DESIGN AND DEVELOPMENT OF ANFIS BASED INTEGRATION FOR RENEWABLE BASED MICRO-GRID

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ABSTRACT- The primary objective of this work is to develop an adaptive neuro-fuzzy inference system (ANFIS) controller approach for a smart DC microgrid. In this work, a DC microgrid is developed using a combination of photovoltaic (PV) and solar power. The proposed ANFIS controller is designed to provide stable and smooth output power. The results obtained from MATLAB/Simulink simulations of the proposed control approach are shown and compared with existing mutual fuzzy logic and FO-PID controllers. This study presents an innovative approach to improve the performance of a microgrid using solar photovoltaic, wind, and battery energy storage. The system incorporates an intelligent adaptive neuro-fuzzy interface, coupled with a shunt voltage source converter. In particular, the design incorporates a self-tuning filter, which eliminates the need for phase-locked loops as well as low- and high-pass filters. Furthermore, the self-tuning filter serves a dual purpose, effectively separating the harmonic and fundamental components while achieving phase synchronization. To control this system, a hybrid ANFIS controller is used. The primary goals of this proposed approach are twofold: first, to reduce THD, and second, to maintain a stable voltage across the DC link capacitor with fast settling times in both grid-connected and islanded conditions.

KEY WORD- Photovoltaic (PV), Adaptive Neuro Fuzzy Inference System (ANFIS), DC-microgird

1. INTRODUCTION

The energy system includes power generation, transmission, and distribution. As one of the core components of the power network, the distribution system is most susceptible to losses. Reducing power losses in the power distribution system is a critical issue, necessitating the integration of microgrids into the distribution system [1]. The main benefits of integrating microgrids into the power system include improved economic and environmental conditions, greater power system reliability, reduced power losses, and greater power consumption. Due to environmental concerns, economic factors, and the rapidly increasing integration of renewable energy resources, the traditional power system is gradually shifting to a more distributed power system. The primary components of a microgrid are loads, distributed generation (DG) units, and energy storage systems [2]. Designing controllers for these microgrid components to manage frequency and peak load control for power sharing in renewable-based microgrids is challenging. [3] The authors present intelligent control of an islanded AC microgrid based on an adaptive neuro-fuzzy inference system to control frequency and droop for power sharing in renewable-based microgrids. A hybrid energy storage system (HESS), which combines batteries and super-capacitors (SC), was developed and presented in [4] for a DC microgrid using an adaptive neuro-fuzzy inference system (ANFIS) controller. The proposed power control method reduces the stress on the battery energy storage system (BESS), thereby prolonging battery life. [5]
The authors pointed out that the random location of distributed energy resources is the main cause of distribution network problems such as reverse power flow, microgrid system islanding,

and relay tripping. To address these problems, it is important to reduce power losses in the radial distribution network (RDN) and improve the voltage profile of distributed energy resources (DER) [6]. Therefore, in Reference [7], the authors analyzed the location of distributed energy resources from both conventional and renewable sources in a radial distribution network using intelligent techniques such as Adaptive Neuro-Fuzzy Inference System (ANFIS), Genetic Algorithm (GA), and Advanced Particle Swarm Optimization (IPSO) to minimize power losses and improve voltage profiles. Uneven distribution of energy consumption among end users causes periodic problems. When the amount of energy produced and consumed is equal, the grid remains stable. Energy storage devices can be used in various ways to make renewable energy a more viable option for energy businesses. Energy storage is crucial to making this energy more widely accessible [8].

By using energy storage systems with better control over frequency and voltage, it is possible to improve the quality of distributed power even during times of high demand. New research is investigating how renewable energy sources and energy storage can be incorporated into an independent microgrid. Combining tidal, wind, and PV energy sources can increase the maximum capacity of an energy storage system. Batteries and supercapacitors are common components of energy storage systems (ESS), allowing for long battery life and fast response to compensate for transient events. Consequently, when combining all energy sources, an AC grid is used instead of supercapacitors. Both DC and AC microgrids can be used in the same system [9]. Consequently, DC microgrids have several advantages over AC microgrids in terms of ease of integration and construction. Some different considerations need to be made when designing an AC system, including considerations such as frequency synchronization and reactive power. Like AC microgrids, DC microgrids can be implemented in a variety of ways, either as independent systems or as part of a holistic system. Recent advances in power electronics have enabled self-sufficient DC microgrids to operate at their maximum efficiency. Unpredictability necessitates proper management of renewable energy supplies. Due to the dynamic disparities between AC and DC microgrids, there have been numerous studies on AC microgrid energy management controls. These control techniques are not suitable for DC microgrids. A traditional DC microgrid uses load converters and power sources to connect the DC link. For a stable and efficient DC microgrid, the DC link voltage must be controlled [10- 12].

