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Optimal Dispatch Control of Hybrid AC Microgrid Using Reinforcement Learning over rule-based approach for Enhanced Renewable Energy Utilization

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Abstract:

The current power systems need intelligent control methods which help them operate their microgrids safely and efficiently with minimal need for traditional diesel generators. This research paper describes the development and execution of an intelligent energy management system (EMS) which operates a hybrid AC microgrid that combines solar photovoltaic (PV) and wind energy conversion system (WECS) and battery energy storage system (BESS) and diesel generator. The primary objective of the proposed system is to reduce diesel generator operating hours by prioritizing renewable energy utilization and optimal battery scheduling while maintaining continuous load supply.

A reinforcement learning (RL)–based supervisory control strategy is developed and integrated into the microgrid framework using MATLAB/Simulink. The RL controller establishes optimal operational procedures which include battery charging and discharging and renewable energy dispatch prioritization and DG activation based on system conditions which include load demand and renewable power availability and battery state of charge (SOC). The proposed controller is compared with a conventional rule-based energy management strategy to evaluate improvements in system performance.

The simulation results show that the RL-based EMS system performs better than the rule-based system because it increases renewable energy usage while decreasing diesel generator usage during testing with different irradiance and wind speed and load demand conditions. The results also confirm enhanced battery utilization efficiency and stable power balance across the common AC bus while ensuring uninterrupted load supply throughout the operating period. The intelligent control system design establishes an effective system for control operations.

Keywords— Hybrid AC Microgrid, Reinforcement Learning (RL), Energy Management System (EMS), Solar Photovoltaic (SPV), Wind Energy Conversion System (PMSG), Battery Energy Storage System (BESS), Diesel Generator (DG) Runtime Reduction, Renewable Energy Utilization, Intelligent Power Dispatch, MATLAB/Simulink Simulation, Distributed Energy Resources (DER), Smart Microgrid Control, Load Demand Management, Sustainable Energy Systems, Autonomous Microgrid Operation

I. INTRODUCTION

The increasing global demand for reliable, sustainable, and cost-effective electrical energy has accelerated the deployment of hybrid microgrids that use Solar Photovoltaic (SPV) systems wind turbine generators Battery Energy Storage Systems (BESS) and Diesel Generators (DG) as their renewable energy sources. Hybrid AC microgrids deliver continuous electricity service to areas that lack traditional utility systems which provide power to remote locations and rural communities and isolated regions. The systems achieve higher energy reliability through their design which integrates multiple energy sources together with storage systems to produce power while decreasing their need for fossil-fuel power generation.

The hybrid microgrid system currently faces a critical technical obstacle that hinders its ability to coordinate distributed energy resources effectively. The system requires an advanced supervisory control system to achieve its goal of minimizing Diesel Generator operational time while providing uninterrupted load power and maintaining system stability. Conventional rule-based Energy Management Systems (EMS) use fixed switching rules and predetermined threshold values as their

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basis for making power dispatch decisions. The methods provide an easy implementation process but they fail to adapt when renewable energy supply changes or load requirements shift which results in suboptimal system performance. Recent developments in Artificial Intelligence (AI) have helped in creating smart control methods to improve the performance of microgrids. Among these methods, Reinforcement Learning (RL) is a powerful technique for energy management because it can learn the best control actions by interacting with the system conditions continuously. Unlike rule-based controllers, the RL-based Energy Management System (EMS) can take decisions automatically based on real-time inputs such as solar irradiance, wind power availability, battery State of Charge (SOC), and load demand variations.

In the proposed hybrid AC microgrid system, Solar PV and wind are used as the main power generation sources. The Battery Energy Storage System (BESS) supports the system by storing extra energy and supplying power when needed through controlled charging and discharging operations. The Diesel Generator (DG) is used only as a backup source and operates when renewable sources and battery power are not enough to meet the load demand. In the wind energy system, a Permanent Magnet Synchronous Generator (PMSG) is used to improve generation efficiency and reliability. The Reinforcement Learning agent works as a supervisory Energy Management System which monitors system conditions and decides the proper switching actions such as battery charging, battery discharging, priority use of renewable energy, and turning the Diesel Generator ON or OFF.

