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Smart Control Strategy for Adaptive Management of Islanded Hybrid Microgrids

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Abstract

This research paper presents a smart power control approach specifically designed for an independent microgrid. The proposed hybrid system consists of various crucial components, including a PV array, super capacitor, DC bus, battery bank, and AC bus working together to generate and store electricity within the microgrid. To address the challenges arising from random fluctuations in ecological parameters and changes in load demand, a supervisory controller is developed to enhance the standalone hybrid microgrid. This allows for optimized power management within the micro grid. The Liebenberg Marquardt algorithm is used to retrieve the trained ANN machine. The two and three hidden layered ANN machines have 96% accuracy on an average, whereas the single-layer ANN machine have poor predictive ability. The proposed model is implemented and analysed using MATLAB/Simulink. The observed results from the simulation experiments validate the effectiveness of integrating available resources in ensuring the resilience and reliability of microgrids.

Keywords: PV, Battery Pack, ANN, microgrids, control strategy, Fuel cell

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1. Introduction

The global energy roadmap has consistently emphasized the risks associated with greenhouse gas emissions and global warming resulting from the diminishing reserves of fossil fuels [1]. As a result, the necessity of switching to cleaner and more sustainable energy sources has gained more and more attention in recent years [2]. Both developed and developing countries have been embracing renewable energy sources, as evident from the present approaches in the global energy sector [3]. Solar energy from photovoltaic (PV) systems and wind power have emerged as highly admired and widely existing green energy sources, playing a pivotal function in harnessing renewable energy. Furthermore, the inclusion of Fuel Cells (FC) alongside wind and solar energy sources contributes significantly to backup power generation [4].

The International Energy Agency (IEA) has established an ambitious target of achieving 953 TWh of global electricity production from PV systems by 2025, reflecting a remarkable growth of more than 400% since 2014 [5]. However, renewable energy sources are inherently intermittent, heavily reliant on weather patterns and environmental conditions [6]. To address this challenge, a combination of multiple power sources can be integrated with storage space modules like super capacitors and batteries, enabling the development of an efficient and resilient network [7]. The renewable energy must have to be control by hybrid sources to make sure long-term use of integrated model, distributed generation. It is identified as a microgrid (MG), aligns line with current developments in global energy planning [8].

The power systems worldwide are experiencing significant transformations due to environmental concerns and economic factors, resulting in the integration of numerous Distributed Generation (DG) [9]. To address the limitations of distributed generation, a novel concept known as microgrid has been projected to effectively control confined DG units and loads. Typically, an AC micro grid, with a large incursion of DG units and storage space, offers increased capacity and control flexibility when coupled to predictable AC power systems in grid-tied scenarios [10–12]. Nevertheless, certain energy resources in the micro grid, such as fuel cells, batteries and PV panels operate on DC power. Hence, inverters are necessary to connect these DC sources to the grid. Additionally, there is a growing demand for DC loads like LED lighting and computers, which require power factor correctors (PFCs) to change steady state alternating supply to the required direct supply.

The establishment of a DC supply arrangement, directly connecting DC sources loads by well-organized DC/DC converters, intuitively reduces redundant power conversion circuits and simplifies the complexity. This approach enables the DC grid to exhibit major characteristics, including large efficiency and low power adaptation cost. Previous studies have proposed the concept of a DC microgrid to integrate various distributed generators [13, 14]. Notably, several pilot projects of DC microgrids have been implemented, such as less voltage DC micro grid resulting in 10% energy savings for data centres than AC baseline cases. DC microgrids offer several advantages over AC micro grids, including some energy transfer links, high efficiency and reduced losses. Moreover, unlike traditional grid-tied inverters that require precise phase and frequency tracking of AC voltage, DC microgrids eliminate these requirements, significantly influencing controllability and reliability. Consequently, DC microgrids are better suited for integrating distributed renewable energy sources [15, 16].

However, for comprehensive microgrids aiming to integrate various complementary sources to mitigate environmental impacts and reduce maintenance downtime, a pure DC grid is deemed unsuitable. The hybrid AC/DC micro grid approach enables easier integration of sources, maximum efficiency during the conversion of power, reduced capacity of storage devices, and increased dependability.

The magnitude of power generated by PV sources exhibits substantial variations contingent upon prevailing weather conditions. Take, for instance, solar panels, whose efficacy is deeply tied to the abundance of sunlight. In the presence of copious sunshine, solar panels demonstrate heightened productivity, translating into a greater output of electrical energy. Conversely, during cloud-laden skies, their power generation capability diminishes, as the reduced sunlight limits their photovoltaic potential. Analogously, wind turbines, another essential facet of renewable energy, are contingent upon wind intensity for optimal functioning. When confronted with robust and sustained winds, wind turbines exhibit heightened kinetic energy conversion, leading to a substantial amplification in electricity generation. In contrast, during periods of calm or feeble winds, their power output experiences a discernible decrease [17, 18].

