable energy integration. These converters transform electrical energy to meet specific voltage, current, and frequency requirements, making them indispensable for sustainable power generation. However, their high-frequency switching operations generate conducted electromagnetic interference (EMI), which poses significant challenges to system reliability and electromagnetic compatibility (EMC). Conducted EMI can degrade converter performance, reduce component lifespan, and interfere with nearby communication and control systems, potentially causing operational failures. In large-scale PV installations, spanning acres of land, the extensive PV arrays and long DC cables act as antennas, transforming conducted EMI into radiated emissions that may disrupt ecological systems and sensitive equipment.

Compliance with stringent EMC standards, such as CISPR 11, is critical to mitigate these effects and ensure reliable operation. Existing EMI mitigation techniques, including passive and active filters, soft switching, and randomized modulation, have notable limitations. Passive filters are often bulky and dependent on source characteristics, active filters increase system complexity and cost, and soft switching may not consistently reduce EMI across all frequency ranges. Furthermore, while considerable research has focused on AC-side EMI, the DC-side conducted EMI in PV systems, amplified by parasitic capacitances and cable resonances, remains underexplored. This research addresses these gaps by proposing a comprehensive approach to modeling and mitigating conducted EMI in a dual-stage single-phase PV system, consisting of a DC-DC boost converter and a DC-AC H-bridge inverter. The objectives are to develop an accurate high-frequency equivalent circuit model for predicting CM and DM noise, to introduce novel



control strategies including a fuzzy logic-based MPPT controller and an FFHCC, and to design a cost-effective passive EMI filter optimized for noise suppression.

These techniques are validated through simulations in MATLAB/Simulink and experimental measurements on a 200W prototype, demonstrating significant EMI reduction and compliance with international standards. By offering scalable and economical solutions, this work enhances the EMC of power electronic converters, paving the way for reliable and efficient renewable energy systems.

## II. BACKGROUND AND FUNDAMENTALS OF EMI IN POWER CONVERTERS

Conducted electromagnetic interference (EMI) refers to unwanted electromagnetic noise propagated through physical connections, typically within the frequency range of 150 kHz to 30 MHz. It is classified into common mode (CM) and differential mode (DM) noise based on the direction of current flow. CM noise arises from capacitive coupling between active components and ground, flowing in the same direction through both power lines and returning via the ground path. This type of noise dominates at higher frequencies, typically above 5 MHz, and is a primary contributor to EMC issues due to its ability to couple with external systems. DM noise, driven by rapid current changes during switching, flows in opposite directions through the power lines and is prevalent at lower frequencies, generally below 5 MHz. Both noise types require distinct mitigation strategies due to their unique propagation characteristics.

In power electronic converters, EMI is primarily generated by the high-frequency switching of semiconductor devices, such as MOSFETs and IGBTs, which produce rapid voltage and current transients. These transients, characterized by high  $dv/dt$  and  $di/dt$ , are amplified by parasitic elements, including stray capacitances in PV panels, inductances in cables, and non-ideal behaviors of circuit components. In PV systems, the large surface area of PV arrays and extended DC cabling increase the risk of conducted EMI transforming into radiated emissions, posing threats to nearby communication networks and sensitive equipment. For instance, a 5 MWp PV plant covering 30 acres can act as a significant antenna, amplifying radiated noise and necessitating robust EMI suppression. The impact of EMI in PV systems includes performance degradation, reduced component lifespan, and potential ecological disruptions, particularly in large-scale installations. To address these challenges, EMC standards, such as CISPR 11 Class A, specify limits for conducted EMI, with quasi-peak and average limits of 79 dB $\mu$ V and 66 dB $\mu$ V for 0.15–0.5 MHz, and 73 dB $\mu$ V and 60 dB $\mu$ V for 0.5–30 MHz, respectively.