The main objective of this work is to design and implement a Reinforcement Learning-based Energy Management System to reduce the operating time of the Diesel Generator while increasing the use of renewable energy and ensuring continuous power supply to the load in a hybrid AC microgrid. The proposed EMS model is developed in MATLAB/Simulink and tested using different solar irradiance levels, wind speed variations, and load demand changes over a 24-hour operation period.

The simulation results show that the RL-based supervisory control strategy gives better performance by giving priority to renewable energy sources, improving battery usage, and reducing the operating time of the Diesel Generator while maintaining stable microgrid operation. Therefore, the proposed intelligent EMS can be used as an effective solution for future hybrid renewable microgrid systems to improve reliability, flexibility, and sustainability.

II. MICROGRID CONFIGURATION

The system design implements a hybrid AC microgrid which combines Solar Photovoltaic (SPV) generation with a wind energy conversion system that uses Permanent Magnet Synchronous Generator (PMSG) technology together with Battery Energy Storage System (BESS) and Diesel Generator (DG) components. The primary objective of the proposed architecture is to minimize Diesel Generator operating hours through intelligent supervisory control while ensuring reliable and uninterrupted load supply under varying renewable generation and load conditions.
The proposed configuration uses Solar PV arrays together with wind energy conversion systems as its main sources of renewable energy which power the microgrid. The SPV array is connected to a common DC link through a DC–DC boost converter which uses Maximum Power Point Tracking (MPPT) control to extract maximum available solar energy under varying irradiance conditions. The wind turbine generates power through a Permanent Magnet Synchronous Generator (PMSG) which produces variable-frequency AC output that three-phase rectifiers convert into DC power for connection to the common DC link.
The Battery Energy Storage System (BESS) establishes a connection to the DC link through a bidirectional DC–DC converter (BDC) which enables the system to regulate charging and discharging processes depending on operational needs and State of Charge (SOC) boundaries. This arrangement allows the battery to store excess renewable energy during surplus conditions and supply power during renewable generation shortages which results in improved system stability and decreased Diesel Generator usage.
The combined renewable energy sources and BESS connect to the AC bus through a three-phase Voltage Source Converter (VSC). The VSC converts DC-

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link power into regulated AC power which provides electrical energy for local loads.

The installation of an R–C filter (R_f "-" C_f)at the PCC will improve power quality. The filter system removes VSC-generated switching-frequency harmonics while it controls transient voltage swings and meets harmonic standards needed for microgrid stability. The Diesel Generator functions as a backup power system which connects through controllable switches to the AC bus. The switches enable power system operators to choose between connecting and disconnecting the DG based on their current requirements. The DG system starts operating when both renewable energy sources and battery power become too weak to supply sufficient electricity. The selective operation method enables organizations to decrease fuel usage while they enhance operational performance.

A Reinforcement Learning (RL)–based Energy Management System (EMS) operates as the central controller for the hybrid microgrid system. The RL controller continuously monitors system operating conditions including:

- solar PV generation
- wind power availability
- battery State of Charge (SOC)
- load demand

The RL agent uses system states to find the best control methods which include:

- battery charging
- battery discharging
- renewable energy prioritization
- Diesel Generator ON/OFF scheduling

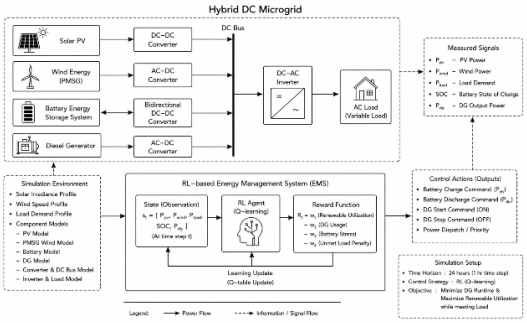
The RL controller establishes an ideal dispatch system through ongoing interaction with the microgrid system because it wants to decrease Diesel Generator usage while increasing renewable energy power and providing constant electricity to customers.

The proposed architecture enables microgrid operation in islanded mode and operates as a dynamic energy distribution system which adapts to different environmental and user demand requirements. The complete system model runs on MATLAB/Simulink to test controller functioning during actual operational settings.

