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Research Paper

# ANALYSIS OF RENEWABLE ENERGY SOURCES AND ELECTRICAL VEHICLES INTEGRATION INTO MICROGRID

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## Abstract

The increasing penetration of renewable energy sources in microgrid systems has intensified the need for intelligent control strategies capable of ensuring reliability under high load demand and variable generation conditions. While conventional standalone microgrids incorporating photovoltaic, wind, and diesel generator units offer partial autonomy, their operational resilience during extreme contingencies remains limited. In this work, an enhanced microgrid architecture is proposed as an extension of an existing off-grid renewable-based system by integrating the utility grid as an emergency backup source. The grid connection is activated only during critical operating conditions when renewable generation and diesel support are insufficient to meet the load demand, thereby improving system reliability without compromising autonomous operation. Furthermore, the conventional diesel generator controller is upgraded using an Artificial Neural Network (ANN)-based control strategy. The proposed ANN continuously evaluates the instantaneous power contribution from solar and wind sources and dynamically determines the additional power required from the diesel generator to maintain power balance. This intelligent coordination ensures accurate load matching and stable operation under fluctuating generation scenarios. Additionally, the system load capacity is increased from

15 MW to 20 MW with unity power factor operation to evaluate the scalability and

robustness of the proposed control approach. Simulation results demonstrate that the coordinated operation of renewable sources and ANN-controlled diesel generation successfully supplies the enhanced load demand, confirming the effectiveness of the proposed modifications for reliable high- capacity microgrid operation.

**Keywords**

Microgrid, Renewable Energy Sources (RES), Electric Vehicles (EV), Artificial Neural Network (ANN), Power Management, Smart Grid

## 1. INTRODUCTION

The increasing demand for electrical energy, along with growing environmental concerns, has accelerated the shift toward sustainable and renewable energy sources. Conventional power generation methods based on fossil fuels contribute significantly to greenhouse gas emissions, leading to global warming and environmental degradation. As a result, renewable energy sources such as solar and wind have gained considerable importance due to their clean, abundant, and eco-friendly nature.

Microgrids have emerged as an effective solution for integrating renewable energy sources into the power system. A microgrid is a localized energy system capable of operating independently or in conjunction with the main grid. It typically consists of distributed energy resources such as photovoltaic (PV) systems, wind turbines, energy storage devices, and backup generators. Microgrids offer several advantages, including improved reliability, reduced transmission losses, and enhanced energy access, especially in remote and rural areas.

However, renewable energy sources are inherently intermittent and unpredictable. Solar power generation depends on sunlight availability, while wind energy varies with atmospheric conditions. This variability creates challenges in maintaining power balance, voltage stability, and continuous supply, particularly under fluctuating load conditions. To overcome these limitations, diesel generators are commonly used as backup sources to support the system during periods of low renewable energy generation. These methods often result in increased fuel consumption, slower response, and reduced system efficiency. Therefore, there is a need for an intelligent control strategy that can dynamically manage power flow and improve system performance.

In this project, an Artificial Neural Network (ANN)-based controller is proposed to enhance the operation of the diesel generator. The ANN controller continuously monitors the power generated by renewable sources and the load demand, and accordingly adjusts the diesel generator output to maintain power balance. Additionally, a utility grid connection is introduced as an emergency backup source to ensure uninterrupted power supply during critical conditions. Furthermore, the system is designed to handle an increased load demand from 15 MW to 20 MW while maintaining unity power factor. The proposed system is modeled and analyzed using MATLAB/Simulink,

## 2. LITERATURE REVIEW

Recent research highlights various approaches for RES and EV integration:

- Conventional PI controllers suffer from slow dynamic response under fluctuating RES conditions.
- Fuzzy logic controllers improve performance but require expert knowledge and rule design.
- Model Predictive Control (MPC) offers optimization but increases computational complexity.
- ANN-based controllers demonstrate superior adaptability and learning capability for nonlinear systems.