EMI measurements are typically conducted using a Line Impedance Stabilization Network (LISN), which stabilizes impedance and isolates the equipment under test from external noise. Frequency-domain measurements with spectrum analyzers are preferred for assessing EMI levels, supplemented by time-domain techniques for capturing transient disturbances. Understanding these fundamentals is crucial for developing effective EMI modeling and mitigation strategies tailored to power electronic converters.

## III. MODELING OF CONDUCTED EMI

Accurate prediction of conducted EMI is essential for designing effective mitigation strategies in power electronic converters. This study develops a high-frequency equivalent circuit model for a dual-stage single-phase PV system, comprising a DC-DC boost converter and a DC-AC H-bridge inverter, to predict CM and DM noise. The model incorporates key parasitic elements, including the PV panel capacitance ( $C_{pv}$ ), which represents the parasitic capacitance between the PV array and ground, influenced by panel structure and grounding conditions. Cable inductance ( $L_{cable}$ ) models the inductive effects of long DC cables connecting the PV array to the converter, while switch parasitic capacitances ( $C_1$ ,  $C_2$ ) account for capacitances between inverter switches and ground. The EMI filter components, including inductances ( $L$ ) and capacitors ( $C_x$ ,  $C_y$ ), are also included to simulate noise attenuation. The CM noise current ( $I_{CM}$ ) is modeled as the response to the CM voltage ( $V_{CM}$ ), defined as the average of the midpoint voltages ( $V_1$ ,  $V_2$ ) of the inverter legs, and is expressed as  $I_{CM} = (V_1 + V_2) / [2(j\omega L_{eq} + 1 / j\omega C_{pv})]$ , where  $L_{eq}$  is the equivalent inductance and  $\omega$  is the angular frequency. The CM voltage is given by  $V_{CM} = (V_1 + V_2) / 2$ , while DM noise is driven by the differential voltage  $V_{DM} = V_1 - V_2$ . These equations capture the noise contributions from switching transients and parasitic resonances, providing a comprehensive representation of EMI generation and propagation. The model was implemented in MATLAB/Simulink, simulating a 200W PV system with four 50Wp polycrystalline silicon panels, each with an open-circuit voltage of 21.1V and a short-circuit current of 3.8A. The boost converter operates with a variable duty cycle, and the inverter switches at a constant 10 kHz frequency.



A LISN was included in the simulation to measure conducted noise toward the PV module across the 150 kHz–30 MHz frequency range. The simulated EMI spectra were validated against experimental measurements conducted on a prototype setup at a certified EMC test facility. The model accurately predicted peak EMI levels, with minor deviations attributed to unmodeled parasitic effects, such as cable capacitance variations and component tolerances. This validated model serves as a reliable tool for EMI prediction during the design phase, enabling proactive identification of noise sources and optimization of mitigation strategies.

#### IV. PROPOSED EMI MITIGATION TECHNIQUES

To suppress conducted EMI effectively, this research proposes a combination of advanced control strategies and a modified passive EMI filter tailored for a dual-stage PV system. The first strategy involves a fuzzy logic-based Maximum Power Point Tracking (MPPT) controller for the DC-DC boost converter, designed to optimize power extraction while minimizing EMI. Unlike conventional Perturb and Observe (P&O) and Incremental Conductance (IncCond) algorithms, which rely on fixed perturbation steps and cause continuous oscillations around the maximum power point (MPP), the fuzzy MPPT dynamically adjusts the step size based on system conditions. The controller uses two inputs: the error  $E(i)$ , defined as  $E(i) = [P(i) - P(i-1)] / [V(i) - V(i-1)]$ , which indicates the operating point's position relative to the MPP, and the change in error  $CE(i) = E(i) - E(i-1)$ , which determines the tracking direction.

