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Original Article

Evaluate Power Sharing Coordination Performance of Grid-Connected Microgrids Operation in Radial Distribution System using ANFIS Controller

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Abstract *- Power management techniques for coordinating several microgrids with Renewable Energy Resources (RERs) are one of the most important operational factors in ensuring optimal power supply. In this study, power management in grid-connected Microgrids using an Adaptive Neuro Fuzzy Inference System (ANFIS) control technique has been examined. An ANFIS-based power dispatch is presented with four (4) microgrids integrated into a 34-bus distribution network, and each Microgrid consists of a wind turbine coupled with two mass drive trains coupling Permanent Magnet Synchronous Machine (PMSM) generator, a solar Photovoltaic (PV) panel, and a Battery Energy Storage System (BESS). The proposed study aimed at evaluating the performance of coordination multiple grid-connected microgrids operation based on power sharing in a 34-bus radial distribution network. Maximum Power Point Tracking (MPPT) is used to harvest available PV model power. Available grid power and load demand were used as input data for training ANFIS. The proposed concept is implemented in MATLAB/SIMULINK. The system evaluation performance is taken in terms of optimal power dispatch between multiple Microgrids; the system is capable of storing excess power from one Microgrind with low storage capacity into another Microgrid with enough storage capacity. The effectiveness of the power dispatch in a 34-bus radial distribution network under grid-connected and Islanded mode of Microgrids using ANFIS controller has been successful for optimal power dispatch.*

Keywords *- ANFIS controller, Optimal power dispatch, Coordination, Radial distribution network, Renewable energy resources.*

1. Introduction

The primary drivers of global interest in renewable energy sources are the rising rates of fossil fuel consumption and public pressure to reduce pollutant emissions in the power-producing sector. The penetration of renewable energy sources in distribution networks results from reduced distribution infrastructure, minimizing system power losses, and power quality enhancement [1]. The management of these renewable sources is challenging. Hence, the proper controllers are needed to manage these sources integrated into the distribution network; because of this, in reference [2], the authors proposed a method that combines the Ant Lion Optimization (ALO) and Bat algorithms to improve the power management of microgrid utilizing droop control in sharing the power generated. A load sharing Adaptive (ANFIS) droop control strategy for hybrid microgrids was also proposed in [3]. In another study, a Distributed Model Predictive Control (DMPC) based cooperative energy management strategy for grid-connected microgrids was proposed in [4], where internal power exchanges between microgrids were virtualized based on a two-level structure. In resolving the demand and generation uncertainties in the interconnected and island-based operation of the domestic Microgrid (MG), a unique energy management framework integrating proactive and reactive approaches was presented in [5] for energy scheduling.

An adaptive droop control method was proposed in [6] to improve the operation communication of Multiple Grid-Connected Microgrids with a Multi-Layer coordinated control scheme to manage the power exchange among other microgrids. It was underlined that the Hybrid Energy Storage System (HESS) used included a method for suppressing power fluctuations. In managing the load demand in a grid-connected Microgrid network for simulating the best energy management in a smart grid system that is connected to the grid, the Seagull Optimization Algorithm and the Radial Basic Functional Neural Network (SOA-RBFNN) were proposed in [7].

A hybrid Distributed Generator (DG) with storage units and Grid Integration using ANFIS for Power control and management techniques were employed [8] to control and stabilize the power under various dynamic scenarios to reduce the discrepancies in the PV plant caused by changes in temperature in order to increase system performance. In [9], [10], Photovoltaic, Wind, and techniques for managing battery power in hybrid AC/DC microgrids using hybrid ANFIS PID with Elephant Herding Optimization (EHO) based cost optimization with droop control technique were utilized for the purpose of managing electricity; an interlink converter distributes the load between AC and DC system. Maintaining a consistent power flow between all renewable energy sources (PV, WT) and the load while maintaining effective microgrid power management is important to ensure that the battery power does not exceed the design limits. A supervisory controller using an Artificial Neuro-Fuzzy Interference System (ANFIS) with an Elephant Herd Optimization (EHO) algorithm was proposed in [10] with a hybrid power management technique in a Microgrid environment. Another study based on ANFIS and GA Approaches to enhance Microgrid performance through hybrid energy storage system integration was proposed in [11]. Power Quality (PQ) enhancement in using PID, ANFIS, Distributed Power Flow Controller (DPFC) [12], Black Widow Optimization (BWO), and Fractional Order Proportional-Integral-Derivative (FOPID) were introduced by [13] where distributed power flow controller (DPFC) is integrated into a hybrid power system (HPS) for a distribution network to reduce Power Quality (PQ) issues such voltage sag, swell, interruptions, and harmonic elimination.

