A Comprehensive Study of Peak-to-Average Power Ratio Reduction Techniques in OFDM-Based Wireless Communication Systems

Kamini Upadhyay[1], Sandeep Ojha[2], Alok Kumar Mishra[3]
[1,2,3] *Department of Electronics and Communication RITM, Lucknow*

***Abstract*—Orthogonal Frequency Division Multiplexing (OFDM) is widely recognized as an efficient multicarrier transmission technique for high-speed wireless communication. However, its inherent high Peak-to-Average Power Ratio (PAPR) remains a major limitation, leading to inefficient power amplifier operation and signal distortion. This paper provides a comprehensive review of prominent PAPR reduction techniques, including clipping and filtering, coding, tone reservation and injection, Selected Mapping (SLM), Partial Transmit Sequence (PTS), and advanced methods such as lattice-based and precoding schemes for MIMO-OFDM systems. Trade-offs in terms of Bit Error Rate (BER), spectral efficiency, computational complexity, and system compatibility are discussed. Simulation results highlight the effectiveness of these techniques in reducing PAPR while addressing practical implementation challenges. Future directions focus on low-complexity, standard-compliant solutions suitable for next-generation wireless networks.**

***Index Terms*—OFDM, Peak-to-Average Power Ratio (PAPR), Multicarrier Modulation, SLM, PTS, MIMO-OFDM, PAPR Reduction, Wireless Communication**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has emerged as one of the most significant multicarrier transmission techniques in contemporary wireless and wired broadband communications. This popularity is largely due to its exceptional robustness in handling the challenging characteristics of wireless channels, particularly the multipath fading effect, which often degrades signal integrity and data throughput in single-carrier systems [1]. By decomposing a high-rate data stream into multiple lower-rate sub-streams and transmitting them simultaneously over orthogonal subcarriers, OFDM effectively transforms a frequency-selective fading channel into numerous flat fading channels, thereby simplifying equalization at the receiver end. This inherent ability to combat inter-symbol interference (ISI) without the need for complex time-domain equalizers makes OFDM highly suitable for broadband applications that demand high spectral efficiency and reliable performance in non-line-of-sight (NLOS) conditions.

The fundamental advantage of OFDM lies in its efficient use of spectrum and its capacity to provide high data rates while preserving the quality of service (QoS) across diverse channel conditions. Standards such as IEEE 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), Digital Video Broadcasting (DVB-T), and 4G LTE have all adopted OFDM or its variants to meet the ever-increasing demand for high-speed data transmission in modern communication networks. More recently, 5G New Radio (NR) technologies have also incorporated OFDM as their foundational waveform, extending its relevance well into the next generation of wireless communications [2]. Its flexibility in supporting multiple access schemes, like OFDMA (Orthogonal Frequency Division Multiple Access), and its compatibility with advanced techniques such as Multiple-Input Multiple-Output (MIMO) have further solidified OFDM's role as a backbone technology for broadband wireless systems.

Despite these remarkable strengths, OFDM is not without significant challenges. One of its most critical drawbacks is the inherently high Peak-to-Average Power Ratio (PAPR) of the transmitted signal [3]-[9]. The high PAPR arises because an OFDM signal is composed of the sum of multiple independently modulated subcarriers. When these subcarrier signals add constructively, they can create signal peaks that are substantially higher than the average signal power. Statistically, the probability of such peaks increases with the number of subcarriers, resulting in a signal that demands a wide dynamic range in the radio frequency front end.

This high PAPR condition poses severe practical limitations, particularly in the design and operation of the high-power amplifier (HPA) at the transmitter. Power amplifiers are ideally operated within their linear region to maintain signal fidelity. However, when the input signal exhibits large peaks, the amplifier must accommodate these peaks without entering into saturation or nonlinearity [10]-[18]. If the amplifier is driven into its nonlinear region by these peaks, the output signal undergoes distortion, generating unwanted spectral components. These distortions manifest as intermodulation products that spill energy into adjacent frequency bands, leading to spectral regrowth and increased adjacent channel interference. To prevent this, the amplifier is typically backed off from its maximum output power to operate well within the linear range, but this back-off comes at the cost of power efficiency.