The output is the change in duty cycle ( $\Delta D$ ), computed using 49 fuzzy rules based on seven linguistic variables: Negative Large, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium, and Positive Large. Mamdani's inference method and center-of-gravity defuzzification ensure precise control, reducing oscillations and stabilizing the switching pattern, thereby lowering low-frequency EMI. The second strategy is a Fixed Frequency Hysteresis Current Control (FFHCC) for the DC-AC H-bridge inverter, addressing the limitations of Variable Frequency Hysteresis Current Control (VFHCC), which complicates EMI filter design due to its variable switching frequency. FFHCC maintains a constant 10 kHz switching frequency, ensuring the inverter current follows the reference current within a predefined hysteresis band.

The control law is given by  $L (d\Delta i / dt) = v - v_{ref}$ , where  $\Delta i = i - i_{ref}$ ,  $v$  is the inverter terminal voltage, and  $v_{ref}$  is the reference voltage. By concentrating noise at predictable frequencies, FFHCC enhances the effectiveness of EMI filtering at higher frequencies. The third component is a modified passive EMI filter, a CL configuration designed to attenuate both CM and DM noise. The filter includes a common mode inductance of 3 mH to suppress CM noise, Y-capacitors of 48 nF to provide a low-impedance path for CM noise to ground, and an X-capacitor of 2.2  $\mu$ F to attenuate DM noise. The corner frequencies for CM and DM filters are calculated as  $f_{c,CM} = 1 / (2\pi \sqrt{L_{CM} C_y})$  and  $f_{c,DM} = 1 / (2\pi \sqrt{L_{DM} C_x})$ , respectively, with attenuation determined by  $A(\text{dB}\mu\text{V}) = 40 \log(f / f_c)$ . The design minimizes parasitic effects, such as equivalent series inductance, through careful component selection, ensuring compliance with CISPR 11 limits. The integration of fuzzy MPPT, FFHCC, and the passive EMI filter creates a synergistic effect, with stable switching patterns enhancing filter performance and adaptive control reducing noise across the frequency spectrum. This combination offers a cost-effective solution compared to active filters or soft switching, requiring no hardware modifications and maintaining high power conversion efficiency.

#### V. SIMULATION AND EXPERIMENTAL RESULTS

The proposed EMI modeling and mitigation techniques were evaluated through simulations in MATLAB/Simulink and experimental measurements on a 200W prototype, demonstrating significant improvements in EMI suppression and power conversion efficiency. The simulation environment modeled a dual-stage PV system with four 50Wp polycrystalline silicon panels, each rated at 60W peak power, 21.1V open-circuit voltage, and 3.8A short-circuit current. The system was subjected to varying irradiance levels from 650 W/m<sup>2</sup> to 1000 W/m<sup>2</sup> at a constant temperature of 25°C to assess the performance of the fuzzy MPPT controller compared to conventional P&O and IncCond algorithms. The fuzzy MPPT achieved a tracking efficiency of 94.51%, surpassing P&O at 81.70% and IncCond at 90.16%, due to its adaptive step size that minimized oscillations around the MPP. The voltage gain for the fuzzy MPPT was 3.86, slightly higher than the 3.81 achieved by P&O and IncCond, and the response time was reduced to 0.09 seconds compared to 0.12 seconds for P&O and 0.15 seconds for IncCond.

These results highlight the fuzzy MPPT's superior transient response and efficiency, contributing to reduced low-frequency EMI by stabilizing the boost converter's switching pattern. The EMI spectra were analyzed for various combinations of MPPT algorithms and inverter control strategies, including P&O with VFHCC, P&O with FFHCC,