Integrating renewable energy sources into a distribution network result in changes in bus voltage profile; hence, managing PV inverters' reactive power is challenging. Therefore, to enhance voltage regulation and reactive power sharing in Low Voltage (LV) distribution networks, the authors in [14] proposed local droop control to determine bus voltage deviation. A study was done on coordinating the sub-grid power management in a hybrid AC-DC Microgrid with different renewable sources to analyze the effects of using a traditional proportional-integral controller, a fuzzy logic controller, and an ANFIS-based controller in the battery's control strategy when subgrids are exposed to electric power fluctuation in distribution networks thereby reducing voltage variations during load changes was conducted in reference [15]. In maintaining a stable operation of the hybrid AC/DC Microgrid consisting of solar energy and wind, a coordination control of the hybrid system power dispatch is necessary for system stability and power balance in order to improve the Distributed Generators (DG) utilization efficiency, protect converters and maintain the stable operation of distribution network power flow [16]. In order to enhance power generation and conversion, the authors in [17] recommend coordinated power management for a microgrid that incorporates solar PV plants with Maximum Power Point Tracking (MPPT). The hybrid MPPT solution was built on a Particle Swarm Optimization-Adaptive Neuro-Fuzzy Inference System (PSO-ANFIS) for maximizing PV power quickly and integrating battery energy storage management to keep an isolated microgrid's voltage and frequency stable. In reference [18], a Generalized Current-Based Control (GCBC) approach was used to coordinate distributed energy resources in a grid-connected Low-Voltage Microgrid with a focus on regulating the microgrid power dispatchability at the Point of Common Coupling (PCC) while making sure of sharing current proportionally. A proposed Low Voltage (LV) Microgrid based on intelligent coordinated control for enhanced voltage and frequency regulation with efficient switchover operation is introduced in [19] using ANFIS to control power balance, voltage, and frequency by minimizing transient during power exchange in a distribution network. In achieving power decoupling, the authors emphasized that an inverse droop control was used in achieving that.

A hybrid Radial Basis Function Neural Network (RBFNN) and Squirrel Search Algorithm (SSA) was proposed in [20]to manage energy in grid-connected hybrid power systems more intelligently and economically while taking into account the forecast of load demand, fuel cost involvement, hourly grid power variation, and operation with a maintenance cost of a microgrid system. To improve Power Flow (PF) between the renewable energy source (PV, MT, WT, and battery) and load and lower the cost of electricity to customers connected to a distribution network. In the suggested methodology, a Hybrid Whale Optimization (HWO) and an Artificial Neural Network (ANN) approach were combined in reference [21]. For the purpose of achieving optimal power flow (OPF) for the transportation of wind energy in power transmission in an IEEE 30-bus system, a novel meta-heuristic algorithm, namely a Coati Optimization Algorithm (COA) and a war Strategy Optimization (WSO) was proposed in [22]. It was indicated in the paper that the algorithm minimizes the total Electricity Generation Expenditure (EEGE) alongside the value point effect and minimizes the Voltage Fluctuation Index (VFI). Maintaining power balance under variable generation and consumption conditions in a grid-connected Microgrid, a droop control with MPPT technique was applied to Photovoltaics (PVs) and Wind Turbines(WTs) in [23] to enhance power sharing and minimize power (active power) interruption to a consumer. With multiple sources of renewable energy plant coordination in a Microgrid architecture, the authors in reference [24] proposed an Adaptive Neuro-Fuzzy logic Interface System (ANFIS) Based reactive power and active power (QP) droop control for regulating voltage and frequency in Standalone Microgrid having Diesel generator, Wind generator, PV System, and Battery Energy Storage System (BESS) to improve power quality, system stability, and reliable power supply. Achieving effective power flow control in a DC Microgrid without negatively damped oscillations caused by power electronic devices acting as Constant Power Loads (CPLs) in a Microgrid network, an adaptive controller with Cubature KALMAN Filter (CKF) utilizing neuro-fuzzy inference system (ANFIS) is proposed in the article [25] considering Disturbance Accommodation Technique (DAT) in a given network, while in [26], [27] investigated into using Electric Spring (ES) with a Hybrid ANFIS-GA Based control technique to enhance DC Microgrids a voltage regulation authorize to meet the demand for power by controlling system load demand.