Despite advancements, there is still a need for efficient real-time control strategies that can manage both RES variability and EV charging/discharging dynamics effectively.

## 3. SYSTEM DESCRIPTION

The proposed System presents an enhanced hybrid microgrid system aimed at improving reliability, efficiency, and operational stability under varying load and generation conditions. The system integrates renewable energy sources, namely photovoltaic (PV) and wind energy systems, along with a diesel generator and an emergency utility grid connection. An Artificial Neural Network (ANN)-based intelligent controller is employed to optimize the operation of the diesel generator. The microgrid primarily operates using renewable energy sources such as solar and wind power. These sources are considered the main contributors to the load demand due to their environmental benefits and cost-effectiveness. However, due to the intermittent nature of renewable energy, a diesel generator is incorporated as a secondary power source to support the system during periods of insufficient generation.

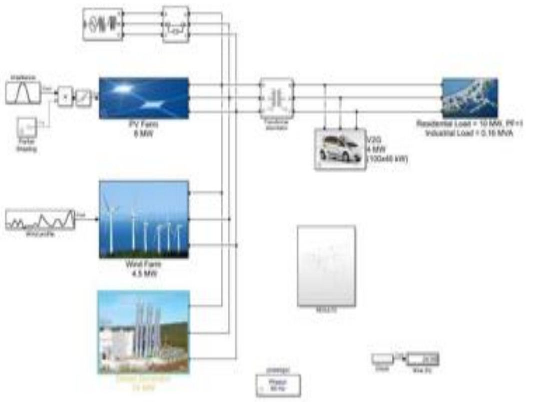

Fig 1. Proposed on-grid ANN controlled circuit configuration

### 3.1 Microgrid Structure

The proposed microgrid consists of:

- Solar PV system
- Wind energy conversion system
- Battery Energy Storage System (BESS)
- Electric Vehicle charging station (V2G enabled)
- Local loads

### 3.2 Electric Vehicle Integration

EVs act as both loads and energy sources through Vehicle-to-Grid (V2G) technology. During peak demand, EVs discharge power to support the grid, while during low demand they charge from RES or grid.

## 4. ANN CONTROLLER DESIGN

The ANN controller is designed to manage:

- Power flow between RES, EVs, and loads
- Voltage and frequency regulation
- Battery charging/discharging control

### 4.1 ANN Structure

- Input Layer: Voltage, current, SOC of battery, RES output power
- Hidden Layers: Nonlinear processing neurons
- Output Layer: Control signals for converters

### 4.2 Training Algorithm

The ANN is trained using backpropagation with supervised learning:

- Training data obtained from system simulations
- Error minimization using gradient descent

## 5. MATHEMATICAL MODELING

### 5.1 Solar PV Output

$$P_{PV} = \eta \cdot A \cdot G$$

Where:

$\eta$= efficiency,

$A$= area,

$G$= solar irradiance

### 5.2 Wind Power Output

$$P_{wind} = \frac{1}{2}\rho A v^3$$

### 5.3 Battery Model

$$SOC = SOC_{initial} + \frac{1}{C}\int i(t)dt$$

### 5.4 Power Balance Equation

$$P_{RES} + P_{EV} + P_{grid} = P_{load} + P_{loss}$$

## 6. CONTROL STRATEGY

The ANN controller performs:

- Maximum power extraction from RES
- Optimal EV charging scheduling
- Load demand balancing
- Grid support during disturbances

**Control Objectives:**

- Minimize THD
- Maintain voltage within limits
- Improve system efficiency
- Ensure stable operation in islanded mode

## 7. Simulation and Results

Electrical cars consist of two components. An internal energy source powers the batteries of electric vehicles, while an electric motor facilitates the vehicle's propulsion. Electrical vehicles require external energy sources to charge their batteries. Under these circumstances, it is necessary to charge the cars. EVs utilise several forms of charging. Charging stations can be classify into various categories based on their charging speed and voltage.