DC link voltage has been the focus of many control approaches. [13] discusses energy resource planning and management with hybrid microgrids. [14] suggests that fuzzy controllers and voltage management can be used to adjust DC voltage. [15] investigates a fuzzy logic control method based on reduced-rule fuzzy logic. Dual proportional-integral controllers should be used. Only linear and time-limited methods are available for handling DC links. Extensive research has been conducted on various energy storage technologies for microgrids. The H control method has been quite successful. Backstepping control is discussed in [16]. Lyapunov-based control and feedback linearization are investigated in [17]. Paper [18] investigates a hybrid controller combining backstepping and sliding mode controllers. It concludes that most of these controllers are sensitive to fixed gains due to external shocks and parameter uncertainty.

2. LITERATURE REVIEW

FL-C and PI-C features were combined to develop a hybrid controller for STAPF with the intention of reducing THD for a variety of loads [1-3]. Furthermore, STF-based STAPF was developed to manage current signal THD as well as reactive/real power [4]. Furthermore, advances in artificial intelligence control methods for STAPF, such as FL-C, ANNC, etc., successfully addressed PQ issues during dynamic power system load variations [5-7]. PV systems with MPPT were proposed for UPQC, and their performance was analyzed under variable loading conditions with a view to reducing THD [8]. Additionally, FF-ANNC was designed for UPQC associated with PV/wind to regulate DLCV and handle reactive power. Furthermore, DVR/DSTATCM was integrated into solar, wind, and fuel cell microgrids to address current and voltage-related PQ problems [9]. However, UPQC was suggested to address PQ problems caused by nonlinear electric arc furnace loads. Furthermore, performance comparisons with DSTATCOM were conducted [10]. Furthermore, the results were validated by experimental setups [11]. FL-C was developed for UPQC for various nonlinear loads to reduce current distortions and thus improve THD [12]. Furthermore, Fourier analysis was suggested for combining renewable sources, solar energy, with wind energy and fuel cells to reduce THD [13].

To improve the DLCV balance, the meta-heuristic BBO algorithm was chosen for optimal selection of PI-C gain parameters and fast response to fault conditions [14]. A new meta-heuristic, HBO, based on the intelligent hunting behavior of honey badgers was proposed to solve the optimization problem. Furthermore, a fuzzy-based hybrid strategy was adopted to maximize the benefits from PV. However, to reduce the complexity, ANN was considered only for UPQC reference signal generation for PQ problems. Furthermore, a fuzzy backpropagation approach was suggested for 5-level UPQC to handle PQ problems [15]. This variable power will affect the power balance and voltage at the common connection point. Even a small change in wind speed causes a large change in the power output. As a result, large voltage fluctuations can cause large variations in the voltage at the load side, which can lead to uncontrolled voltage fluctuations. This research paper develops a method to reduce the fluctuations in the power output of a wind turbine. A DSP controller is used for this purpose. The developed method is tested and simulated using MATLAB's Sim Power System tool [16]. The development of new power semiconductor devices such as thyristors and new circuit topologies have improved the performance and reduced the cost of power electronic converters. These advances have opened up a wide range of new applications for power electronic converters in various industries and sectors. In the case of a power electronic converter, any power semiconductor device can act as a switch to control the flow of current [17].

3. PROPOSED SYSTEM

With the proposed system, a smart DC-microgrid is connected to a hybrid energy system consisting of wind, solar, and BSS, all connected to DC-link capacitors through their respective converters. FOPID is used to control the converters on the source side. For example, in a smart university, fans, laboratory test benches, and lighting might be considered high-priority loads. The proposed ANFIS method controls AC/DC converters on the load side. In both wind and solar (PV) systems, algorithms are used to track the highest power point so that they operate at full capacity. The energy management system calculates the total amount of energy consumed and generated to choose the most effective control strategies.

Therefore, in this paper, an intelligent energy management system using an ANFIS controller is proposed to transmit the effective power of the grid-connected microgrid to the distribution network to address the aforementioned power supply challenges. The main contributions of this paper are:

1) Using an adaptive controller to allocate power sources to additional loads connected to the active distribution network without any interruption to system power flow.

2) Using an intelligent ANFIS-based technique to design a controller for microgrid distributed power sources to support maximum power harvesting.

3) Developing an adaptive power dispatch mechanism for multiple grid-connected microgrids.

