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Research Paper

A Comprehensive Review of Control Systems for Seamless Renewable Energy Integration in Microgrids: Architectures, Strategies, and Future Directions

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Abstract
Microgrids are essential for integrating high levels of renewable energy, offering localized power generation, greater resilience, and lower dependence on fossil fuels as part of the worldwide shift to cleaner energy systems. This systematic review examines the latest control strategies designed to smoothly incorporate variable sources—mainly solar photovoltaic and wind—into microgrids, while addressing major concerns like power quality issues, reduced system inertia, forecasting errors, islanding transitions, and synchronization with the main grid. The discussion covers traditional methods such as droop-based power sharing, PID controllers, and state-space approaches, alongside more advanced options like model predictive control (MPC) for handling constraints, AI-based techniques (neural networks for forecasting and reinforcement learning for adaptive dispatch), and distributed multi-agent frameworks (using consensus algorithms or game-theoretic peer-to-peer energy trading). Performance aspects—including robustness against uncertainty, response time, efficiency improvements, computational demands, and economic feasibility—are compared based on important studies from 2015 to 2026. Special attention is given to real-world relevance in developing regions, particularly Vietnam's Power Development Plan VIII (PDP8), which aims for major renewable growth by 2030 despite challenges like grid congestion, energy curtailment, and climate risks in rural and island areas. The review points out ongoing difficulties (such as insufficient hardware testing, cybersecurity weaknesses, and scalability issues) but also highlights potential solutions through new technologies and supportive policies. In the end, it stresses the importance of advancing control strategies to ensure microgrids operate reliably, affordably, and sustainably in pursuit of net-zero energy goals.
Keywords: *Microgrid control, renewable energy integration, model predictive control, artificial intelligence in power systems, distributed energy management, smart grids.*

I. Introduction

Microgrids have emerged as critical components in modern power systems, facilitating the integration of large-scale renewable energy sources (RES).By enabling localized energy generation, enhancinggrid resilience, and reducingdependence on fossil fuels,theyplay a pivotal role in the global transition to sustainable energy (Samal et al., 2025; Ojo et al., 2025). Thesesystems effectively manage the variability of intermittent renewable sources like solar photovoltaic (PV) and wind energy while tackling issues suchas power quality degradation, low system inertia, forecasting inaccuracies, transientconditions during islanding, and synchronization challenges with the main grid (Eyimaya et al., 2024; Bihari et al., 2021). Central to this integration are control strategies, which have evolved from traditional decentralized approaches to sophisticated, intelligent frameworks capable of addressing variability, uncertainty, and multi-objective optimization (Shehu et al., 2026; Hasan et al., 2023). Conventional control methods remain valuabledueto their simplicity, reliability, and minimal communication needs, making them effective for basic power distribution and regulation in microgrids dominated by renewables (Juma et al., 2024; Shahgholian, 2021). Among thesemethods, droop control mimics the behavior of synchronous generators by linking frequency to active power and voltage to reactive power, enabling autonomous inverter operations without requiringcentralized coordination (Samal et al., 2025; Ojo et al., 2025). Additional techniques such as PID controllers and state-space modeling enhance local stability and regulationbut face challenges underconditions of high RES penetration and system nonlinearities (Mohammadi et al., 2024; Ahmad et al., 2025). Advanced solutions,suchas model predictive control (MPC), offer predictive optimization and constraint management.Moreover,artificialintelligence (AI) and machine learning (ML) techniques—suchas neural networks for energyforecasting and reinforcement learning for adaptive energydispatch—enhance the adaptability and scalabilityof microgrid management.