The inefficiency of power amplifiers due to high PAPR translates directly into higher power consumption, which is particularly detrimental for battery-powered mobile and portable devices. For base stations and access points, it means greater operational costs and increased heat dissipation requirements, adding to the system's overall complexity and environmental impact. Therefore, from both a performance and an energy efficiency perspective, mitigating the PAPR problem is critical for the practical deployment of OFDM-based systems.

Another consequence of high PAPR is its impact on the analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) used in modern transceivers. High PAPR signals require converters with a wide dynamic range to avoid clipping and quantization noise [19]-[21]. This requirement demands high-resolution converters that are more expensive, consume more power, and introduce design challenges, especially in systems where compact size and low power consumption are paramount. Thus, the PAPR problem permeates multiple layers of the communication system, from RF circuitry to the digital domain, making its resolution a priority for researchers and system designers alike.

Numerous PAPR reduction techniques have been proposed over the past decades, each with its advantages and trade-offs. Conventional methods include amplitude clipping and filtering, which directly limit the peaks but introduce in-band and out-of-band distortions that can degrade bit error rate (BER) performance and require additional filtering stages [22]-[25]. Coding techniques, such as block coding and Golay complementary sequences, attempt to select codewords that naturally produce lower peaks, but they often suffer from low coding efficiency and increased complexity for large subcarrier counts.

More advanced signal processing methods, such as Selected Mapping (SLM) and Partial Transmit Sequence (PTS), generate multiple alternative signal representations by applying different phase rotations or sub-block combinations and then select the signal with the lowest PAPR. While these methods can achieve significant PAPR reductions—often in the range of 2–5 dB—they introduce additional computational overhead and may require the transmission of side information to the receiver to correctly demodulate the data. Failure to transmit or correctly decode this side information can result in catastrophic data loss.

Techniques like tone reservation and tone injection strategically modify certain subcarriers to counteract signal peaks but may slightly reduce data throughput or increase transmit power. More recent innovations involve lattice-based approaches and precoding strategies, especially for MIMO-OFDM systems, where spatial diversity can be exploited to achieve even lower PAPR levels. For instance, directed SLM (dSLM) leverages the diversity potential inherent in MIMO configurations, showing sharper CCDF decay and improved performance compared to conventional SLM.

The practical implementation of these techniques must balance competing objectives: the extent of PAPR reduction achieved, the complexity of the algorithm, the impact on BER, and the compatibility with existing communication standards. For example, while sophisticated optimization-based methods can theoretically provide near-constant envelope signals, they may be computationally prohibitive for real-time systems, especially in scenarios with high subcarrier counts and massive MIMO arrays.

In the context of evolving technologies such as 5G NR and upcoming 6G networks, the challenge of high PAPR takes on added significance. These systems not only employ wideband OFDM signals but also incorporate advanced features like carrier aggregation, massive MIMO, and millimeter-wave operation, all of which exacerbate the PAPR issue [2]. At the same time, the drive toward energy-efficient and green communications necessitates minimizing power amplifier inefficiencies.

Therefore, developing efficient, low-complexity, and standard-compliant PAPR reduction methods remains an active area of research. Hybrid approaches that combine multiple techniques—such as precoding combined with SLM or PTS—are being explored to harness the benefits of each method while mitigating their individual drawbacks. Additionally, adaptive and machine learning-based schemes show promise in dynamically selecting the most suitable PAPR reduction strategy based on real-time channel and traffic conditions.

The structure of this paper as follows: Section II provides an in-depth discussion of the mathematical background and the fundamental PAPR characteristics of OFDM signals. It explains how the Peak-to-Average Power Ratio is defined, its statistical distribution, and the typical methods used to evaluate it, such as the Complementary Cumulative Distribution Function (CCDF). Section III presents a comprehensive review of various PAPR reduction techniques, categorised into conventional methods, signal distortion techniques, coding-based approaches, and advanced signal processing methods. This section discusses the principles, strengths, and limitations of each method and outlines their impact on system performance metrics such as BER, complexity, and spectral efficiency. Section IV focuses on the implementation trade-offs and comparative analysis of the discussed techniques. It examines practical aspects like computational requirements, hardware constraints, and the feasibility of integration into existing wireless communication standards. Section V highlights the simulation results and performance evaluations of different PAPR reduction techniques. Representative CCDF curves are presented to illustrate the effectiveness of these methods under various system configurations and modulation schemes. The results are analysed to provide insights into their real-world applicability. Lastly, Section VI concludes the study with key findings and future directions.