4. PROPOSED ANFIS CONTROLLER

ANFIS uses neural networks and fuzzy logic, as well as low-level computing capabilities. To simulate complex and nonlinear systems, ANFIS requires only a few simple input and output parameters. Fuzzy interference systems can be refined with the help of neural networks. To establish correlations between inputs and outputs, ANFIS's hybrid learning technique uses both human experience and data on inputs and outputs. Analyzing nonlinear functions and detecting nonlinear parameters in online control using ANFIS, and using time series models to predict parameters in time series models, are examples of ANFIS's layered structure.

5. SIMULATION AND RESULTS

Combining the learning capabilities of a neural network with a rule-based fuzzy system significantly increases performance, making it possible to incorporate historical data into the classification process. The development of a neural-fuzzy system involves building the system using fuzzy logic definitions and refining it through neural network training methods, as well as training the neural network itself.

Through the implementation of the ANFIS controller, an adaptive network is constructed from nodes and directed connections connecting neurons. The adaptability of individual nodes influences the outputs of intermediate nodes, allowing adjustments to network settings based on optimization principles to minimize a specified error metric. Common learning principles for adaptive networks include the chain rule and gradient descent.

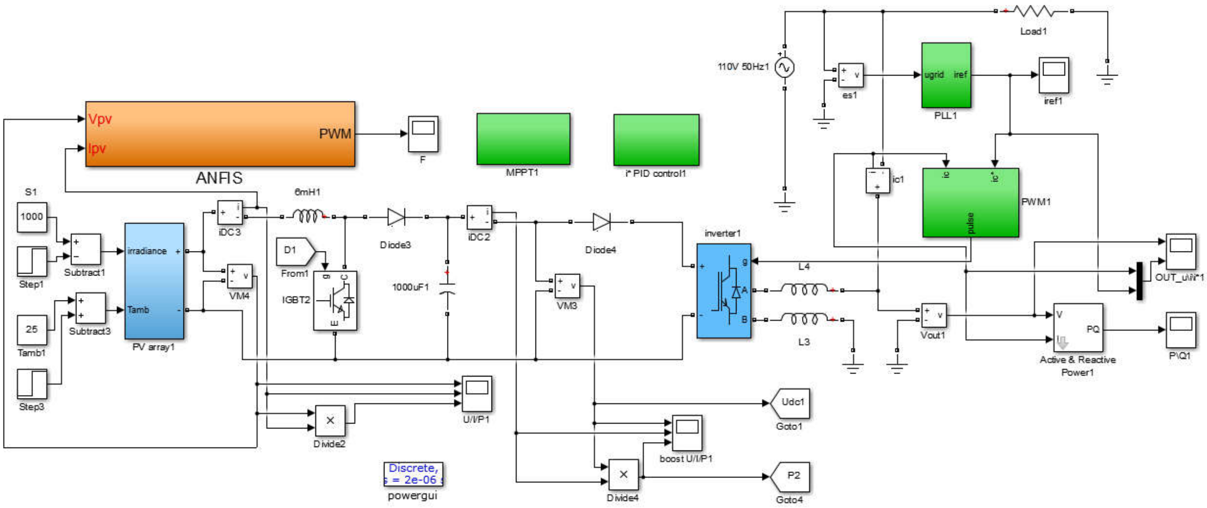

Figure 1. Simulation Modal

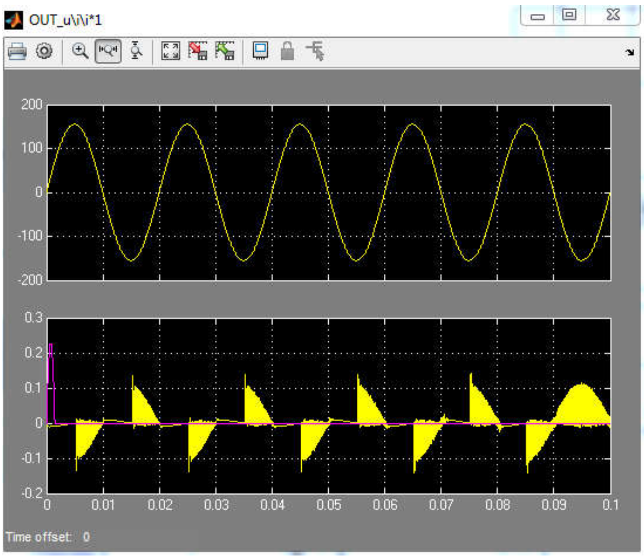

Figure 2. Output Power Supply

(A PWM (Pulse Width Modulation) inverter is a device that converts direct current (DC) to alternating current (AC) by modulating the width of the pulses in the output signal. It produces an AC waveform that is close to a sine wave by generating a series of pulses of varying widths. PWM control is widely used in inverter circuits due to its excellent controllability and high efficiency.)