Distributed multi-agent systems using consensus protocols and gametheory-based peer-to-peer (P2P) trading further enable decentralized coordination and self-sufficient operations (Quizhpe et al., 2024; Adeyinka et al., 2024). This review synthesizes advancements in control strategies for microgrid management based on key research published between 2015 and 2026.The focus lies on their application to hybrid solar-wind systems integrated with battery storage. The strategies are evaluated using performance metrics such as robustness to uncertainties, response times, efficiency improvements, computational requirements, and cost implications (Samal et al., 2025; Shehu et al., 2026; Ojo et al., 2025). The study also examines practical implications for emerging economies, particularly Vietnam's Power Development Plan VIII (PDP8).Vietnam'sPDP8 sets ambitious targets for renewable energy expansion by 2030 butfaces challenges such as grid congestion, excessive energycurtailments, and climate vulnerabilities in rural and island regions (Ha-Duong, 2024; Ministry of Industry and Trade, Vietnam, 2023). The study addresses the core challengeof achieving seamless renewableenergy integration in microgrids despite operationalcomplexities and uncertainties.Intermittentenergy sourcesleadto voltage and frequency fluctuations, reducedsystem inertia heightens risksassociatedwith the rate of change of frequency (RoCoF), and islanded microgrid operations require precise control to prevent instability. In Vietnam'scase,PDP8's renewable goals are hindered by grid bottlenecks—regions in the south experience energy curtailment of up to 20%—and extreme weather events that amplify risks. These conditions underscore the urgent need for adaptive and resilient control strategies (Ha-Duong, 2024). Research gaps persist in areas such as hardware validation for real-world scalability, cybersecurity measures, and tailored solutions for developing economies (Eyimaya et al., 2024; Hasan et al., 2023). The reviewencompasses conventional methods like droop control, advanced solutionssuch as MPC, intelligent approachesleveraging AI/ML techniques, and distributed models emphasizing hybrid solar-wind-battery systems. Asystematic review methodology guides thisstudy. Peer-reviewedworkswereesourced from academic databases suchas IEEE Xplore, Scopus, and Google Scholar usingsearchterms like"microgrid control strategies,""renewable energy integration," and "Vietnam microgrids"withina timeframe spanning 2015–2026. Only articles focusedon practical RES integration were included; purely theoretical studies or non-English works were excluded. Fromover 150 articles reviewed, 80 were selected for in-depth analysis.

II. Fundamentals of microgrids and renewable integration

Microgrids are self-contained and adaptable power systems that bring together distributed energy resources (DERs), loads, and energy storage, functioning either linked to the main grid or independently in islanded mode. They come in three primary types: AC, DC, and hybrid AC/DC. AC microgrids use an alternating current bus (usually 50/60 Hz), which makes them highly compatible with existing utility setups, traditional AC loads such as motors and household appliances, and straightforward grid connection. DERs like solar inverters and wind converters connect through power electronics, but converting DC sources often leads to efficiency losses of about 5–10%. DC microgrids operate on a direct current bus (commonly 380–750 V), naturally matching modern electronics, LED lighting, electric vehicles, solar PV, and batteries, thereby cutting out extra conversion steps and improving overall efficiency by 10–20% in many cases. However, they encounter difficulties with voltage transformation, fault protection (no natural current zero-crossing), and connecting to AC equipment. Hybrid AC/DC microgrids combine both systems through interlinking converters (ILCs) that allow bidirectional power flow between the AC and DC sides. Recent research shows that hybrids effectively reduce conversion losses, better manage power flows, and enable greater use of renewables by taking advantage of AC's compatibility with legacy systems and DC's efficiency for RES and storage. Essential elements include DERs (such as solar PV, wind, and microturbines), energy storage (mainly lithium-ion batteries, along with flywheels or supercapacitors), controllable loads (with demand response capabilities), power electronics interfaces, and communication/control layers for coordination. In places like Vietnam, where rural and island regions have abundant solar resources but face typhoon risks, hybrid designs are gaining popularity for their resilience and ability to cut reliance on diesel generators.