II. PAPR IN OFDM SYSTEMS

A multicarrier OFDM signal is generated by summing a large number of independently modulated subcarriers. Each subcarrier carries a portion of the total data stream and is modulated using techniques such as Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK). The resulting time-domain signal is the inverse Fourier transform of these modulated subcarriers. Due to the independent phases and amplitudes of the subcarriers, their constructive or destructive interference can lead to significant fluctuations in the instantaneous signal amplitude.

The Peak-to-Average Power Ratio (PAPR) is the metric used to quantify the severity of these fluctuations. Mathematically, the PAPR of an OFDM signal is defined as the ratio of the maximum instantaneous power to the average power of the signal over a given time interval. This can be written as:

$$\mathrm{PAPR} = \frac{\max |x(t)|^2}{E[|x(t)|^2]} \tag{1}$$

where x(t) denotes the continuous-time OFDM signal and E[·] represents the statistical expectation operator, which gives the average power of the signal. The numerator captures the largest signal peak that can occur due to the coherent addition of subcarriers, while the denominator represents the average signal power that the system would deliver if all subcarriers contributed equally and constructively in an uncorrelated fashion.

The high PAPR in OFDM arises from the large dynamic range introduced by these peaks. For instance, with a larger number of subcarriers, the probability that multiple subcarriers align constructively increases, leading to higher peak power. Conversely, the average power remains largely unchanged because the data symbols modulated onto each subcarrier are statistically independent and typically have equal energy.

To understand the statistical behaviour of PAPR, it is important to consider the distribution of the OFDM signal amplitude. When the number of subcarriers is large, the real and imaginary parts of the time-domain OFDM signal can be approximated as Gaussian random variables due to the Central Limit Theorem. Consequently, the amplitude follows a Rayleigh distribution, and the power follows an exponential or chi-square distribution with two degrees of freedom.

Since the instantaneous power fluctuates, it is practical to use statistical tools to assess the probability of encountering large peaks. This is where the Complementary Cumulative Distribution Function (CCDF) becomes an essential performance measure. The CCDF of the PAPR is defined as the probability that the PAPR of a given OFDM signal exceeds a specific threshold z:

$$\text{CCDF} = P(\text{PAPR} > z) \quad (2)$$

The CCDF provides a probabilistic measure of how frequently high peaks occur in the transmitted signal. For example, a CCDF value of 1% at 10 dB implies that in 1% of the transmitted OFDM symbols, the peak power is more than 10 dB above the average power. The CCDF is widely used to evaluate and compare the effectiveness of different PAPR reduction techniques, as it succinctly illustrates how the probability of high peaks diminishes with the application of such methods.

For an OFDM signal with NNN subcarriers and under the assumption of Nyquist rate sampling, a simplified approximation of the CCDF is given by:

$$P(\text{PAPR} > z) = 1 - (1 - e^{-z})^N \quad (3)$$

This expression assumes that the individual samples are uncorrelated and that the time-domain signal samples are independently and identically distributed, which holds reasonably well when oversampling is used. However, this analytical model becomes less accurate when the number of subcarriers is small or when practical factors like pulse shaping, oversampling, and windowing are applied.

In practice, accurate estimation of the CCDF typically requires oversampling the OFDM signal by a factor LLL (commonly L=4 or higher). This oversampling ensures that the discretized representation sufficiently captures the peaks that might occur between the Nyquist-rate samples, which could otherwise be underestimated.

Overall, the mathematical definition of PAPR and its statistical characterization through the CCDF provide critical insights for system designers. They highlight the need for power amplifiers with sufficient linearity and dynamic range to handle these peaks, or alternatively, the need for robust PAPR reduction techniques that lower the peak levels while maintaining signal fidelity. The choice of a suitable PAPR reduction method is thus driven by understanding the probabilistic behaviour of the signal peaks as quantified by the CCDF and the acceptable trade-offs in power efficiency, complexity, and BER performance.

III. PAPR REDUCTION TECHNIQUES

This section outlines the most significant methods developed for PAPR reduction, highlighting their principles and trade-offs.

A. Clipping and Filtering

Amplitude clipping limits the signal peaks at a predefined threshold. While simple to implement, it introduces in-band distortion and out-of-band radiation, which require filtering. Repeated clipping and filtering can reduce these effects but add complexity.