Research in identifying the ideal capacity, energy dispatching, and techno-economic advantages of a standalone Microgrid for remote area distribution network expansions with the integration of renewable energy sources such as Photovoltaic (PV), Wind Turbine (WT), Battery Energy Storage System (BESS), and Diesel Generator (DG) of interest for dependable power supply were investigated according to [28]. In addition, the authors in the papers [1], [12], [29] voltage sag or swell, voltage unbalance, frequency deviations, power characteristics, total harmonic distortion, and neutral current correction in multi-microgrid networks as a result of the penetration of nonlinear loads and the fusing of power electronic converters. To enhance power quality in many microgrids, the authors employ this analysis. An intelligent energy management strategy was employed to estimate demand for Electric Vehicles (EVs), forecast solar-based electricity generation, and optimize PV generation and grid power consumption [30]. The goal was to reduce the peak demand at electric vehicle charging stations that are grid-connected and powered by solar energy. Performance analysis of an islanded microgrid was conducted in [31] based on an adaptive neuro-fuzzy system to control power and frequency fluctuations considering power sharing among multiple Distributed Generators(DGs) in a standalone Microgrid. Meanwhile, intelligent battery energy storage system charging and discharge control in a three-phase distribution using ANFIS was proposed in [32] to ensure batteries are not overcharged or over-discharged to enhance long lifespan in a modified IEEE 9 bus system.

From the above literature survey, it is important to emphasize that quiet approaches are used in power quality management, voltage, and frequency control, with few works carried out on power sharing between multi-microgrids in a radial distribution network. Yet, considering multiple sources of Microgrid power generation where excess power is generated and cannot be stored in another storage system in different Microgrid energy storage systems is not realized in the literature, hence a gap in Microgrid energy management system. The continued integration of multiple distributed energy sources into conventional grid systems needs immediate attention on creating a system capable of mitigating the wastage of excess generated power more than load demand, which cannot be stored for future use. Having mentioned these, the novelty of this proposed work is managing power generated using an adaptive technique of power dispatching and ensuring an effective storage management system where excess power from one Microgrid is stored in another Microgrid with the excess storage system. To demonstrate this, in this proposed work, four microgrids, each made up of a Photovoltaic (PV) plant, Wind Turbine (WT), and Battery Energy Storage System (BESS), were considered and integrated into a modified 34-bus radial distribution network using an ANFIS controller to control power sharing in a 24-hour horizon.

The main contributions of the proposed work are as follows;

(1) Coordination of multiple grid-connected Microgrids for optimal power dispatch in a Radial Distribution Network (RDN).

(2) Using an Adaptive control system capable of storing excess power from one Microgrid with low storage capacity into another Microgrid with enough storage capacity.

(3) Controlling two mass drive train models coupling the wind turbine and the generator, a Permanent Magnet Synchronous Machine (PMSG) using ANFIS controller for optimum power generation.

(4) Utilizing ANFIS controller to maintain charging and discharging of the Battery Energy Storage System (BESS).

The remaining sections of this document are structured as follows: Section 2 consists of Materials and methods. Simulation results and discussion are presented in section 3. Section 4 contains the conclusions of this paper.

2. Materials and Methods

Throughout this paper, MATLAB/SIMULINK software was used for the modeling of the radial distribution network, the uncertainty of the PV plants, the modeling of the Wind Turbine, the Battery storage system, data training of the ANFIS controller, the design of the drive train, and the entire simulation of the proposed system.