Solar and wind power lead renewable integration in microgrids because of their availability and falling costs, but their inconsistent output creates major operational demands. Solar PV generation depends on sunlight intensity and temperature, following predictable daily patterns yet experiencing sudden drops (up to 50–80% of rated capacity in minutes) from clouds or shade. Wind turbines produce power based on wind speed cubed, making them highly sensitive to gusts, daily cycles, and seasonal changes—offshore wind, targeted in PDP8, offers higher yields but adds forecasting difficulties. Combining solar and wind provides natural balance: solar is strongest midday, while wind often peaks at night or during cloudy weather, reducing overall variability when storage is included. This intermittency affects power quality through voltage and frequency swings, higher harmonics from inverters, flicker, and reduced system inertia (leading to fast rate-of-change-of-frequency risks). To handle these issues, stochastic modeling methods are commonly used—Markov chains for irradiance shifts, Gaussian processes for uncertainty, copula-based techniques for spatial and temporal wind correlations, or

Monte Carlo simulations for probabilistic forecasts. These tools help capture resource randomness, supporting better reserve planning and control decisions in microgrids.

Microgrid control follows a well-defined hierarchical structure outlined in IEEE Std 2030.7-2017 for energy management systems, ensuring smooth operation across different time scales. Primary control operates locally and quickly (milliseconds to seconds), typically applying droop methods to mimic synchronous generator behavior: frequency drops with active power and voltage drops with reactive power, enabling autonomous sharing among inverters without communication, though it causes steady-state errors under load variations. Secondary control (seconds to minutes) fixes these errors, restoring nominal voltage and frequency through PI controllers, consensus methods, or distributed algorithms, and supports synchronization during mode changes. Tertiary control (minutes to hours) handles overall optimization, including economic dispatch, optimal power flow, maximum RES use, storage scheduling, and grid/market interactions. This layered structure allows smooth transitions between grid-connected and islanded modes, black-start capability, and enhanced resilience. Even with these controls, renewable-heavy microgrids face ongoing challenges: intermittency demands fast storage response to prevent instability; forecasting errors (typically 10–20% MAPE for solar and wind) create supply-demand imbalances; islanding transitions require accurate synchronization to avoid damaging transients; and main grid connection risks reverse power flows, voltage rise, congestion, and curtailment (as seen in Vietnam’s southern provinces, where up to 20% of renewable output has been curtailed due to bottlenecks). PDP8 updates (2025) stress smart grids, large-scale storage, and regional connections to reduce these problems, but aging infrastructure and weather risks continue to hinder high-RES deployment.

III. Control strategies for renewable integration

Control strategies are essential for making renewable energy work smoothly in microgrids. They have developed from straightforward decentralized solutions to advanced, smart systems that manage large fluctuations, uncertainty, and multiple goals at once. Traditional methods give basic independence and ease of use, while newer ones like model predictive control (MPC) bring forecasting, optimization, and strict limit handling. Lately, artificial intelligence and machine learning have been used to create flexible, data-based decisions, and distributed setups allow scalable, reliable teamwork among different parts. This section looks at these strategies, based on studies from 2015 to 2026, paying special attention to how they apply to solar-wind combinations and battery-supported systems. Comparisons focus on key performance aspects: ability to handle uncertainty, response speed, efficiency improvements, computing needs, and cost considerations.

Traditional control techniques are still widely chosen because they are dependable, simple to install, and require almost no communication, which makes them ideal for basic power sharing and regulation in microgrids with lots of renewables. Droop-based decentralized control, a standard approach since its early development, mimics synchronous generators by connecting frequency to active power and voltage to reactive power. This lets inverters connect and share loads automatically without a central controller. It performs especially well in islanded solar-wind setups, where inverters balance loads on their own using droop settings, although it often leaves small steady-state errors in voltage or frequency when loads vary. PID controllers work together with droop to give accurate local control of voltage, current, or frequency loops in inverters. They react quickly to linear changes but are less effective against nonlinear effects like sudden renewable fluctuations. Model-based methods, such as state-space modeling and linear quadratic regulators (LQR), strengthen stability checks by clearly describing system dynamics, allowing eigenvalue-based small-signal stability analysis in hybrid configurations. Important studies include Samal (2025), who examined 194 papers and grouped conventional methods (PI/PD/PID, droop) for inverter control and voltage/frequency regulation, praising their low processing needs but noting only moderate toughness; Saimadhuri (2025) on droop and virtual impedance for parallel inverters in renewable systems; and Ojo (2025), which points out droop’s cost advantages in small-to-medium microgrids despite stability issues at high renewable levels. Other research, like Shahgholian (2025) on droop in DC microgrids and Li (2024) on GPS-synchronized fixed-frequency droop, shows good results in solar-wind setups with power sharing errors under 5% in balanced cases. These techniques are good for initial setups but usually need extra support when renewable shares are high, as seen in solar-wind-battery tests with fast settling times in milliseconds but steady-state errors reaching 3–5%.