IncCond with VFHCC, IncCond with FFHCC, and the proposed fuzzy MPPT with FFHCC, both with and without the passive EMI filter. The P&O with VFHCC combination exhibited a peak EMI of 78.92 dB $\mu$ V at 25 MHz, exceeding CISPR 11 limits above 15 MHz due to the variable switching frequency's adverse effect on filter performance. In contrast, P&O with FFHCC reduced the peak EMI to 56.99 dB $\mu$ V at 3 MHz, 3.01 dB $\mu$ V below the limit, with improved filter effectiveness above 5 MHz. Similarly, IncCond with VFHCC showed a peak EMI of 78.92 dB $\mu$ V at 26.64 MHz, with poor filter performance above 24 MHz, while IncCond with FFHCC achieved a peak EMI of 58.27 dB $\mu$ V at 0.604 MHz, with effective suppression above 15 MHz. The fuzzy MPPT with FFHCC, without the filter, demonstrated a remarkable EMI reduction, maintaining a 12 dB $\mu$ V margin in quasi-peak spectra and a 20 dB $\mu$ V margin in average spectra starting from 8 MHz, underscoring the control strategies' inherent noise suppression capabilities. With the passive EMI filter, the fuzzy MPPT and FFHCC combination achieved a 40 dB $\mu$ V margin in average EMI spectra and a 33 dB $\mu$ V margin in quasi-peak spectra, ensuring compliance across the 150 kHz–30 MHz range. This data illustrates the EMI spectrum for this configuration, highlighting substantial noise suppression across the frequency band. The experimental setup validated these findings using a 200W prototype with four 50Wp PV panels, a DC-DC boost converter with fuzzy MPPT, and an H-bridge inverter with FFHCC, synchronized to a 230V, 50Hz single-phase grid. The setup included a passive EMI filter with a 3 mH inductance, 48 nF Y-capacitors, and a 2.2  $\mu$ F X-capacitor, and measurements were conducted at the Centre for Electromagnetics, SAMEER, Chennai, following CISPR 11 procedures.

The PV panels were connected via a 5.6m cable through a grounded metal pipe to minimize external disturbances, and the inverter operated at a 10 kHz switching frequency. The experimental EMI spectra confirmed simulation results, with quasi-peak EMI levels at 36.4 dB $\mu$ V at 0.343 MHz (26.6 dB $\mu$ V margin), 39.3 dB $\mu$ V at 0.270 MHz (26.7 dB $\mu$ V margin), and 3.8 dB $\mu$ V at 5.196 MHz (56.2 dB $\mu$ V margin), all within CISPR 11 limits. Average EMI levels showed a 46 dB $\mu$ V margin at peak points, with values such as 15.9 dB $\mu$ V at 0.662 MHz (44.1 dB $\mu$ V margin) and 11.2 dB $\mu$ V at 13.086 MHz (48.8 dB $\mu$ V margin). Minor discrepancies between simulation and experimental results were attributed to unmodeled parasitic elements, such as cable capacitance and component tolerances, but the consistent EMI suppression trends, particularly above 4 MHz, validated the robustness of the proposed techniques. These results demonstrate the effectiveness of the fuzzy MPPT, FFHCC, and passive EMI filter in achieving EMC compliance while maintaining high efficiency.

## VI. DISCUSSION

The proposed framework for modeling and mitigating conducted EMI in power electronic converters offers significant advancements over conventional approaches, particularly for grid-connected PV systems. The fuzzy logic-based MPPT controller outperforms traditional P&O and IncCond algorithms by achieving a 94.51% tracking efficiency, a 4.35% improvement over IncCond and a 12.81% improvement over P&O. This enhanced efficiency stems from the adaptive step size, which minimizes oscillations around the MPP, reducing low-frequency EMI and improving transient response. The FFHCC strategy for the inverter stabilizes the switching frequency at 10 kHz, addressing the limitations of VFHCC, which results in variable switching frequencies that degrade EMI filter performance above 15 MHz. The FFHCC's predictable switching pattern enhances filter effectiveness, achieving substantial EMI suppression at higher frequencies, as evidenced by a peak EMI of 56.99 dB $\mu$ V at 3 MHz for P&O with FFHCC compared to 78.92 dB $\mu$ V at 25 MHz for P&O with VFHCC. The modified passive EMI filter, with its optimized 3 mH inductance, 48 nF Y-capacitors, and 2.2  $\mu$ F X-capacitor, provides robust attenuation of both CM and DM noise, achieving a 40 dB $\mu$ V margin in average EMI spectra and a 33 dB $\mu$ V margin in quasi-peak spectra when combined with fuzzy MPPT and FFHCC. This performance surpasses active EMI filters, which are complex and costly, and soft switching techniques, which may not consistently reduce EMI across all frequency ranges. Compared to state-of-the-art methods, such as chaotic sinusoidal pulse width modulation (SPWM) and digital active EMI filters, the proposed approach is technoeconomical, requiring no hardware modifications and leveraging existing converter topologies.