Microgrid Component Specifications

Component	Specification	Remarks
SPV Capacity	25 kW	Peak generation during daytime operation
Wind Turbine	30 kW PMSG-based WECS	Variable-speed renewable generation
BESS Capacity	50 kWh	Li-ion battery with SOC limits (20–90%)
DG Capacity	50kW	Backup synchronous generator
Load Demand	30 kW ± 20 kW	Time-varying dynamic load
Rectifier (Wind)	Three-phase uncontrolled rectifier	Converts PMSG output to DC
BDC	Bidirectional 50 kW	Battery charge/discharge control
DC Link	400–600 V	Common coupling point of sources
Filter L_f	Harmonic-limiting inductor	Current smoothing
Filter R_f–C_f	High-frequency harmonic suppression	Power quality improvement

Block diagram



Design Methodology of Microgrid Components

Component	Design Considerations
SPV Array	Sized based on daytime peak load demand and irradiance profile
Wind System	Rated to complement solar generation during low irradiance periods
BESS	Provides 3–4 hours autonomy with safe SOC operating limits

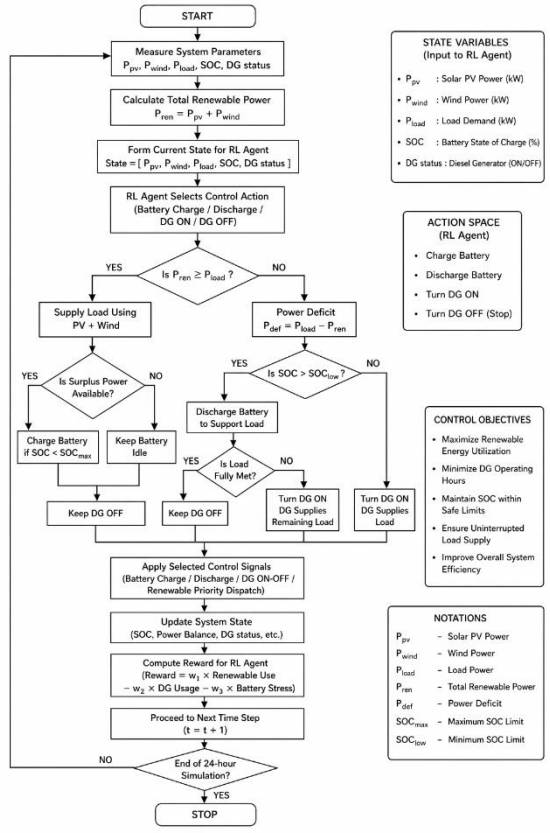
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DG	Sized to support full load during zero renewable availability
VSC	Rated for combined SPV + wind + battery maximum transfer capability
Rectifier	Converts variable-frequency PMSG output into stable DC link voltage
BDC	Enables bidirectional battery energy flow for EMS scheduling
Filters	Designed to suppress switching harmonics without affecting fundamental frequency

III. DESIGNED CONTROL STRATEGY

The created control system for the proposed hybrid AC microgrid system operates to decrease Diesel Generator (DG) running time while maintaining continuous load delivery through its smart management of Solar Photovoltaic (SPV) systems and Permanent Magnet Synchronous Generator (PMSG) wind energy production and Battery Energy Storage System (BESS) systems. A supervisory controller uses a Reinforcement Learning (RL) system to execute Energy Management System (EMS) operations which select the best power distribution methods for different renewable energy production and electricity consumption patterns. The proposed RL-based controller uses solar irradiance and wind speed and battery State of Charge (SOC) and load demand changes as its real-time operating conditions to dynamically modify its control approach which differs from traditional rule-based control systems that depend on fixed switching points. The system uses adaptive capacity to achieve effective renewable energy usage and to minimize unnecessary Diesel Generator operation.

Power flow



A. Control Objectives

The main objectives of the proposed control strategy are:

1. To maximize utilization of available renewable energy sources solar PV and wind generation
2. To use battery storage for balancing short-term power mismatches between generation and load
3. To minimize Diesel Generator operation by activating it only during renewable energy shortages
4. The system needs to maintain continuous power supply which will help to keep microgrid operations running smoothly and
5. The system needs to operate batteries within their safe charging limits.

B. Control Architecture

The proposed RL-based Energy Management System is organized into three hierarchical layers.

1. Measurement Layer The measurement layer continuously acquires system

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operating parameters including solar PV output power wind turbine generated power battery State of Charge SOC load demand DC-link voltage and DG operating status. The system uses sensors and Simulink monitoring blocks to capture these measurements which serve as inputs to the supervisory controller.

