ISSN PRINT 2319 1775 Online 2320 7876

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Enhancing Grid-Connected Power Systems with Renewable Energy Storage: Optimizing for Power Quality and Reliability

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Abstract

The central objective of the Multi-Objective Optimization Dispatch (MOOD) problem is to achieve a dual aim: firstly, to curtail operational expenses and minimize power loss in efficient conservation systems, and secondly, to minimize emissions of harmful pollutants such as nitrogen oxides, sulfur dioxide, and carbon dioxide. To facilitate the resolution of this multifaceted problem, a weighted sum approach is adopted, effectively transforming it into a single optimization challenge. Furthermore, the Analytical Hierarchy Process (AHP) method is employed to compute weight coefficients, which are determined based on the relative importance of each objective function, aligning with stakeholders' preferences.

1. Introduction

Hybrid renewable energy sources (HRES) integrated with grid connectivity are gaining importance as a solution to meet the increasing demand for electrical power while reducing environmental issues and reliance on fossil fuels. However, managing power quality in grid-connected systems with devices like battery energy storage systems (BESS), photovoltaic (PV) systems, and wind turbines poses challenges. In less industrialized countries like those in Sub-Saharan Africa (SSA), investing in renewable energy options can be hindered by high initial costs despite the need to counter climate change. Fuel cells (FCs) offer a potential option for generating clean and effective energy [1]. To address power flow regulation issues in hybrid renewable energy systems like photovoltaic-wind systems, a novel control method using the unified power flow controller (UPFC) has been proposed. Solar photovoltaic (PV) systems have emerged as promising distributed generation sources that harness free and clean energy from sunlight to produce electricity [2]. However, the growing penetration of distributed generation may lead to power quality problems and load power mismatches, requiring further investigation and control measures. The paper is organized into different sections, including a literature review, the proposed work, results and discussion, and conclusions. The research aims to address power quality challenges and optimize the integration of hybrid renewable energy systems with grid connectivity, contributing to sustainable and reliable energy solutions [3]. In summary, the study highlights the importance of hybrid renewable energy systems and addresses power quality issues, paving the way for a more sustainable and efficient power generation and distribution network.

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2. Literature Review

To address power quality issues in grid-connected hybrid renewable energy systems (HRES), innovative techniques such as Atom Search Optimization (ASO) and Unified Power Flow Controller (UPQC) are recommended. Power devices like UPQC effectively mitigate power quality problems such as voltage and current sag, swell, and total harmonic distortion. The UPQC is controlled by a fractional-order PID controller using system parameters optimized through the ASO technique, yielding better results compared to the conventional PI controller. The test system is modeled using MATLAB/Simulink. The proposed research introduces an intelligent control technique for grid-connected hybrid power systems, combining solar-based PV, wind turbines, and battery storage to achieve Optimum Power Quality Enhancement (OPQE). Within the HRES system, the Unified Power Quality Conditioner with Active and Reactive Power (UPQC-PQ) is constructed using a fractional-order proportional integral derivative (FOPID) controller based on ASO. The main objectives are to control voltage, reduce power loss, and minimize total harmonic distortion. The novel approach addresses various PQ issues like sag, swell, disturbances, real and reactive power, and THD through the ASO-based FOPID controller in different operating modes. In Sierra Leone, the multi objective particle swarm optimization (MOPSO) method was utilized to address the supply gap in grid-connected hybrid systems. This involved optimizing the distribution of photovoltaic (PV) modules, wind turbines, and biomass gasification plants with sugarcane bags, battery energy storage systems (BESS), and diesel generators. The aim was to reduce the probability of deficient power supply, diesel energy consumption, life span costs, and carbon dioxide (CO2) emissions in Kabala and Kenema Districts. The optimal results identified the most cost-effective and ecologically beneficial course of action for policymakers. Overall, the integration of hybrid renewable energy sources with grid connectivity offers a significant solution to meet the growing demand for electric power while reducing reliance on fossil fuels and mitigating environmental issues. The utilization of optimization techniques like ASO and UPQC enhances power quality and ensures a more sustainable and efficient power generation and distribution network.