This inherent variability of renewable energy sources necessitates a comprehensive understanding of meteorological patterns and regional climate to effectively harness their potential. Furthermore, it underlines the importance of diversifying renewable energy installations across geographically distinct locations, so as to capitalize on favourable weather conditions and minimize the impact of adverse ones [19].

Policymakers and energy planners must consider this dynamic nature when designing sustainable energy systems to ensure a consistent supply of green energy to meet the burgeoning energy demands of modern society. Ultimately, the ongoing advancements in technology and the continued support for renewable energy will contribute to mitigating the challenges posed by weather-induced fluctuations, piloting in a cleaner and more sustainable energy landscape for the future. The amount of power generated by these sources can vary greatly, depending on the weather conditions. For example, if there is a lot of sunshine, a solar panel will generate more power than if it is cloudy. Similarly, if there is a lot of wind, a wind turbine will generate more power than if it is calm [20-21].

As a result, for achieving effective power operation, this research presents an energy management strategy utilizing Artificial Neural Network (ANN) methodology. ANN theory, a model that can be mathematically analyzed, is used in the projected energy organization strategy to improve the neural communication method of organisms. For proper energy organization of the total distribution network, the technique uses the right number of hidden layers of the ANN.

This article is presented as: Section II, the HPS structure is explained. Section III, Supervisory model of hybrid grid is introduced. Section IV explores the findings and has a discussion. The paper's conclusion is reached in Section V.

2. Proposed hybrid AC/DC MG

A sophisticated power system known as a hybrid AC/DC MG possess both AC and DC components to achieve efficient and dependable energy distribution. It is made up of following components: an AC sub-microgrid, a DC sub-microgrid, and conversion of power units. The stability of the system as a whole and the maintenance of a stable voltage depend heavily on the AC sub-microgrid. A straightforward circuit breaker can be used to connect it directly to the utility AC grid. Various AC power generators, as well as applications like induction motors and conventional lighting are supported by the AC sub-microgrid. To guarantee a steady and dependable supply, these devices are connected.

An interlinking converter links the DC MG to the grid. It works as a separate distribution system created especially for DC power sources like solar panels, fuel cells, and batteries. Utilizing straightforward DC/DC converters, these DC power sources are integrated into the DC sub-microgrid.

It can also be connected to some AC, like motors with adjustable speeds. A crucial factor to take into account is the hybrid microgrid's strategic placement of energy storage. Batteries can be installed inside an interlinking converter, an AC sub-microgrid, a DC sub-microgrid, or any combination of these. The kind of loads, power flow requirements, operational dependability, and cost-effectiveness all play a role in determining the best place for energy storage. However, the scope of this discussion does not go any further in exploring the specific optimisation of energy storage.

As shown in figure 1, the operational modes are divided into three different configurations. The working of the hybrid system and the microgrid is represented by modes (1-3). Whether the microgrid is connected to the utility grid or operating in islanding condition, the AC MG works autonomously in Mode 1 and requires efficient control of AC voltage or current to deal with the flow of power. The DC MG works independently in Mode 2, where it emphasis on controlling the DC electrical parameters to promote effective power transfer between DC sources and DC loads.

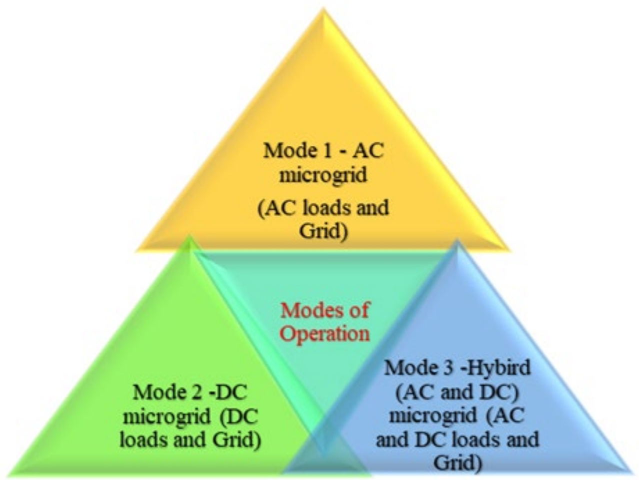

Figure 1. Modes of hybrid grid

The hybrid MG work collectively in mode 3 to enable the best possible management of power between networks. It can be effectively balanced in this mode by the microgrid, improving operational stability and efficiency. A hybrid MG can offer a flexible and reliable power distribution infrastructure by comprehending and putting these operational modes into practise, combining the benefits of both AC and DC systems. This integration paves the way for a more effective and resilient power grid by enabling improved energy management and sustainability.