2. Decision Layer RL Agent The Reinforcement Learning agent acts as the supervisory decision-making unit of the hybrid microgrid. The RL controller selects the best control action for each time period based on current system state information. The RL agent gives priority to renewable energy production and battery resource usage before it plans the Diesel Generator work schedule.
3. Execution Layer The execution layer implements the control decisions generated by the RL agent through battery charging control battery discharging control renewable power utilization prioritization Diesel Generator ONOFF switching. The system uses converter control signals together with switching logic to implement these commands in the MATLABSimulink microgrid model.

C. Reinforcement Learning Control Logic
The RL agent operates in a hybrid microgrid environment which researchers developed for training purposes through their MATLAB/Simulink simulated environment. The controller learns optimal switching policies through interaction with system operating conditions.

State Space The state variables used by the RL controller include

- solar PV power P_pv
- wind generation power P_wind
- load demand P_load
- battery SOC
- DG operating status

These variables represent the real-time operating condition of the microgrid. **Action Space**

The action space of the RL agent consists of supervisory switching decisions

- battery charging command
- battery discharging command
- Diesel Generator ON command
- Diesel Generator OFF command
- renewable priority enable signal solar wind utilization control

These actions allow flexible power dispatch depending on system conditions.

Reward Function

The reward function is designed to encourage renewable energy utilization while penalizing unnecessary Diesel Generator operation and unsafe battery usage. The reward structure can be expressed as

$$R = w_1(P_{pv} + P_{wind}) - w_2 P_{DG} - w_3 \mid SOC - SOC_{ref} \mid$$

where:

- P_{pv} represents solar generation
- P_{wind} represents wind generation
- P_{DG} represents Diesel Generator output power
- SOC represents battery state of charge
- SOC_{ref} represents preferred SOC operating level
- w_1, w_2, w_3 are weighting coefficients

This reward formulation promotes renewable utilization, reduces DG operation, and maintains safe battery operating limits. D. Control Flow Strategy The operational sequence of the RL-based supervisory controller is summarized as follows Measure solar PV generation, wind generation, load demand, and battery SOC Evaluate current system operating state Determine optimal control action using RL policy Supply load using renewable

D. Control Flow Strategy

The operational sequence of the RL-based supervisory controller is summarized as follows:

1. Measure solar PV generation, wind generation, load demand, and battery SOC
2. Evaluate current system operating state
3. Determine optimal control action using RL policy
4. Supply load using renewable energy sources as first priority
5. Use battery support when renewable generation is insufficient

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6. Activate Diesel Generator only when renewable and battery support cannot meet load demand
7. Maintain SOC within predefined safe limits
8. Repeat the control process at each simulation time step

E. Advantages of the Proposed Control Strategy

The proposed RL-based EMS provides several operational advantages compared to conventional rule-based control:

- significant reduction in Diesel Generator operating hours
- improved renewable energy utilization
- intelligent battery charge/discharge scheduling
- adaptive response to varying environmental conditions
- improved microgrid operational stability
- suitability for autonomous islanded microgrid operation

State Variables and Action Space

State Variables	Control Actions
Solar PV power	Renewable priority dispatch
Wind power	Renewable support scheduling
Load demand	Battery or DG compensation
Battery SOC	Charge / Discharge control
DG status	Start / Stop DG

Reinforcement Learning Parameters

Parameter	Value / Description
Learning Algorithm	Deep Q-Network (DQN)
State Space	$P_{pv}, P_{wind}, P_{load}, SOC, DG\ status$
Action Space	Battery charge, discharge, DG ON/OFF
Reward Function	Renewable maximization – DG penalty – SOC deviation penalty
Training Episodes	1000+ episodes
Simulation Duration	24-hour operating cycle
Time Resolution	15-minute equivalent step (compressed simulation time)

IV. SIMULATION RESULTS

The performance of the proposed Reinforcement Learning (RL)–based Energy Management System (EMS) was evaluated using a MATLAB/Simulink model of a hybrid AC microgrid over a 24-hour operating period under variable solar irradiance, wind speed, and load demand conditions. The simulation considers coordinated operation of Solar PV generation, wind generation using a Permanent Magnet Synchronous Generator (PMSG), Battery Energy Storage System (BESS), and a Diesel Generator (DG).