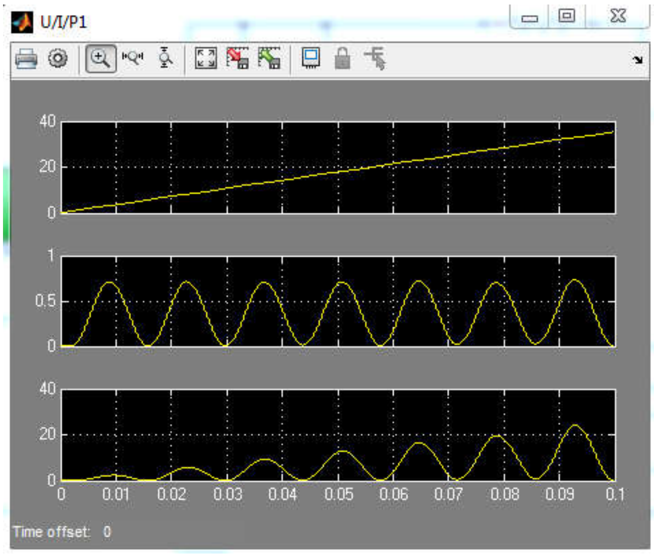

Figure 3. Power Supply after PWM

(In inverter circuits, the optimal sine-wave AC voltage for driving a motor can be generated by periodically changing the ON state (duty) of the PWM control. With PWM, a fixed DC input voltage source can produce a sinusoidal output waveform with variable frequency and amplitude. PWM methods in inverters provide fine control over the output voltage waveform in the VSI, enabling accurate voltage control as well as current control.)

Boost Power Supply after PWM- The carrier wave is a triangle or sawtooth wave that operates at a significantly higher frequency than the reference wave. When the carrier signal exceeds the reference, the output is in one state, and when the reference exceeds the carrier, the output is in the opposite state. A filter block is required to get closer to a sine wave. A low-pass filter is an electronic filter that passes low-frequency signals and attenuates (reduces) signals with frequencies higher than the cutoff frequency.

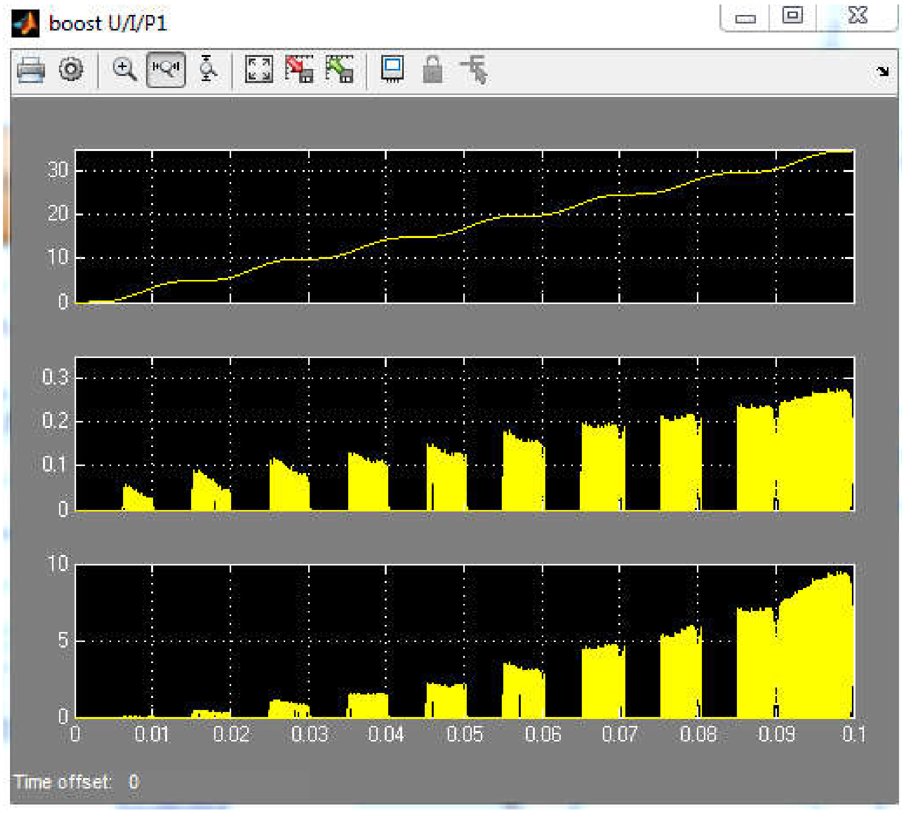

Figure 4. Boost Power Supply after PWM
(The PWM signal is generated by feeding a reference and a carrier signal through a comparator that generates an output signal based on the difference between the two inputs. The reference is a sinusoidal wave at the frequency of the desired output signal.)