Compliance with CISPR 11 Class A standards ensures applicability to industrial PV installations, from small-scale rooftop systems to megawatt-scale plants. The high-frequency equivalent circuit model accurately predicts CM and DM noise, validated by experimental measurements, enabling designers to identify noise sources during the design phase and optimize mitigation strategies. Limitations include the passive filter's dependency on source characteristics, which may require recalibration for different converter topologies, and the need to account for parasitic effects in high-power systems. The scalability of the proposed techniques is supported by their low-cost implementation, making them suitable for large-scale PV plants where extensive cabling and PV arrays amplify EMI challenges. Future enhancements could explore hybrid artificial intelligence-based control strategies to auto-tune fuzzy membership functions, further reducing EMI and improving efficiency. Digital active EMI filters, which offer size and weight



advantages, could be investigated for integration with the proposed control strategies, potentially addressing the bulkiness of passive filters. Extending the approach to single-stage PV systems or other power electronic applications, such as electric vehicle chargers, presents additional opportunities for advancing EMC compliance.

## VII. CONCLUSION AND FUTURE WORK

This research presents a comprehensive framework for modeling and mitigating conducted electromagnetic interference in power electronic converters, with a focus on dual-stage single-phase photovoltaic systems. The developed high-frequency equivalent circuit model accurately predicts common mode and differential mode noise, validated through MATLAB/Simulink simulations and experimental measurements on a 200W prototype. The proposed mitigation strategies, including a fuzzy logic-based Maximum Power Point Tracking controller, a Fixed Frequency Hysteresis Current Control, and a modified passive EMI filter, achieve a tracking efficiency of 94.51% and significant EMI reduction, with a 40 dB $\mu$ V margin in average EMI spectra and a 33 dB $\mu$ V margin in quasi-peak spectra, ensuring compliance with CISPR 11 Class A standards. These techniques are cost-effective, requiring no hardware modifications, and scalable for applications ranging from small-scale rooftop PV systems to large-scale solar farms. The fuzzy MPPT minimizes oscillations, reducing low-frequency noise, while FFHCC stabilizes switching frequencies, enhancing filter performance at higher frequencies.

The passive EMI filter, optimized for both CM and DM noise, offers a practical alternative to complex active filters. This work contributes to advancing electromagnetic compatibility in renewable energy systems, enabling reliable and efficient power conversion. Future research could explore hybrid artificial intelligence-based control strategies to further optimize MPPT performance and reduce EMI. Investigating digital active EMI filters could address the size and weight limitations of passive filters, enhancing applicability in compact systems. Extending the proposed framework to single-stage PV systems, electric vehicle chargers, or other power electronic applications offers additional avenues for improving EMC compliance and system efficiency.