The objective of the simulation study is to compare the effectiveness of the proposed RL-based supervisory control strategy with a conventional rule-based energy management strategy in terms of:

- renewable energy utilization
- Diesel Generator operating hours
- battery State of Charge (SOC) regulation
- load supply continuity
- overall system efficiency

The system parameters considered in the simulation are summarized below.

A. System Configuration

The hybrid AC microgrid model includes the following component specifications:

- Solar PV capacity: 20 kW
- Wind generation system: 30 kW PMSG-based WECS
- Battery Energy Storage System: 50 kWh capacity with
- Diesel Generator capacity: 50 kW
- Load demand: 30 kW ± 20 kW time-varying dynamic load
- Simulation duration: 24-hour operating cycle
- Simulation platform: MATLAB/Simulink

Two control strategies were evaluated:

1. Conventional rule-based EMS
2. Proposed Reinforcement Learning–based EMS

B. Renewable Energy Utilization

The RL-based EMS demonstrated improved renewable energy utilization by intelligently prioritizing available solar and wind generation before scheduling battery discharge or Diesel Generator support.

Under the rule-based control strategy, renewable utilization was limited during certain operating intervals due to fixed switching thresholds and conservative battery charging logic. As a result,

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surplus renewable energy was occasionally underutilized.

In contrast, the RL controller dynamically scheduled battery charging during renewable surplus periods and reserved stored energy for peak demand intervals, thereby improving renewable penetration and reducing dependence on the Diesel Generator.

Renewable Utilization Comparison

Metric	Rule-Based Strategy	RL Strategy	Improvement
Solar Utilization (%)	83.2	91.8	+10.3%
Wind Utilization (%)	78.5	89.5	+14.0%
Total Renewable Utilization (%)	80.9	90.6	+12.0%

Additionally, wind energy contribution further supported load supply during non-solar operating hours, reducing the need for DG activation.

C. Diesel Generator Operation

One of the primary objectives of the proposed control strategy is to minimize Diesel Generator operating hours while maintaining uninterrupted load supply.

Simulation results show that the RL-based controller significantly reduced DG runtime by:

- prioritizing renewable sources
- intelligently scheduling battery discharge
- delaying DG startup until absolutely necessary

Compared with the rule-based control strategy, the RL controller reduced DG participation substantially.

Metric	Rule-Based Strategy	RL Strategy	Improvement
DG Runtime (hours/day)	14 hours	11 hours	21% reduction
DG Energy Contribution (kWh/day)	83.2 kWh	65.2 kWh	18 kWh reduction (≈21.6%)

This reduction directly improves fuel savings and lowers environmental impact.

D. Battery State-of-Charge (SOC) Profile

Battery SOC variation plays a critical role in ensuring microgrid stability and extending battery lifetime.

The RL-based EMS maintained SOC within a safe operating range by avoiding:

- deep discharge conditions
- unnecessary overcharging cycles
- excessive switching between charge and discharge modes

Compared with the rule-based controller:

Parameter	Rule-Based Strategy	RL Strategy
SOC Range	15% – 100%	30% – 95%

Maintaining SOC within this controlled operating band improves battery reliability and increases storage system lifespan.

E. Load Supply Performance

Simulation results confirm that the total generated power from Solar PV, wind generation, BESS discharge support, and Diesel Generator backup successfully satisfied load demand throughout the 24-hour operating period.

The RL controller ensured:

- continuous load supply
- smooth power sharing between sources
- reduced DG dependency during renewable availability

Comparison between total generation and load demand plots verifies that the load was met at all time intervals without interruption.

F. Performance Plot Observations

The simulation plots obtained from MATLAB/Simulink illustrate:

- improved renewable energy dispatch under RL control
- reduced Diesel Generator participation
- smoother battery SOC trajectory
- balanced power sharing among microgrid