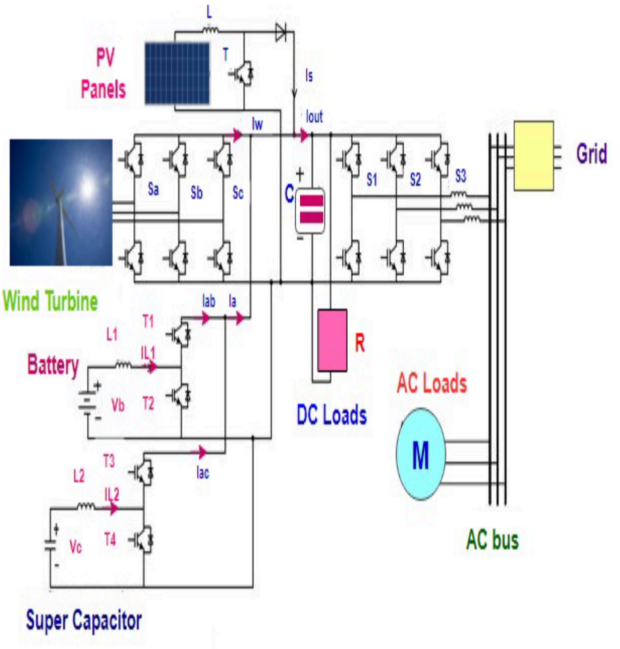

Figure 2. Hybrid AC/DC microgrid

The hybrid MG design and the EMS operation method are described in detail in this section. A layout of the hybrid MG is depicted in Figure 2. An interlink converter, controlled by microgrid controllers, is used to link hybrid networks. Each power converter in the distribution network is managed by a controller. The distribution-network voltage is maintained by the controller. Power control and distributed generators connected to the distribution network are used by an ANN to manage energy. The control of the microgrid manages energy through its energy storage system, with the exclusion of distribution-network mishap that result in stand-alone process. When a microgrid central controller generates a reference voltage, it affects the operational modes and the power output from the controllers, particularly to control the system voltage.

3. Supervisory model of hybrid Grid

The control of the microgrid uses an ANN to determine the power consumed and mode of operations in the network. Figure 3 depicts the process used to apply an artificial neural network for appropriate energy sharing in a hybrid microgrid. Three input layers, varying hidden, and single output layers make up the structure used as depicted in figure 4. A specific weight has been assigned to individual layer. The output is obtained from the input and sent to output layer via the hidden. Each layer's output value is currently based on its weight.

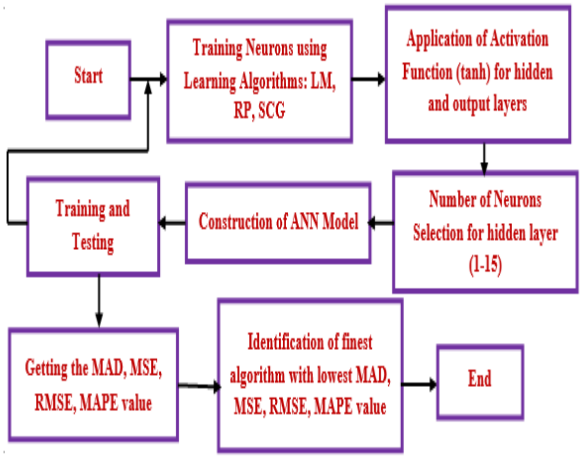

Figure 3. ANN methodology

For the investigation, an ANN model is created in the simulation software MATLAB Simulink. 20% of the information is used to test, and the 80% is utilized to train. Three different learning algorithms, including Scaled Conjugate Gradient (SCG), Resilient Back Propagation (RP) and Levenberg Marquardt (LM), are found to be the most frequently used algorithms in ANN after a thorough review of the literature. But, in this model, Levenberg Marquardt Back Propagation algorithm is preferred since the convergence rate is fast. The quantity of weights and biases reveals the level of structure complexity.

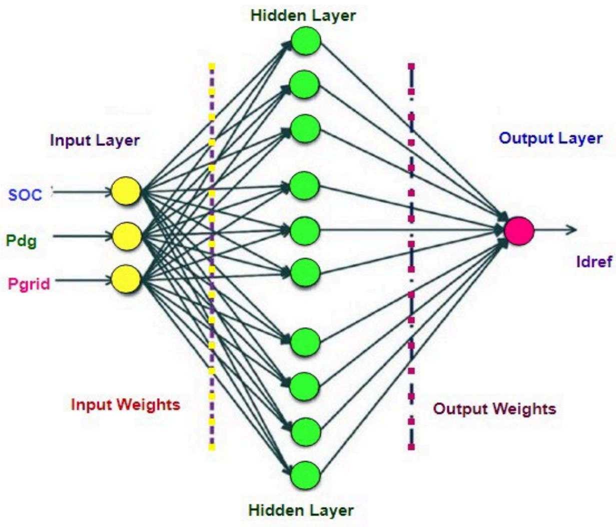

Figure 4. Structure of a neural network

4. Results and discussion

The popularity of 2-layer ANNs has been attributed to their propensity to approximate a wide range of nonlinear functions. Even though significant research has been done to increase the 2-layer ANN's performance, such as learning speed, the statement is disputable and questionable. But since several scientists have sustained to make use of the double layer network, a lot of research has been done to enhance its performance, and as a result, when compared to networks with more layers, the two-layer networks become visible to perform better.