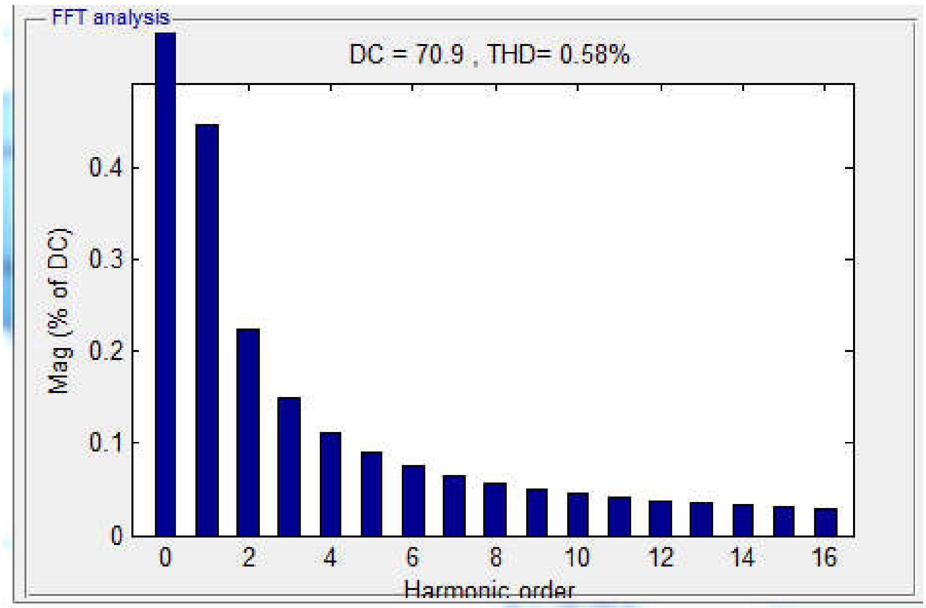

Figure 5. The value of THD (0.58%)

(Total harmonic distortion (THD) is a measure of the amount of harmonic distortion in an electrical signal, defined as the ratio of the RMS value of all harmonic frequencies to the RMS value of the fundamental frequency. It measures how much a waveform deviates from a pure sine wave. High THD indicates poor signal quality, which can lead to problems such as equipment failure, excessive heat, or inefficiency. THD is often expressed as a percentage and can be applied to voltage or current signals.)

ANNs exhibit increasing intelligence, power, speed, and adaptability over time. ANFIS combines the advantages of ANNs and FLCs, using a data-driven learning approach that uses fuzzy logic to transform inputs into desired outputs through a highly interconnected neural network, and numerically maps inputs and outputs using weights. Tuning the parameters of a fuzzy inference system using ANFIS is similar to tuning the parameters of a fuzzy logic system using a neural network, although it involves fewer steps and variables. The ANFIS toolbox creates a fuzzy inference system from input/output mapping data and adjusts the membership.

Table 1 Simulation Results

Sl. No	Simulation	Filter	THD Value
1.	Fuzzy and PI Controller [17]	1000 uF	6.72 %
2.	PWM and ANFIS	1000 uF	0.58 %

6. CONCLUSIONS

ANFIS is designed for shunt VSCs integrating solar and BESS (microgrids) with the aim of controlling DLCV, reducing THD, and monitoring system performance at a constant solar temperature of 25°C during changing load, solar irradiance, and wind velocity. STF is developed to eliminate the need for PLLs. Performance monitoring of the developed technology in four simulation studies clearly demonstrates that it reduces load current THD. Throughout this paper, MATLAB/SIMULINK software was used for modeling of radial distribution network, uncertainty of PV plant, training of modeling data of ANFIS controller and full simulation of the system. Considering the erratic nature of power source in a distribution network, an ANFIS controller was used to select the appropriate power source considering the availability of power supply and load demand. This study employed Sugeno-type Adaptive Neuro-Fuzzy Inference System (ANFIS) as it integrates well with optimization and adaptive methods. In determining the optimal dispatch of microgrid source, input fuzzy sets and rules were used.

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