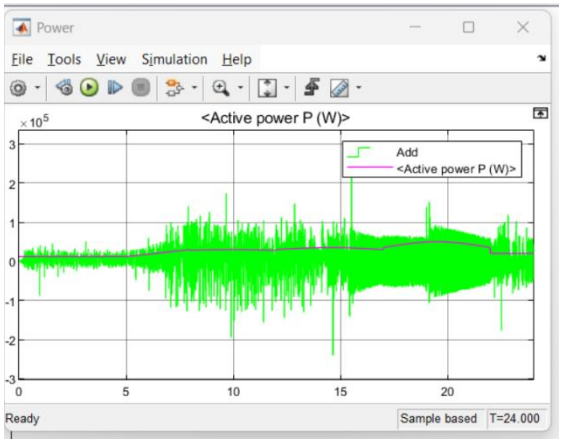
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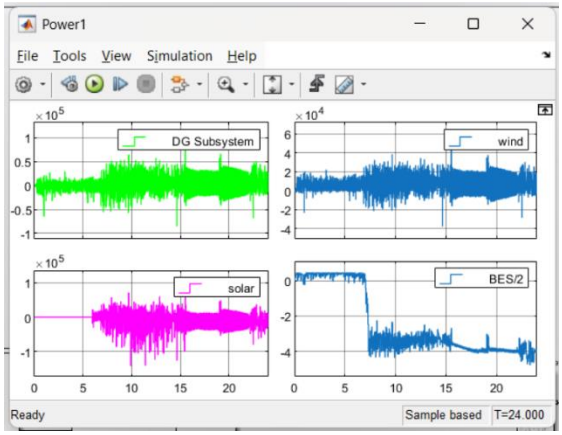
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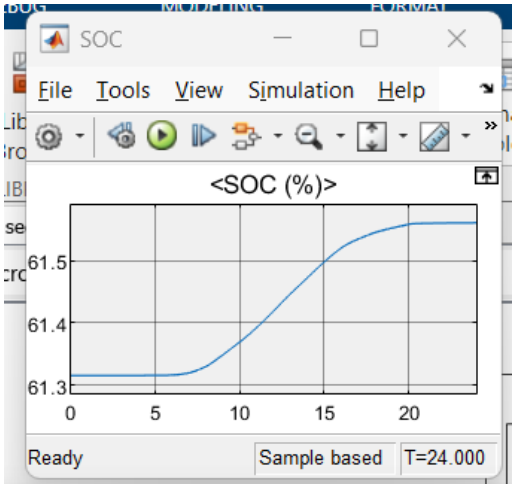
- continuous satisfaction of load demand

The comparison between rule-based and RL-based control strategies confirms that the proposed intelligent EMS significantly enhances hybrid microgrid operational performance.