In contrast to ANN architectures with more layers, the two-layer network, however, presents a straightforward and uncomplicated ANN layout. The observable drawback in basic double layer network is the trained machine's highest inherent error due to insufficient number of neurons to accurately represent the sophistication of multifaceted machines.

This article's evaluations show that as the number of biases and weights increases, the difficulty in the trained system is sufficiently supported, resulting in enhanced performances on the test data. This is true regardless of the layers and neurons. Researchers may find ways to accelerate the operations for higher numbered hidden layer.

The MSE is used to evaluate an ANN's performance. Compared to a low MSE, a large MSE denotes subpar performance. The network training for each architecture is stopped after 500 epochs, the error obtained in Table 1 indicated from the 200th epoch. As the number of neurons in the hidden layers increases, performance is seen to improve the number of layers in proposed system. The three-layered ANN performs better than the two and single layer ANN when comparing performance across different numbers of layers. At the conclusion of the training, the 3-layer ANN architecture has the best performance.

Table 1. MSE values of different number of hidden layers

No. of Neurons	One number of Hidden Layer	Two numbers of Hidden Layer	Three numbers of Hidden Layer
1	0.865	0.758	0.945
2	0.953	0.853	0.954
3	0.920	0.933	0.948
4	0.928	0.916	0.962
5	0.920	0.933	0.948
6	0.931	0.925	0.958
7	0.943	0.916	0.929
8	0.859	0.941	**0.969**
9	0.905	0.917	0.945
10	0.921	0.925	0.957

The scatter plot's R-square values are nearer to unity, indicating a stable estimation model. Mean Square Error (MSE) which shows low error between the actual and estimated values. The regression curve for training, validation, testing, under testing and training are shown in Figure 5. The LM algorithm with 3 hidden layer is the model which fits the data the best.

R stands for the system's linear correlation coefficient. Measured and predicted data have a linear relationship when R = 1. The measured and predicted data are in good agreement when R is near to 1. R values for training and testing data for the current work are around 0.96

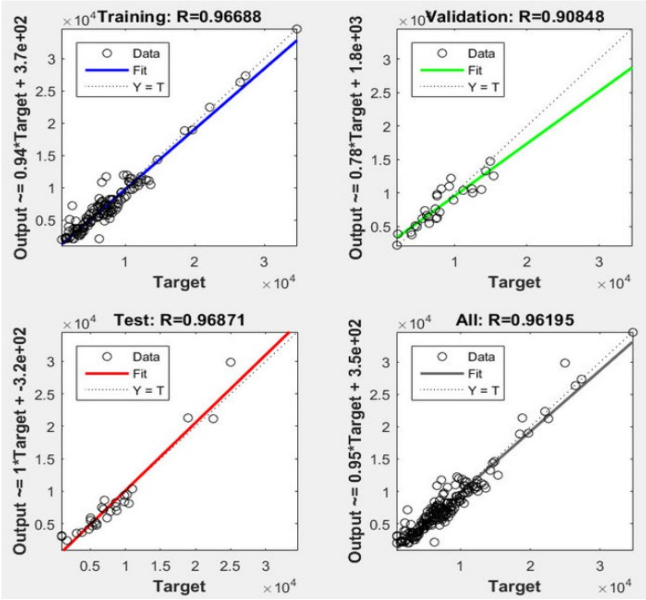

Figure 5. Regression plot for the training, validation, and test of the ANN model

5. Conclusion

An ANN-based supervisory controller is used in the research to show the potential for a smart power control method for independent microgrids that makes use of a variety of energy sources and storage technologies. By using this strategy, even in unpredictably changing environmental conditions, a steady and dependable supply of power may be met to satisfy dynamic demands. The ANN-based supervisory controller improves power management by balancing energy production and consumption while lowering the carbon footprint of the microgrid. The microgrid's sustainability and resilience are further increased by the incorporation of alternative storage technologies and renewable energy sources. The application of the suggested model using MATLAB/Simulink verifies the effectiveness of the smart power control strategy. Given their decentralised nature, efficiency, and integration of renewable energy sources, microgrids are a possible replacement for traditional centralized power systems. It is projected that as microgrid and smart power control research develops, it will support continued efforts to provide sustainable energy solutions, promoting a cleaner, more dependable, and ecologically conscious energy future.

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