Advanced model predictive control (MPC) overcomes many weaknesses of traditional methods by directly optimizing future behavior while respecting limits, which makes it very useful for renewable integration with storage. MPC setups usually rely on finite-horizon forecasts of loads, solar irradiance, and wind speeds to reduce costs or deviations, taking into account battery state-of-charge (SOC) limits, power ramp rates, and voltage boundaries. Real-time use in microgrids shows strong handling of uncertainty through receding-horizon updates. Important examples include Shehu (2026), which reviewed hybrid MPC setups that reduced costs by 25–40% and ran in real time on embedded hardware in standalone systems; Yaghoubi (2025), a meta-analysis of MPC studies from 2016 to 2025 showing better multi-objective results in both grid-connected and islanded modes; and Jacob (2025), which introduced decentralized continuous-set MPC for hybrid solar-wind DC microgrids with 99.96% power tracking precision and 2–3.5% better energy capture than standard methods. Strengths include excellent robustness to prediction errors and strict limit compliance (for example, SOC boundaries to prevent over-discharge), but drawbacks come from high computing needs—requiring solvers like quadratic programming—which can slow response in very fast dynamics (milliseconds) compared to droop control. Newer versions solve this through explicit or approximate MPC, finding a good balance between toughness and practicality in renewable-heavy systems.

AI and machine learning-based controls represent the current cutting edge, offering flexibility in complex, uncertain situations through learning from data. Neural networks, such as LSTM and ANN, are excellent for short-term solar and wind forecasting, feeding directly into dispatch decisions, while reinforcement learning (RL) agents discover optimal policies for adaptive energy management through trial-and-error interaction with the environment. Combining these with IoT enables edge computing for quick sensor data processing, reducing delay in fault detection and control. Trends since 2020 focus on deep RL for long-term optimization and hybrid setups that mix AI with conventional methods. Important studies include Mastoi (2026) on AI for forecasting, adaptive control, and demand response in smart grids; Addai (2026) reviewing AI-improved droop with ML/RL for better renewable integration; Waghmare (2025) on RL-based microgrid control trends; and Abo-Elkhair (2025) combining ANN/RL with PI for stronger stability. These approaches deliver 12–25% cost savings and better fault detection (up to 98% accuracy in some cases), though challenges remain around training data needs and interpretability.

Distributed and multi-agent systems support scalability and resilience by spreading decisions across DERs, loads, and storage units. Consensus algorithms allow agreement on variables like voltage references without a central authority, while game theory models strategic interactions in peer-to-peer (P2P) energy trading, optimizing bids and allocations. Blockchain adds security to transactions and control signals in decentralized setups. Reviews by Tariq (2025) on P2P multi-energy trading with blockchain/game theory; Luo (2022) on distributed game-theoretic trading; and Kumar (2024) on resilient multi-microgrid sharing show reduced single-point failures and up to 80% less communication overhead using event-triggered consensus. These methods fit well in community microgrids with prosumers, supporting secure P2P trading alongside renewables.

Conventional methods provide simplicity and quick response but fall short under high renewable variability; MPC and AI deliver better optimization at greater complexity; distributed approaches stand out for scalability. The best choice depends on microgrid size, renewable share, and available resources—hybrid combinations often produce the strongest overall performance.

IV. Simulation and experimental tools

Simulation and experimental validation are crucial for building, testing, and improving control strategies in microgrids that rely heavily on renewables. They connect theoretical concepts to actual performance, helping reduce risks before real-world use and ensuring systems meet standards—especially when renewables cause frequent changes and instability.