The challenges facing the development of EVs involve enhancing their range and reducing the time required for charging. Currently, researchers are conducting ongoing, rigorous investigations to address these issues. To expedite the charging process of an electric car, it is advisable to charge the vehicle using DC.

We enhance the power output of the charging stations to reduce the duration of charging for EVs. Consequently, the quantity of charging stations with a power exceeding 350 kW is progressively growing. Several charging plugs equip the charging stations, enabling simultaneous charging for multiple automobiles. Simultaneously charging numerous automobiles can lead to significant issues within the microgrid. The escalating load demand on the grid poses a significant issue. The integration of renewable energy sources and EVs into a microgrid is modelled in Fig.1

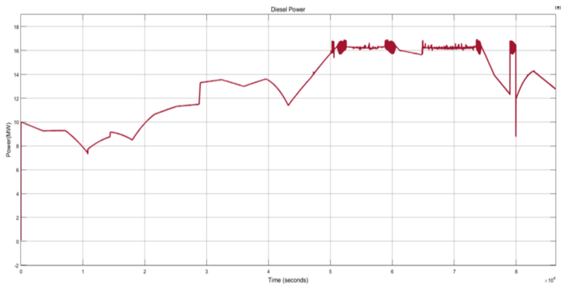


Fig 2. Power generated by the generator throughout the day

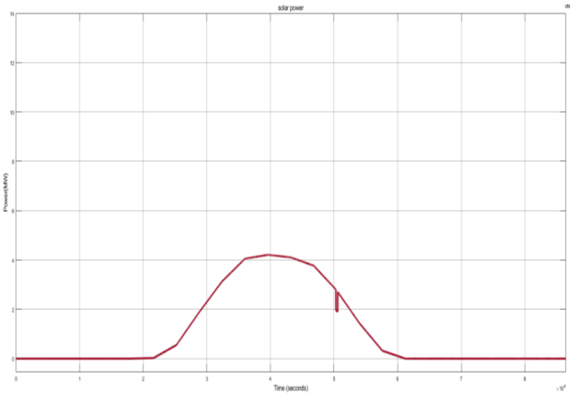

Fig 3. Power generated by the solar throughout the day

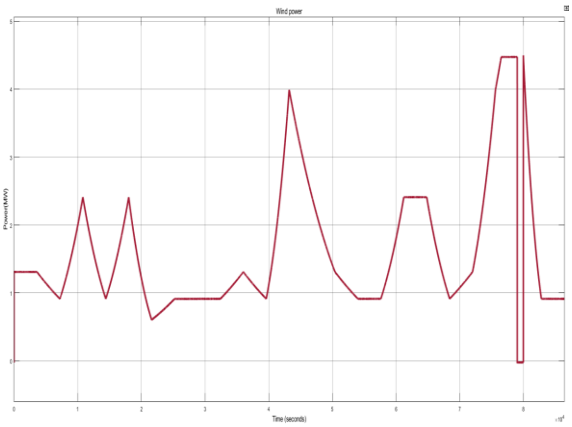

Fig 4. Power generated by the wind throughout the day

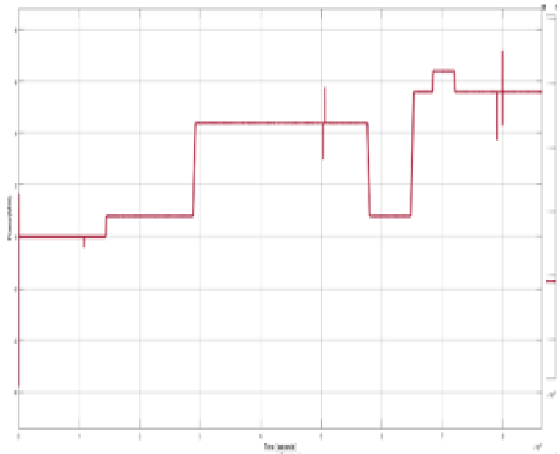

Fig 5. Charged and regulated into the microgrid throughout the day.