2.1. Data Training of ANFIS Controller for Optimal Power Dispatch

Considering the erratic nature of DG power sources in a distribution network, an ANFIS controller was used to select the appropriate energy sources available, considering power supply availability and load demand. This study was employed using the Sugeno-type Adaptive Neuro-Fuzzy Inference System (ANFIS) [33]–[35] since it integrates well with optimization and adaptive methods. In determining the optimal dispatch of Microgrid sources, input fuzzy sets and rules were used. The load demand [$P_{LD}(t)$] and available power supply [P_{MG}(t-1)] of the microgrid DGs were taken into consideration as the input, and the reference power (P_{MG}Ref) as an output of the ANFIS controller in this paper. The membership function for the input variable was considered as the available power sources and the system load demand. In order to create the fuzzy design and its input variables, a system's input-output details are used to derive the initial rule set. The second layer (product) multiplies inputs from the minimum regulatory base by tweaking the initial rule set. The third layer is employed in the ANFIS structure to stabilize the weights. The output of the fourth layer, which generates the consequence of regulation, is a direct feature of the outcome of the third layer. In the fifth layer, each regulatory outcome is reported [17], [27], [32]. Figure 1 simplifies the suggested ANFIS structure.

2.2. ANFIS Training Data Formulation

In dispatching the distributed energy sources in a Microgrid system integrated into the grid, the proposed ANFIS technique requires the right training data. The required energy management training data were based on the load demand [PLD(t)] at a particular moment and the available generation [PMG(t-1)] from DG sources. The objective function of the proposed system is indicated using Equation (1) for data training to establish the reference power that must be generated from distributed sources. The parameters considered are main grid power, Photovoltaic (PV), Wind Turbine Power(WTP), with and without battery storage power (BESS). The power balance was expressed mathematically in Equation (2) and is taken into account for system operation. System operation constraints are considered in Equation (3), while Equation (4) was used for reference power estimation. Finally, the general training data for the ANFIS was done using Equation (5) based on the reference power obtained in Equation (4).

$$P_A(t) = \sum_{t=1}^{N} [P_{GRID}(t) + P_{PV}(t) + P_{WT}(t) \pm P_{BESS}(t)] \quad (1)$$

$$\sum [P_{GRID}(t) + P_{PV}(t) + P_{WT}(t) + P_{BES}(t)] = \sum P_{LD}(t) + \sum P_{Loss}(t) \quad (2)$$

$$\begin{bmatrix} P_{A_{MIN}}(t) \le P_A(t) \le P_{A_{MAX}}(t) \\ P_{GRID_{MIN}}(t) \le P_{GRID}(t) \le P_{GRID_{MAX}}(t) \\ P_{PV_{MIN}}(t) \le P_{PV}(t) \le P_{PV_{MAX}}(t) \\ P_{WD_{MIN}}(t) \le P_{WD}(t) \le P_{WD_{MAX}}(t) \\ P_{BESS_{MIN}}(t) \le P_{BESS}(t) \le P_{BESS_{MAX}}(t) \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} P_A^{Ref}(t) = P_{LD}(t) \\ P_{GRID}^{Ref}(t) = P_{GRID}(t) \\ P_{PV}^{Ref}(t) = P_{PV_{MPPT}}(t) \\ P_{WT}^{Ref}(t) = P_{WT}(t) \\ P_{BESS}^{Ref}(t) = P_{BESS}(t) \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} P_{MG}(0), & P_{LD}(1) \\ P_{MG}(1), & P_{LD}(2) \\ P_{MG}(2), & P_{LD}(3) \\ & . \\ & . \\ & . \\ & . \\ P_{MG}(t-1), & P_{LD}(t) \end{bmatrix} = \begin{bmatrix} P_{Ref}(0) \\ P_{Ref}(1) \\ P_{Ref}(2) \\ . \\ . \\ . \\ . \\ P_{Ref}(t) \end{bmatrix} \quad (5)$$