MATLAB/Simulink remains the most popular software for modeling microgrids and renewable integration. Its intuitive block-based design, rich libraries (like Simscape Power Systems and the Renewable Energy Toolbox), and smooth connection to control design tools make it excellent for dynamic simulations of solar PV, wind turbines, batteries, inverters, and layered control systems. Users can easily test droop control, MPC, or AI-based methods while watching transients, power flows, and stability indicators. Recent work shows its value: simulations of hybrid solar-wind setups with MPPT algorithms demonstrate stable voltage regulation and maximum energy capture under shifting sunlight and wind conditions. PSCAD/EMTDC specializes in electromagnetic transients (EMT), delivering higher accuracy for fast events like inverter switching, fault behavior, and harmonic studies in grids rich with renewables. It is particularly strong for modeling grid-following and grid-forming inverters, protection systems, and low-inertia situations, with built-in renewable models (wind/solar farms) and detailed machine representations. OPAL-RT simulators link software and hardware through real-time processing, supporting both phasor-domain (ePhasorSim) and EMT-domain (eMEGAsim) simulations at sub-microsecond time steps. These platforms support quick prototyping of controls, direct code generation from Simulink models, and connections to communication protocols (Modbus, DNP3), making them ideal for testing large networked microgrids.

Hardware-in-the-Loop (HIL) testing brings controllers into realistic scenarios by linking physical hardware (microgrid controllers, inverters, relays) to a real-time simulator that mimics the power system, loads, and renewables. Controller HIL (CHIL) safely tests islanding transitions, fault ride-through, cybersecurity measures, and adaptive dispatch without endangering equipment or causing outages. OPAL-RT HIL setups are widely used for microgrid work: examples include testing grid-forming inverter controls in networked setups, evaluating supervisory energy management systems for typical load patterns, and checking resilience to disturbances or cyber threats while monitoring communication timing and synchronization. Power HIL (PHIL) extends this by connecting actual power devices (converters, batteries) to amplified simulated signals, allowing high-power tests of interactions like voltage support or black-start sequences.

Case studies show the practical benefits in different settings. In rural Vietnam, HOMER-based designs (often combined with Simulink checks) have guided isolated microgrids on islands such as Con Dao, optimizing hybrid PV-wind-diesel-battery setups for 60 kW loads while tackling typhoon resilience and reducing diesel use—real projects cut emissions and costs through simulated sensitivity studies. Other rural Vietnamese efforts focus on adaptive controls for off-grid reliability to meet PDP8 objectives. In Europe, initiatives like EU smart grid projects (e.g., RE-EMPOWERED) showcase microgrid pilots blending renewables with district heating and biomass, verified through simulations and HIL for forecast-driven balancing and multi-energy coordination. Industrial cases, such as hybrid microgrids in Spain with PV, storage, and EV charging, use real-time tools to confirm self-sufficiency and grid support capabilities.

Benchmarking depends on standardized test scenarios to ensure fair comparison and compliance. IEEE 1547-2018 (with updates) sets core requirements for DER interconnection, covering ride-through (voltage/frequency), anti-islanding, power quality, and intentional islanding—applied at the point of common coupling (PCC). Annexes outline waveform analysis, open-phase detection, and performance verification, often tested in PSCAD or OPAL-RT for certification. Other standards include IEEE test feeders for distribution systems with DERs and the IEC 62898 series for microgrid-specific features like black-start and seamless transitions. These scenarios—covering normal operation, faults, islanding/resynchronization, and high-RES disturbances—enable objective evaluation of control robustness, with metrics such as settling time, overshoot, and energy curtailment guiding refinements.

In summary, combining MATLAB/Simulink for design exploration, PSCAD for transient precision, OPAL-RT for real-time and HIL validation, and standards like IEEE 1547 for benchmarking creates a strong toolset. In Vietnam, these tools directly support PDP8-driven pilot projects by enabling affordable, resilient designs suited to remote and island challenges before full deployment.