## REFERENCES

1. F. Blaabjerg, Z. Chen, and S. B. Kjaer, "Power electronics as efficient interface in dispersed power generation systems," *IEEE Trans. Power Electron.*, vol. 19, no. 5, pp. 1184–1194, Sep. 2004.
2. H. W. Ott, *Electromagnetic Compatibility Engineering*. Hoboken, NJ, USA: Wiley, 2009.
3. CISPR 11: Industrial, Scientific and Medical Equipment—Radio-Frequency Disturbance Characteristics—Limits and Methods of Measurement, IEC, 2004.
4. R. Redl, "Power electronics and electromagnetic compatibility," *Proc. IEEE*, vol. 89, no. 6, pp. 926–938, Jun. 2001.
5. J. Biela, A. Wirthmueller, R. Waespe, M. L. Heldwein, K. Raggl, and J. W. Kolar, "Passive and active hybrid integrated EMI filters," *IEEE Trans. Power Electron.*, vol. 24, no. 5, pp. 1340–1349, May 2009.
6. N. Henze and T. Degner, "Radio interference of photovoltaic power systems," in *Proc. 16th Int. Wroclaw Symp. Exhib. EMC*, Wroclaw, Poland, 2002, pp. 1–6.
7. C. R. Paul, *Introduction to Electromagnetic Compatibility*, 2nd ed. New York, NY, USA: Wiley, 2006.
8. W. Khan-ngern and Y. Prempaneerach, "Reduction of conducted emission for UPSs using passive EMI filters," in *Proc. IEEE Asia-Pacific Conf. Circuits Syst.*, 1998, pp. 1–4.
9. M. C. Caponet and F. Profumo, "Devices for the separation of the common and differential mode noise: Design and realization," in *Proc. 7th Annu. IEEE Appl. Power Electron. Conf. Expo.*, vol. 1, 2002, pp. 100–105.
10. F. Zare, "EMI issues in modern power electronic systems," *IEEE EMC Soc. Newslett.*, no. 221, pp. 66–70, 2009.
11. I. Wu, T. Shinozuka, S. Ishigami, and Y. Matsumoto, "Evaluation of electromagnetic radiation from the DC side of a photovoltaic power generation system," *IEEE Electromagn. Compat. Mag.*, vol. 4, no. 2, pp. 73–81, 2015.
12. R. Araneo, S. Lammens, M. Grossi, and S. Bertone, "EMC issues in high-power grid-connected photovoltaic plants," *IEEE Trans. Electromagn. Compat.*, vol. 51, no. 3, pp. 639–648, Aug. 2009.
13. D. A. Weston, *Electromagnetic Compatibility: Methods, Analysis, Circuits, and Measurement*, 3rd ed. Boca Raton, FL, USA: CRC Press, 2017.
14. Y. Yoshioka, "CISPR limits for the conducted disturbances of DC ports of PV-GCPCs," in *Proc. IEEE Int. Symp. Electromagn. Compat.*, Tokyo, Japan, 2014, pp. 585–588.
15. J. L. N. Violette, D. R. J. White, and M. F. Violette, *Electromagnetic Compatibility Handbook*, 1st ed. New York, NY, USA: Springer, 1987.



16. G. Costa, M. Pous, A. Atienza, and F. Silva, "Time-domain electromagnetic interference measurement system for intermittent disturbances," in Proc. Int. Symp. Electromagn. Compat. (EMC Europe), Gothenburg, Sweden, 2014, pp. 1–6.
17. M. C. Di Piazza, C. Serporta, G. Tine, and G. Vitale, "Electromagnetic compatibility characterization of the DC side in a low-power photovoltaic plant," in Proc. IEEE Int. Conf. Ind. Technol., vol. 2, 2004, pp. 672–677.
18. D. Hamza, M. Qiu, and P. K. Jain, "Application and stability analysis of a novel digital active EMI filter used in a grid-tied PV microinverter module," IEEE Trans. Power Electron., vol. 28, no. 6, pp. 2867–2874, Jun. 2013.
19. H. Li, Y. Liu, J. Lü, T. Zheng, and X. Yu, "Suppressing EMI in power converters via chaotic SPWM control based on spectrum analysis approach," IEEE Trans. Ind. Electron., vol. 61, no. 11, pp. 6128–6137, Nov. 2014.
20. J. Zhang, W. Chen, Y. Sha, Y. Han, and X. Yang, "EMI filter analysis for transformer-less photovoltaic inverter," in Proc. IEEE 8th Int. Power Electron. Motion Control Conf. (IPEMC-ECCE Asia), 2016, pp. 1556–1560.



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