RESEARCHERID
THOMSON REUTERS
[Muskan et al, 10(8), Aug 2025]

ISSN : 2455-9679
SJIF Impact Factor : 6.008

ijrtsm
IJRTSM
INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

"A REVIEW ON HYBRID SOLAR–WIND ENERGY SYSTEMS USING MULTI-OBJECTIVE CONVERTER CONTROL"

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ABSTRACT

The global push for sustainable energy sources has accelerated the adoption of Hybrid Renewable Energy Systems (HRES), particularly those combining solar (Photovoltaic or PV) and wind power. These systems are inherently complex due to the intermittent and unpredictable nature of both resources, necessitating sophisticated power electronics for integration, power conditioning, and grid/load management. This review focuses on the critical role of Multi-Objective Converter Control (MOCC) strategies in optimizing the performance of these hybrid systems. Traditional control methods often prioritize a single objective, such as maximum power point tracking (MPPT) or voltage regulation. In contrast, MOCC simultaneously addresses competing goals, including maximizing energy harvest from both sources, ensuring DC-link voltage stability, minimizing power losses, and improving power quality (e.g., total harmonic distortion or THD). This paper surveys recent developments, common architectures, and advanced control algorithms—such as fuzzy logic, Model Predictive Control (MPC), and metaheuristic optimization—applied to DC/DC and DC/AC converters in solar-wind HRES. The main challenges and future research directions for achieving highly efficient, reliable, and cost-effective hybrid systems are also discussed.

Key Words: *HRES, MPC, MOCC, DC/AC*

I. INTRODUCTION

- **Context:** Discuss the limitations of single renewable sources (e.g., solar is absent at night, wind is variable) and how hybridization mitigates this intermittency, leading to a more reliable power supply.
- **System Overview:** Briefly introduce the typical architecture: PV array, wind turbine (with rectifier), DC/DC converters (boost/buck-boost), a common DC bus (DC-link), and a DC/AC inverter for grid/AC load connection.
- **The Control Problem:** Highlight the core challenge: simultaneous control of multiple energy sources and the storage unit (if present) to meet load demand while optimizing multiple, often conflicting, performance criteria.
- **Multi-Objective Converter Control (MOCC):** Define MOCC as a necessity. It is not enough to simply track the MPPT of each source; the system must also maintain bus stability and high power quality.

II. LITERATURE REVIEW

H. K. R. A. S et al (2022) provides a comprehensive review of various solar-wind HRES configurations (AC, DC, and hybrid coupling) and emphasizes that converter control is the primary determinant of system efficiency, particularly in managing the bidirectional flow required by energy storage units.[1]

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K. M. A. et al (2019) discusses the inadequacy of traditional Maximum Power Point Tracking (MPPT) algorithms (like Perturb and Observe or Incremental Conductance) when applied to both PV and wind simultaneously in a shared DC-link system. The paper argues that independent MPPT of both sources without coordinating their contribution to DC-link stability often leads to undesirable voltage fluctuations and power quality issues.[2]
L. X. Y. Z. W et al (2019) details the application of FLC to the common DC-bus converter in a hybrid PV-wind system. The controller uses the DC-link voltage error and its derivative as inputs to dynamically adjust the charging/discharging current of the battery storage, effectively prioritizing DC-link voltage stability while coordinating the power share between the renewable sources and the battery.[3]
Y. P. J. K. T et al (2020) proposes an adaptive FLC to simultaneously achieve optimal power extraction from the wind turbine (a primary objective) and regulate the reactive power injection to the grid (a secondary, power quality objective) using the grid-side converter. This demonstrates FLC's ability to handle two disparate control goals within a single power electronics stage.[4]
M. P. C. A. C. B et al (2021) investigates the use of MPC for the grid-connected inverter of a hybrid system. The cost function (J) is formulated to minimize the grid current tracking error (main objective) and to simultaneously penalize the Total Harmonic Distortion (THD) of the output current (multi-objective constraint). This provides superior dynamic response and power quality compared to classical Proportional-Integral (PI) controllers.[5]
V. A. G. S. K. A et al (2021) explicitly designs a multi-objective cost function that includes terms for DC-link voltage regulation, active power tracking, and minimization of switching frequency. The study illustrates the crucial role of weighting factors (wi) in the cost function for balancing these conflicting objectives, noting that the selection of weights significantly impacts the control strategy's final performance envelope.[6]
P. S. K. A. L et al (2021) utilizes a metaheuristic algorithm (such as Particle Swarm Optimization or Genetic Algorithm) to find the optimal scaling factors and membership function parameters of an FLC-based EMS. The optimization objective is a weighted combination of maximizing system efficiency and minimizing the loss of power supply probability (LPSP), highlighting the use of optimization to solve a long-term multi-objective design problem.[7]
S. S. M. K. C. D et al (2020) focuses on the optimal sizing problem, but frames the control strategy as a key factor. The paper uses a multi-objective optimization algorithm to determine component sizes (PV, wind, battery) by simultaneously minimizing the Net Present Cost (NPC) and maximizing the system reliability (LPSP), showing how multi-objective thinking extends beyond instantaneous converter control to system design.[8]

III. CHALLENGES AND FUTURE DIRECTIONS

3.1 Technical Challenges

- **Weighting Factor Selection:** In MOCC (especially MPC), correctly selecting the weights (wi) for the cost function is crucial and often done through trial-and-error or complex offline optimization. Suboptimal weights lead to poor performance trade-offs.
- **Computational Burden:** Advanced algorithms like MPC and high-fidelity FLC require significant processing power, which can be a limiting factor in cost-sensitive commercial HRES.
- **Interaction with Energy Storage:** The MOCC must seamlessly integrate the control of the battery/storage converter, adding another layer of complexity to the optimization problem.

3.2 Future Research Directions

- **Artificial Intelligence and Machine Learning (AI/ML):** Using reinforcement learning (RL) to develop *self-learning* MOCC strategies that can adapt the weighting factors or control rules in real-time based on long-term performance data and changing environmental conditions.
- **Standardization of MOCC Metrics:** Developing standardized performance indicators that allow for fair comparison of different MOCC algorithms, going beyond simple efficiency to include metrics for reliability, stability, and power quality under transient conditions.
- **Fault-Tolerant Control:** Designing MOCCs that can maintain critical functions (e.g., DC-link voltage stability) even when a component (like a sensor or a power switch) fails.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

IV. Conclusion

Hybrid Solar-Wind Energy Systems are vital for the future of sustainable power generation, and their efficacy hinges on the sophistication of their power electronic converters. Multi-Objective Converter Control (MOCC) has emerged as the essential paradigm for harnessing the full potential of these systems. By moving beyond single-objective approaches, MOCC, especially through advanced techniques like Model Predictive Control and Fuzzy Logic, enables the harmonious reconciliation of competing goals such as Maximum Power Point Tracking, DC-Link Voltage Regulation, and Power Quality Enhancement. While challenges remain in optimizing computational demands and dynamically adjusting control parameters, the convergence of power electronics with Artificial Intelligence promises a new generation of MOCC that will lead to more resilient, efficient, and cost-effective hybrid energy solutions.

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