V. Challenges, gaps, and opportunities

The addition of renewable energy sources (RES) to microgrids holds strong promise for sustainability and system resilience, but it also brings a wide array of complex challenges across technical, economic, regulatory, and social areas. From a technical standpoint, the biggest difficulties come from the unpredictable and variable output of solar PV and wind power. These fluctuations often lead to sharp voltage and frequency swings, lower overall system inertia, and faster rates of frequency change (RoCoF) in low-inertia setups. The problems become much more serious in islanded mode, where there is no backup from the main grid, requiring fast and precise control to avoid instability or complete outages. Protection systems face further issues: high levels of RES cause bidirectional power flows and very low fault currents, which make traditional overcurrent relays unreliable, while the different operating modes (grid-connected versus islanded) make coordination much harder. Cybersecurity is becoming an increasingly serious concern, especially as distributed controls, IoT sensors, and edge computing depend more on communication networks—attacks such as data breaches, denial-of-service, or direct tampering with control signals could interrupt power sharing or lead to cascading failures. In places like Vietnam and much of Southeast Asia, these technical problems overlap with environmental realities: frequent typhoons and heavy monsoon rains make intermittency worse and damage equipment, while rural and island microgrids often lack strong backup power during long outages. On the economic side, the high initial costs of advanced storage (particularly lithium-ion batteries), power electronics, and control systems slow down widespread use, especially in developing regions where government subsidies are uneven and payback periods remain long. Regulatory hurdles add to the difficulties: many current policies still favor large centralized fossil-fuel plants, with unclear or missing rules for microgrid ownership, grid connection standards, peer-to-peer energy trading, or direct power purchase agreements (DPPAs). In Vietnam, even though PDP8 sets ambitious goals (30–35% renewables by 2030, excluding large hydro), grid congestion has already forced substantial curtailment (up to 20% in southern provinces), clearly showing mismatches between generation and transmission capacity upgrades.

Research in the field still shows several major shortcomings that slow progress toward large-scale, reliable microgrid deployment. Many studies—around 68% based on recent reviews—are based purely on simulation, without hardware-in-the-loop (HIL) testing or real-world trials, which lowers confidence in how they perform under actual conditions such as measurement errors, model inaccuracies, or cyber threats. Cybersecurity is rarely covered in depth—only about 22–30% of papers deal with it seriously—leaving weaknesses in designs that can withstand attacks on communication links or controllers. Scalability is another area that gets little attention: while distributed and multi-agent methods show promise in cutting communication needs (for example, 80% reduction with event-triggered consensus), very few studies look at very large networks with hundreds of DERs or full multi-microgrid coordination. Standardization is also missing—there are no consistent benchmarking protocols, rules for controller interoperability, or models that consider full lifecycle costs, making it difficult to compare results or roll out systems widely. In advanced control areas, MPC and AI/RL show strong potential (for example, 20–40% cost savings or better stability), but there is still little work on hybrid model-data-driven approaches with solid mathematical proofs, ways to explain black-box AI decisions, or handling extreme uncertainties like severe weather events. Research specific to Vietnam rarely addresses climate-adapted strategies, full lifecycle cost analyses (including battery aging), or combining new technologies such as green hydrogen or EVs for demand response. Real-world testing in tropical, typhoon-prone areas is uncommon, and socio-economic issues—community acceptance, local skill shortages for operation and maintenance, and fair energy access in remote regions—are seldom studied.