B. Coding Techniques

Block coding schemes map data blocks to codewords with inherently lower PAPR. Although effective, their practical application is limited by the need for large lookup tables and added redundancy.

C. Tone Reservation and Tone Injection

- Tone Reservation (TR): Reserves a few subcarriers to generate a compensating signal that reduces peaks.
- Tone Injection (TI): Shifts constellation points by adding specific tones, lowering peak power but increasing transmit power and complexity.

D. Selected Mapping (SLM)

SLM generates multiple candidate OFDM signals using different phase sequences and selects the one with the lowest PAPR. It requires side information transmission to the receiver, which can lower spectral efficiency.

E. Partial Transmit Sequence (PTS)

PTS divides the OFDM block into subblocks and combines them with optimal phase factors to minimize PAPR. Although effective, the search for phase factors can be computationally intensive.

F. Advanced Approaches

- Lattice-based Methods: Utilize signal space structures to extend constellations and reduce PAPR without transmitting side information.
- Precoding for MIMO-OFDM: Recent methods integrate PAPR reduction with precoding,

especially in large MIMO systems, leveraging diversity to achieve lower PAPR.

IV. TRADE-OFFS AND PERFORMANCE EVALUATION

Each PAPR reduction technique inherently involves balancing multiple performance metrics and practical constraints. The effectiveness of any given method is not determined solely by how much it reduces PAPR, but by how it impacts the overall system performance and its feasibility in real-world deployment. The main factors that must be weighed include:

A. PAPR Reduction Capability

This represents the primary goal: lowering the peak-to-average power ratio to make the transmitted OFDM signal more power-efficient and compatible with the linear operating region of power amplifiers. Techniques such as Selected Mapping (SLM) and Partial Transmit Sequence (PTS) can offer reductions in the range of 2–5 dB or more, while more advanced methods like lattice-based coding or convex optimization in massive MIMO systems can push the reduction even further. However, greater PAPR reduction often comes at the cost of increased algorithmic complexity or other performance penalties.

B. Bit Error Rate (BER) Impact

Some PAPR reduction methods, especially those involving signal distortion such as clipping and filtering, introduce non-linear distortions that can cause in-band interference and degrade the Bit Error Rate (BER). An increased BER means more transmission errors, necessitating stronger error correction and potentially reducing throughput. Therefore, it is vital to choose a method that achieves an acceptable PAPR reduction without significantly harming the signal integrity. Non-distortion techniques like SLM and PTS maintain the BER performance well but often require side information to be transmitted reliably, which, if lost, can also lead to catastrophic errors.

C. Computational Complexity

Different methods vary widely in their computational demands. Simple techniques like amplitude clipping are easy to implement in real time but may provide limited reduction and introduce undesirable distortion. In contrast, SLM and PTS require multiple Inverse Fast Fourier Transforms (IFFTs) or extensive phase factor searches for each OFDM symbol, which can significantly increase the processing burden, especially as the number of subcarriers grows. High complexity can limit feasibility in devices with constrained processing resources, such as handheld mobile terminals.

D. Bandwidth Efficiency

Some PAPR reduction techniques require additional bits of side information to be transmitted alongside the data symbols. For example, SLM must inform the receiver which phase sequence was used so the signal can be correctly demodulated. This overhead slightly reduces the effective data rate or requires more bandwidth. Techniques that modify the signal constellation, like tone injection, may also increase the average power or spectral footprint. Maintaining high bandwidth efficiency while reducing PAPR is thus a crucial trade-off that must be carefully managed.

E. System Compatibility

Finally, any practical PAPR reduction solution must align with the constraints and specifications of the deployed communication standard, whether it be LTE, WiMAX, Wi-Fi, or emerging 5G NR systems. Some methods may require significant modifications to the transmitter and receiver structure, which could conflict with standardized hardware and protocols. Others may not be backward compatible or may violate spectral mask requirements due to out-of-band emissions introduced by distortion. Therefore, system designers must ensure that any PAPR reduction method can be integrated with minimal disruption to existing infrastructure and does not violate regulatory requirements.

V. SIMULATION RESULTS

This section presents comparative simulation results that illustrate the effectiveness of various PAPR reduction techniques for OFDM systems as shown in Figure 1. The key metric is the Complementary Cumulative Distribution Function (CCDF) of the PAPR, which indicates the probability that the PAPR exceeds a given threshold.