3. Proposed Work

The proposed architecture involves multiple micro grids (MGs) designed to address power flow measurements and management in each specific MG. The Micro grids, denoted as MG1 to MG6, are connected with separate Smart Meters (SMs) for power flow measurement. The overall system includes a utility grid (UG) and the MGs. The information streams from SMs are fed into a central controller through a multiple-stage unique Energy Management System (EMS). The central controller analyzes fluctuations in electricity output and consumption on each MG to make informed decisions for operating

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the MGs. In the proposed system, each MG consists of renewable energy sources (RES) like solar and wind energy along with battery storage. The MGs can operate in either grid-connected or island-based modes to meet consumer demand.

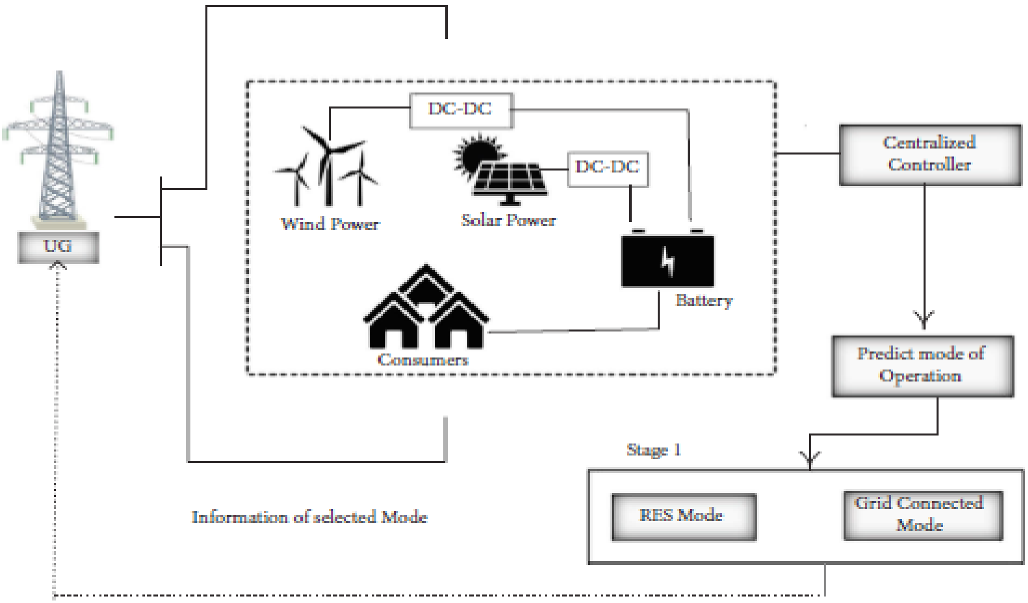

FIGURE 1: Proposed RES-GRID model.

The NN is trained with various L I (light intensity) and WS (wind speed) values as training samples to determine the operation mode. The proposed architecture ensures efficient management of energy through wise mode selection and power exchange in both grid-connected and islanded modes. Weather conditions and resource limitations are taken into account to forecast the future state and make precise operation mode predictions. The NN considers the production limitations of renewable resources and adjusts the operation mode accordingly to meet customer demands. When RES production is insufficient, MGs are operated in grid-connected mode until a specific range is reached, after which they are transferred to islanded mode.In conclusion, the proposed architecture presents an intelligent multi micro grid management system with neural network-based operation mode prediction. This approach allows for efficient control of energy through smart mode selection, considering weather conditions and resource constraints, to ensure stable and reliable power flow in the micro grid network.