Despite these difficulties and gaps, there are many promising opportunities to improve microgrid technology and speed up renewable integration. Technically, hybrid methods—combining MPC with AI (for example, reinforcement learning for better forecasting and dispatch) or distributed consensus with edge computing—can create strong, fast-response control that reduces communication needs while getting the most from renewables. New trends like digital twins for predictive maintenance, quantum-inspired methods for complex scheduling, and blockchain-protected peer-to-peer trading could improve transparency, reliability, and economic benefits. In Southeast Asia, including Vietnam, there is great potential to use abundant solar resources for hybrid solar-wind-storage systems in rural and island areas, cutting diesel use and emissions while building better protection against natural disasters. On the policy side, recent PDP8 updates (especially the 2025 revisions focusing on smart grids and storage) create openings for pilot projects, private investment incentives through DPPAs, and cross-border grid links to share flexibility. Research possibilities include distributionally robust optimization (DRO) for handling uncertainty, lifecycle-focused battery management, shared cyber-physical testbeds for validation, and interdisciplinary approaches that blend climate adaptation with social fairness. By tackling these gaps—through more HIL and field testing, built-in cybersecurity, standard benchmarks, and solutions designed for the region—microgrids can move from experimental projects to widely used solutions that support net-zero targets, fair energy access, and strong, reliable power systems in developing countries.

VI. Future directions and recommendations

The future of control systems for microgrids with high renewable integration depends on embracing new technologies and cross-disciplinary teamwork to solve current limitations and speed up large-scale, reliable rollout. Hybrid quantum-classical algorithms like QAOA could open new doors for tackling tough optimization tasks—real-time economic dispatch, scheduling under deep uncertainty, and coordinating big networks—that are too hard for traditional computers. Early tests already show quicker solutions and better energy use in microgrid setups. Digital twins, kept in sync with real equipment and boosted by AI, will support predictive and self-repairing control, instant fault detection, smarter battery lifecycle management, and better preparation for extreme weather—especially useful in places like Vietnam that face frequent typhoons. Combining control engineering with AI can create clearer hybrid models (for example, federated reinforcement learning to protect privacy in distributed optimization), while working with materials science can push forward advanced batteries with higher energy storage, longer life, and smooth fit into adaptive SOC control. For Vietnam and other developing economies, policy steps should include broader subsidies and mixed financing (building on PDP8 updates and JETP support) to fund smart controls, battery energy storage systems (BESS), and pilot projects; simplifying direct power purchase agreements (DPPAs); adding capacity payments for extra services from microgrids; and pushing standardized rules (such as IEEE 1547 compliance) to lower investment risks and attract more private companies to rural and island areas. A clear research agenda should tackle these key questions: (1) How can hybrid quantum-classical techniques be used practically for real-time dispatch in microgrids with heavy renewable use? (2) How do AI-improved digital twins strengthen predictive maintenance and resilience in island systems prone to climate risks? (3) In what ways can federated learning improve privacy and cybersecurity for distributed energy management? (4) Which frameworks best link advanced battery materials to control strategies to cut degradation and lifecycle costs? (5) How well do blockchain-protected consensus methods support fair peer-to-peer energy trading in community microgrids? (6) Can federated RL that accounts for uncertainty provide cyber-resilient forecasting and dispatch? (7) What standard HIL testbeds and benchmarks are needed to test new controls for scalability in developing regions? (8) How can well-targeted incentives best speed up smart-control pilot projects in rural Southeast Asian microgrids? By following these paths through joint research, technology trials, and well-aligned policies, microgrids can grow into strong, fair foundations for sustainable energy systems.

VII. Conclusion

This review brings together the changing world of control systems for renewable energy in microgrids—from basic setups and layered strategies to advanced MPC, AI/ML-based methods, and distributed solutions. Traditional approaches give solid starting points, but newer advanced and intelligent controls are better at dealing with intermittency, low inertia, and optimization demands, as shown by clear improvements in efficiency, toughness, and cost savings in recent studies. Issues like forecasting errors, cybersecurity weaknesses, and scaling difficulties remain, especially in developing areas such as Vietnam under PDP8 goals, yet there are many promising paths forward through new tools like quantum optimization, digital twins, and combined expertise from different fields.

In the end, strong control systems are key to making high-renewable microgrids deliver reliable, fair, and low-carbon power. By linking technical progress with supportive policies—including focused subsidies, pilot projects, and clear standards—stakeholders can break through obstacles and expand these systems effectively. Ongoing research and real-world testing will turn microgrids into dependable building blocks for worldwide energy transitions, matching sustainability goals and local needs for a cleaner, more secure future.

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