Scenario:

- Modulation: QPSK
- Number of Subcarriers: 256 and 1024
- Oversampling factor: L = 4
- Number of SLM phase sequences: 4
- PTS sub-blocks: 4

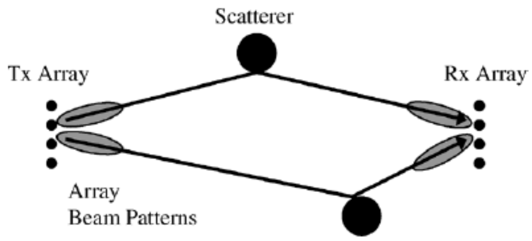

Figure 1. Simple multipath propagation environment showing two paths between transmit and receive. The arrays are capable of resolving the individual multipaths, enabling increased data throughput.

The CCDFs are usually compared in a graph such as Figure 2, which shows the CCDFs of the PAPR of an OFDM signal with 256 and 1024 subcarriers (N = 256, 1024) for QPSK modulation and oversampling factor L = 4. The unmodified OFDM signal has a PAPR that exceeds 11.3 dB for less than 0.1% of the data blocks for N = 256. When SLM is used, the 0.1% PAPR reduces to 8.1 dB (N = 256) and 8.9 dB (N = 1024), resulting in 3.2 dB and 2.8 dB reductions, respectively.

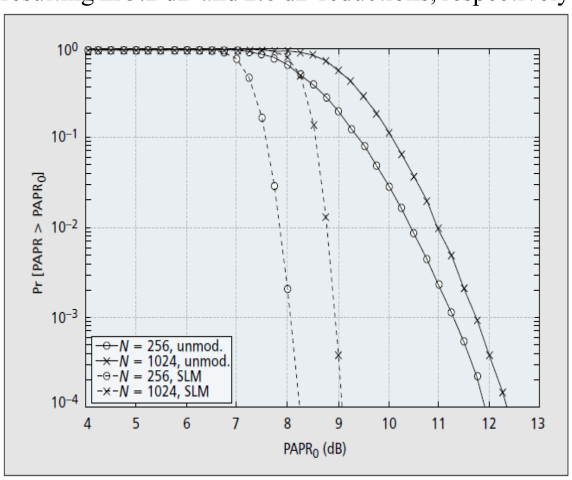

Figure 2. CCDFs of PAPR of an OFDM signal with 256 and 1024 subcarriers (N = 256,1024) for QPSK modulation and oversampling factor 4 (L = 4)

CCDF results as shown in Table1, which observes: SLM, PTS, Directed SLM (dSLM), Lattice-based, and Large-Scale MIMO PMP.

Table 1 CCDF Results

Method	Subcarriers (N)	0.1% PAPR (dB)	PAPR Reduction (dB)
Original OFDM	256	11.3	—
SLM (4 Sequences)	256	8.1	3.2
Original OFDM	1024	11.7	—
SLM (4 Sequences)	1024	8.9	2.8
Directed PTS	256	~7.8	~3.5
Lattice-based Method	256	~7.5	~3.8
dSLM in MIMO (2x2)	256	~7.0	~4.3
Large-Scale MIMO PMP	1024	~0.7	>11

The Selected Mapping (SLM) technique is one of the most widely studied probabilistic approaches for reducing PAPR in OFDM systems. The core idea is to generate multiple statistically independent candidate OFDM signals by applying different phase rotation sequences to the original data block. Among these candidates, the one with the lowest PAPR is selected for transmission. SLM is particularly effective for systems with a moderate number of subcarriers, where generating and testing a reasonable number of phase sequences can yield a PAPR reduction of around 2–4 dB. A key strength of SLM is that it does not introduce any distortion to the transmitted signal, so the Bit Error Rate (BER) performance remains largely unaffected. However, this benefit comes with the requirement to transmit side information — specifically, an index that identifies which phase sequence was chosen. If this side information is lost or corrupted during transmission, the receiver cannot correctly demodulate the signal, resulting in severe decoding errors.