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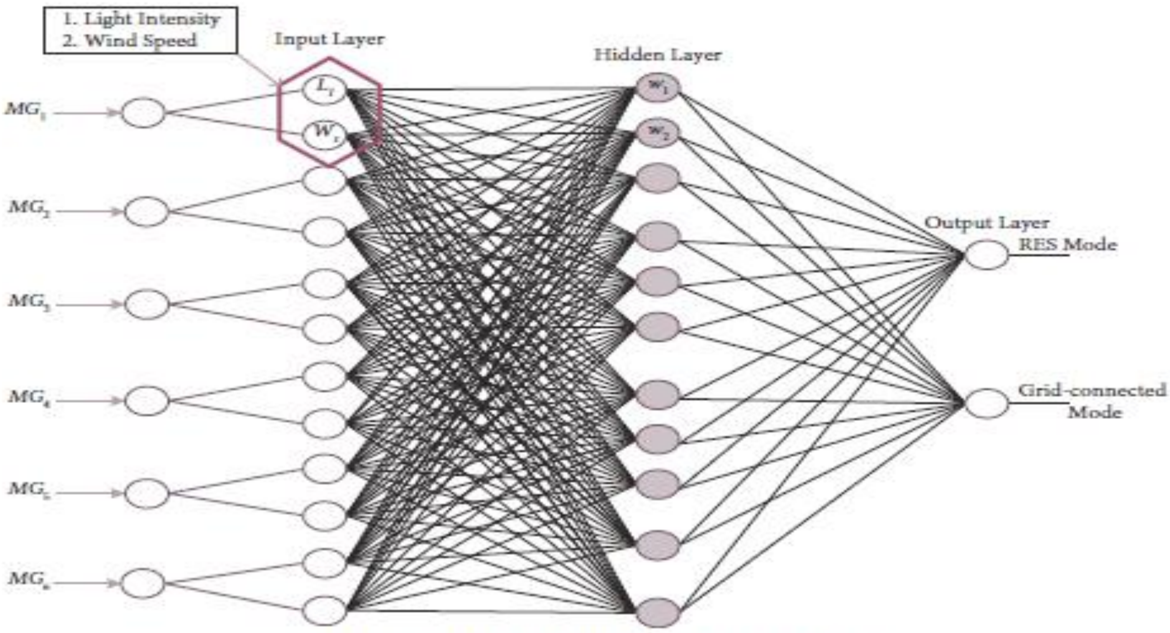

Figure 2: Neural network structure for mode selection.

4. Results and Discussion

Table 1: Simulation setup.

Parameters		Specifications
Number of PV		5
Number of microgrids		5
Wind mills count		5
Simulation time		200 s
	Battery	150 kW
Renewable energy capacity	Wind	60 kW
	PV	60 kW
External grid		200 kW
Mode of operation		Islanded/grid-connected

The proposed RES-GRID performance is validated in this section using proper programming and simulation in MATLAB Simulink. The RES-GRID model consists of six microgrids, each with a different load, and their operational mode is selected based on production using mode prediction, energy management, and power exchanges. The three-stage processing in MatlabR2017b allows for the creation of RES-GRID effectively. The ALO algorithm, a new optimization technique, is used and compared with other optimization algorithms, showing better outcomes and convergence capability for power system problems. Figure 3 and Figure 4 illustrate the fluctuation rate and operational modes in grid-connected and island modes, respectively. The ALO algorithm significantly reduces the overall cost and proves effective in managing the multi-objective optimization dispatch (MOOD) problem of the micro grids. The ALO algorithm has been successfully applied to various electrical power system issues, including reducing fuel costs, minimizing active and reactive power losses, coordinating over

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current relays, improving brushless DC wheel motor performance, and enhancing isolated protection transformer efficiency.

5. Conclusion and Future Work

The objectives encompass several critical aspects, including the minimization of operational expenses, reduction of pollutant emissions, and optimization of power loss in conversion devices. This optimization also takes into account the scheduling of battery charging and discharging, load curtailment strategies, and system constraints. To comprehensively evaluate the model's effectiveness, it is applied to two distinct operational modes: grid-connected and standalone configurations. Additionally, the study includes a comparative analysis against existing heuristic approaches to assess the model's superiority.

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