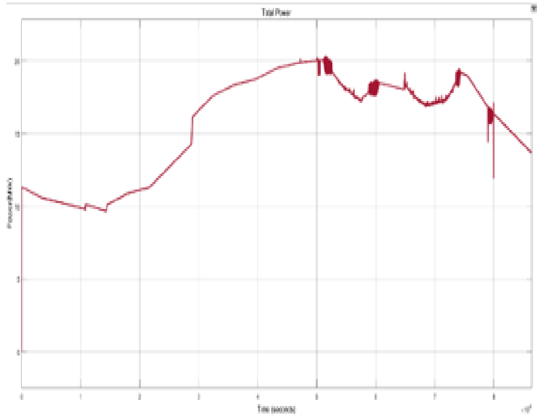


Fig 6. Load drawn power from the microgrid during the day.

**Performance Comparison**

| Parameter | Existing System (14 MW Load) | Proposed System (20 MW, Unity PF) |
|---|---|---|
| Load Power | 14 MW | 20 MW |
| Power Factor | Not unity (typical residential PF< 1) | Unity (PF = 1.0) |
| Microgrid Stability | Stable but sensitive to EV charging & harmonics | More stable due to PF = 1 and improved control |
| Diesel Generator Operation | Higher running time; more fluctuations | Optimized DG usage; improved efficiency |
| Renewable Penetration | Limited due to lower demand | Higher utilization of solar & wind output |
| EV Charging Impact | Higher voltage drop and phase imbalance | Better voltage profile due to PF correction |
| V2G Support | Supports grid but limited capacity | V2G contribution due to increased load & unity PF |
| Harmonics & Power Quality | More distortion at higher EV loads | Reduced harmonics, better THD due to PF= 1 |
| Transformer Loading | Moderate | Higher but efficient loading due to unity PF |
| Energy Balance | Demand ≈ Generation (14 MW) | Demand ≈ Generation (18 MW) with reduced reactive power flow |
| Overall Efficiency | Lower due to reactive power | Higher efficiency (Only real power flows) |

### 7.2. Advantages of Proposed System

- Adaptive and intelligent control
- Handles nonlinearities effectively
- Improved power quality
- Efficient EV integration
- Reduced harmonic distortion

## 9. CONCLUSION

The work presented in this study demonstrates a comprehensive enhancement of a renewable energy– based microgrid through architectural expansion, intelligent control integration, and high-capacity performance validation. By extending an originally off-grid microgrid to include a utility grid connection as an emergency backup source, the proposed system effectively overcomes one of the major limitations of standalone microgrids, namely their vulnerability during extreme operating conditions.

The inclusion of grid backup ensures uninterrupted power supply during prolonged renewable shortages, diesel generator constraints, or abnormal load variations, thereby significantly improving system reliability and resilience. A key contribution of this work lies in the implementation of an Artificial Neural Network– based controller for diesel generator operation. Unlike conventional control strategies, the ANN controller dynamically evaluates real-time renewable power availability and load demand, enabling precise estimation of the additional power required to maintain system equilibrium.

This intelligent coordination allows the diesel generator to operate efficiently, supplying only the necessary deficit power, which results in improved fuel utilization, reduced operational stress, and enhanced system stability. Furthermore, the scalability of the proposed microgrid is validated by increasing the load demand from 15 MW to 20 MW while maintaining unity power factor operation. Simulation results confirm that the coordinated contribution of photovoltaic generation, wind energy conversion, and ANN-controlled diesel support is capable of meeting the increased load demand without compromising voltage or frequency stability

**Future Scope**

- Integration of deep learning techniques
- Real-time hardware implementation
- Smart energy management systems
- IoT-based monitoring and control

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