Partial Transmit Sequence (PTS) is another widely used probabilistic technique that improves upon the basic idea of SLM. In PTS, the input data block is divided into multiple disjoint subblocks. Each subblock is then multiplied by a phase factor, and these subblocks are combined to form candidate OFDM signals with different phase combinations. The optimal combination is selected to minimise the PAPR of the overall signal. PTS typically achieves slightly better PAPR reduction than SLM — often in the range of 3–5 dB — because it offers greater degrees of freedom in how the phases are adjusted. However, this improvement comes at the expense of higher computational complexity: searching for the optimal phase factors across multiple subblocks can be time-consuming, especially as the number of subblocks increases. Like SLM, PTS also usually requires the transmission of side information to the receiver.

Directed Selected Mapping (dSLM) is an enhancement of conventional SLM that is particularly beneficial in Multiple-Input Multiple-Output (MIMO) OFDM systems. While traditional SLM applies random phase rotations, dSLM uses a more structured approach to exploit the diversity provided by multiple transmit antennas. By intelligently selecting phase sequences based on channel conditions and spatial dimensions, dSLM can achieve a sharper decay in the Complementary Cumulative Distribution Function (CCDF) of the PAPR, indicating that large signal peaks become even less likely. This effect is comparable to how diversity gain improves error performance in MIMO systems. Although dSLM can be more complex to implement than standard SLM, its ability to leverage spatial diversity makes it highly effective for next-generation broadband systems with multiple antennas.

Lattice-based PAPR reduction methods represent a more recent and mathematically elegant class of approaches. These techniques work by extending the signal constellation using lattice structures so that each symbol can be represented in multiple equivalent ways within the same constellation. By optimally choosing these equivalent representations, the transmitter can construct an OFDM signal with lower peaks. A significant advantage of lattice-based methods is that they do not require side information to be sent to the receiver, as the signal can be decoded using lattice decoding principles. Furthermore, these techniques are flexible and can be adapted to different modulation schemes, such as QAM and PSK, making them attractive for various standards. The trade-off lies in the increased complexity of the encoding and decoding processes and the potential slight increase in average signal power.

In large-scale or massive MIMO OFDM systems, more sophisticated optimization techniques such as Per-Antenna Power Minimization (PMP) have been proposed. These methods apply convex optimization to jointly design the transmitted signals across all antennas to minimise the maximum peak power, ideally approaching a constant-envelope waveform. A constant-envelope signal theoretically has a PAPR of 0 dB, which is optimal for power amplifier efficiency. In practice, convex optimization for large antenna arrays can achieve significant PAPR reduction — sometimes more than 10 dB compared to conventional precoding. This dramatically relaxes the linearity requirements of the power amplifiers, making hardware design more cost-effective and energy-efficient. However, these techniques demand high computational resources and precise channel state information, which can limit their real-time practicality in some scenarios.

VI. CONCLUSION AND FUTURE SCOPE

Reducing PAPR is essential for energy-efficient OFDM transmission, especially in power-constrained and mobile applications. While many methods have proven effective in simulations, practical implementation must consider real-time complexity, standard compliance, and receiver transparency. Future research should focus on hybrid methods that combine benefits while minimizing drawbacks, as well as machine learning approaches for adaptive PAPR reduction in dynamic channels.

REFERENCES

[1] S. H. Han and J. H. Lee, “An Overview of Peak-to-Average Power Ratio Reduction Techniques for Multicarrier Transmission,” IEEE Wireless Communications, vol. 12, no. 2, pp. 56–65, Apr. 2005.

[2] R. F. H. Fischer, “Precoding and Signal Shaping for Digital Transmission,” Wiley, 2002.

[3] W. Daniel Bliss, et al., “MIMO Wireless Communications,” Cambridge University Press, 2007.

[4] C. Studer, et al., “Precoding for the PAPR Reduction in Large-Scale MU-MIMO-OFDM Systems,” IEEE Transactions on Signal Processing, vol. 60, no. 7, 2012.

[5] Ericsson, Ericsson Mobility Report, Datang Wireless Mobile Innovation center,2017, [Online].

[6] S. Patel, M. Chauhan, K. Kapadiya, 5G: Future mobile technology-vision 2020, J. Netw. Comput. Appl. 54(17) (2012).

[7] J. Mitola, Cognitive Radio: Model-Based Competence for Software Radios (Ph.D. Thesis), Institutionen for Teleinformatik, 1999.

[8] J. Mitola, G.Q. Maguire, Cognitive radio: making software radios more personal, IEEE Pers. Commun. 6(4) (1999)13–18.