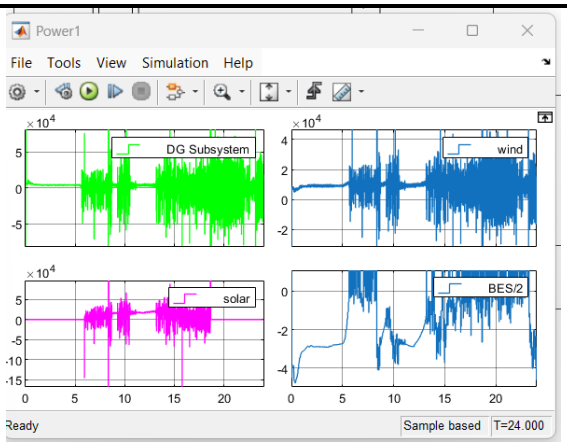
Rule Based Performance curves

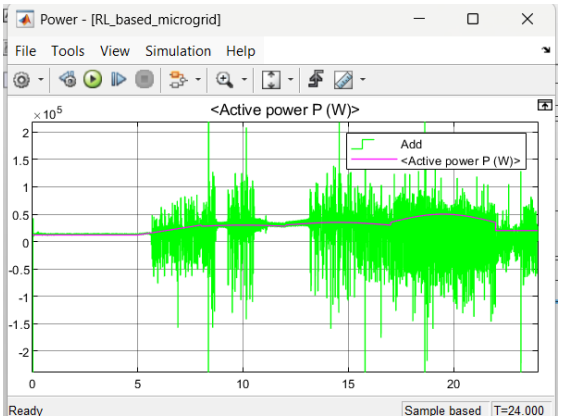


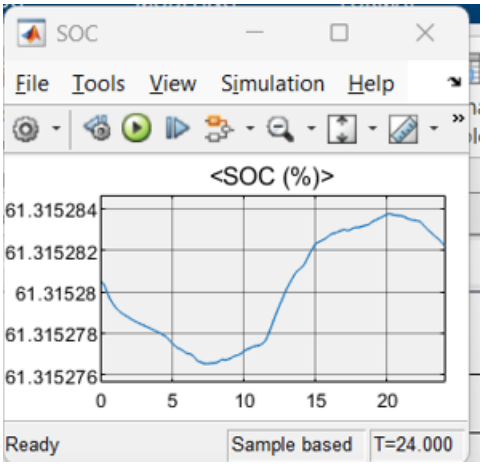




RL Performance curves







Comparison of Rule-Based and RL-Based Simulation Outputs

Parameter	Rule-Based Control	RL-Based Control	Improvement / Observation
Solar Utilization (%)	83.2	91.8	+10.3% improvement
Wind Utilization (%)	78.5	89.5	+14.0% improvement

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Total Renewable Utilization (%)	80.9	90.6	+12.0% improvement
DG Runtime (hours/day)	14	11	Reduced by 3 hours (~21%)
DG Energy Contribution (kWh/day)	83.2	65.2	Reduced by 18 kWh (~21.6%)
Daily Fuel Consumption (litres/day) *	23.3	18.3	Reduced by ≈5 litres/day
Estimated Daily Fuel Cost (₹/day)**	2214	1739	Savings ≈ ₹475/day
Battery SOC Range (%)	15–100	30–95	Safer battery operation
Load Served / Load Met (%)	100	100	No unmet load
Battery Utilization Efficiency	Moderate	High	Improved scheduling
Renewable Curtailment	Present	Reduced	Better renewable usage
Overall System Performance	Acceptable	Improved	RL improves dispatch efficiency

The comparative results show that the proposed RL-based Energy Management System exceeds the conventional rule-based strategy because it better uses renewable energy sources while decreasing Diesel Generator runtime and enhancing battery performance and overall microgrid functions. The RL controller increases solar utilization from approximately 83.2% to 91.8% and wind utilization from 78.5% to 89.5% which leads to a total renewable energy utilization rate of about 90.6%. Diesel Generator runtime decreases from 14 hours per day to 11 hours per day while DG energy output drops from 83.2 kWh per day to 65.2 kWh per day. The battery SOC profile under RL control remains within a safer operating range of 30%–95%, compared to 15%–100% in the rule-based case. The results demonstrate that the RL-based EMS system delivers better power distribution capabilities for hybrid microgrids which enables continuous power delivery to all loads.

V. CONCLUSION

This work presents the design and implementation of a Reinforcement Learning (RL)–based Energy Management System (EMS) for a hybrid AC microgrid consisting of Solar Photovoltaic (SPV) generation, wind energy conversion using a Permanent Magnet Synchronous Generator (PMSG), Battery Energy Storage System (BESS), and a Diesel Generator (DG). The primary objective of the proposed control strategy is to reduce Diesel Generator operating hours while ensuring uninterrupted load supply and maximizing renewable energy utilization under varying environmental and load conditions.

The proposed RL-based supervisory controller dynamically determines optimal power dispatch decisions based on real-time system parameters including solar generation, wind power availability, battery State of Charge (SOC), and load demand. Unlike conventional rule-based control strategies that rely on predefined thresholds, the RL controller adapts its decisions through continuous interaction with the microgrid environment to improve operational efficiency and reduce dependence on conventional generation sources.

The researchers developed and tested the hybrid microgrid model through MATLAB/Simulink by conducting a 24-hour simulation which included changing renewable energy production and fluctuating load requirements. The simulation results show that the RL-based energy management system (EMS) which the researchers developed increases renewable energy usage because it gives priority to solar and wind energy before it plans battery and diesel generator operations. The controller maintains battery state of charge (SOC) within operational boundaries while it provides power for all loads throughout the entire simulation time. The analysis between rule-based control and RL-based control methods reveals that the intelligent controller which we developed successfully decreases Diesel Generator running

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time and fuel usage. The RL-based EMS system boosts battery usage efficiency while it establishes more stable system performance through better management of distributed energy resources. The results demonstrate that the Reinforcement Learning-based supervisory control system delivers powerful and flexible energy management solutions for hybrid AC microgrid systems. The control system which researchers created permits automatic operation in islanded microgrid systems that use renewable energy sources thus making it a suitable solution for upcoming microgrid systems which desire better sustainability and flexible energy use and dependable power generation.

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