[9] K. Kumar, A. Prakash, R. Tripathi, Spectrum handoff in cognitive radio networks: A classification and comprehensive survey, J. Netw. Comput. Appl.61(2016)161–188.

[10] A. Goldsmith, Wireless Communications, Cambridge university press, 2005.

[11] W. Liang, S.X. Ng, L. Hanzo, Cooperative overlay spectrum access in cognitive radio networks, IEEE Commun. Surv. Tutor. 19 (3) (2017) 1924–1944.

[12] M. Song, C. Xin, Y. Zhao, X. Cheng, Dynamic spectrum access: from cognitive radio to network radio, IEEE Wirel. Commun. 19 (1) (2012) 23–29.

[13] R. H. Tehrani, S. Vahid, D. Triantafyllopoulou, H. Lee, K. Moessner, Licensed Spectrum sharing schemes for mobile operators: A survey and outlook, IEEE Commun. Surv. Tutor.18(4) (2016)2591–2623.

[14] Ojha, S.; Pandey, A.K., "Close Loop V/F Control of Voltage Source Inverter using SiNUsoidal PWM, Third Harmonic Injection PWM and Space Vector PWM Method for Induction Motor." *Int. J. Power Electron. Drive Syst.* 2016, *7*, 217–224.

[15] S. Ojha, C. Sharma and A. K. Pandey, "Comparative analysis of close loop three level voltage source inverter using siNUsoidal Pulse Width Modulation and Third Harmonic Injection method for different loads," *2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, Coimbatore, India, 2017, pp. 1-6.

[16] A. P. Sinha, H. Prasad, V. K. Yadav, A. P. Singh and S. Ojha, "Navigating the EV Revolution: COVID-19's Influence and Recent Developments in EVs," *2024 1st International Conference on Innovative Sustainable Technologies for Energy, Mechatronics, and Smart Systems (ISTEMS)*, Dehradun, India, 2024, pp. 1-6.

[17] Ojha, S., & Gupta, R. (2022). Switching Frequency Formulation for Predictive Current Control in Grid-Connected VSI. IETE Journal of Research, 69(11), 8502–8510.

[18] S. Ojha and A. K. Pandey, "Comparative Analysis of Voltage Source Inverter Using SiNUsoidal Pulse Width Modulation and Third Harmonic Injection Method for Different Levels and Loads," IJAER, vol. 10, no. 20, pp. 41451-41457, 2015.

[19] Ojha, S., & Gupta, R., "Formulation of Switching Instant for Improved Dynamic Performance in the Predictive Current Control Technique," IETE Technical Review, 40(2), 220–233.

[20] A. P. Singh, R. Gupta, S. Ojha and V. K. Yadav, "DC Bus Capacitor Discharge during Standstill and Running Condition in PMSM based EVs," *2023 11th National Power Electronics Conference (NPEC)*, Guwahati, India, 2023, pp. 1-6.

[21] Ojha S, Gupta R. Stabilization of DC-link voltage in single-phase AC/DC converter with power factor correction using predictive control algorithm. *Int J Circ Theor Appl*. 2023; 51(11): 5197-5209.

[22] A. P. Singh, R. Gupta and S. Ojha, "DC Link Voltage Balance and Discharge in Three-Level NPC Fed PMSM-Powered EVs Using External Circuit," *2024 IEEE Region 10 Symposium (TENSYMP)*, New Delhi, India, 2024, pp. 1-6.

[23] Ojha, S., Gupta, R. (2023). Selective Harmonic Compensation in Active Power Filter Using Nonlinear Predictive Current Control Method. In: Tripathi, S.M., Gonzalez-Longatt, F.M. (eds) Real-Time Simulation and Hardware-in-the-Loop Testing Using Typhoon HIL. Transactions on Computer Systems and Networks. Springer, Singapore.

[24] S. Ojha and R. Gupta, "Switching Frequency Calculation for Predictive Control Method in Active Power Filter Application," *2022 IEEE International Conference on Power* Electronics, Drives and Energy Systems, Jaipur, India, 2022, pp. 1-6.

[25] G. Sinha, S. Ojha, and A. K. Mishra, "Spectrum Utilization using Multiple Access Techniques", TIJER - INTERNATIONAL RESEARCH

JOURNAL, ISSN:2349-9249, Vol.12, Issue 5, page no. b783-b789, May-2025.