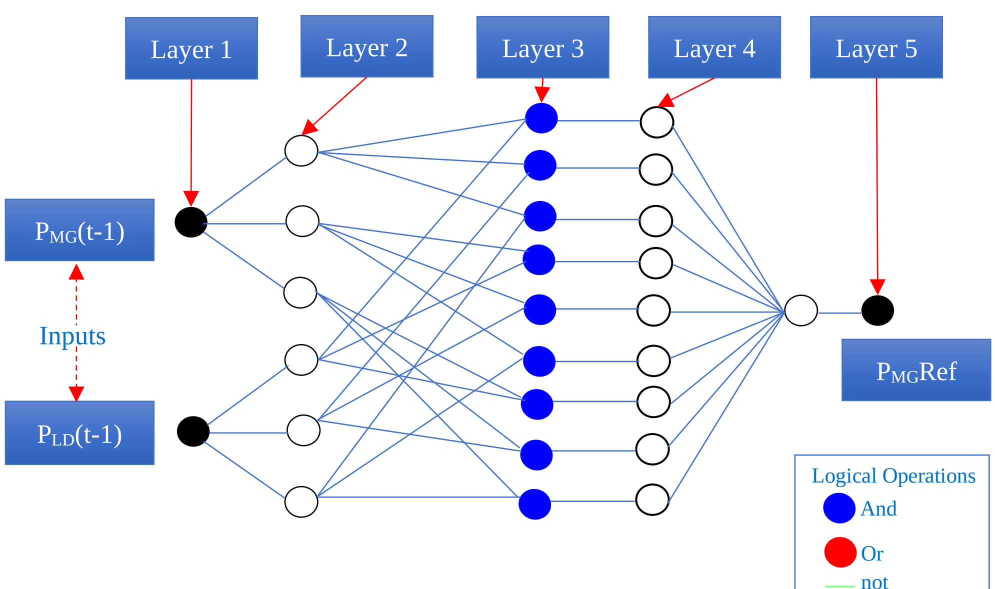

Fig. 1 Proposed ANFIS layer framework

2.3. PV Output Power Considering the Uncertainty

Adequate assessment of the variables that impact PV performance is the foundation for effective PV power generation. Among these variables are temperature, meteorological conditions (clouds, shadows, rain, dust, etc.), the effectiveness of power conversion, and solar radiation on panels (S_{irr}).

Hence, for optimal performance of PV for grid connection, these parameters must consequently be taken into account. In this paper, temperature was considered. Equations (6) and (7) describe the mathematical expression of PV output power with or without taking operating temperature uncertainty into account, and Equation (8) depicts the operating temperature of PV depending on solar irradiation and ambient temperature.

$$P_v = \eta A_{PV} S_{irr}[1 - 0.005(T_o - 25)] \tag{6}$$

$$P_v = \eta A_{PV} S_{irr}[1 - 0.005(T_a + S_{irr} - 25)] \tag{7}$$

$$T_o = T_a + S_{irr} \tag{8}$$

Where S_{irr} is solar radiation on the PV panel, P_V is the power of the PV, A_{pv} is the area of the PV panel, T_a is the ambient temperature, T_o is the PV operation temperature, and η is the efficiency of the PV panel.

2.4. Mathematical Modeling of Wind Turbine

The mechanical power produced by a wind turbine was calculated using the following equations.

$$P_m = \frac{1}{2} x C_p(\lambda, \beta) A_T \rho V^3 \tag{9}$$

$$T_m = \frac{P_m}{\omega_t} \tag{10}$$

$$C_P(\lambda, \beta) = C_1 x \left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\beta^2 - C_5\right) e^{-\left(\frac{C_6}{\lambda_i}\right)} \tag{11}$$

$$\lambda_i^{-1} = (\lambda + 0.008\beta)^{-1} - 0.0035(1 + \beta^3)^{-1} \tag{12}$$

$$\lambda_T = \lambda_T^{optimal} = \frac{\omega_t R_T}{V} \tag{13}$$

Where: *Pm* is the power extracted by the wind turbine or the mechanical power, *V* indicates wind speed(m/s), *A* is the rotor area(m^2) = πr^2 with *r* being the radius of the wind turbine blades, ρ indicates air density(kg/m^3), *Cp* is the power coefficient, β represents the pitch angle, λ the tip speed ratio, ω_t is the relational speed of the wind turbine(rad/sec), λ_i is the intermittent tip speed ratio (TSR) and is related to λ_T and β, as shown in Equation (12). Cp is defined in terms of the turbine coefficient constants from C1 to C6, as indicated in Equation (11). The mathematical equations were modeled in Simulink, as shown in Figure 2.

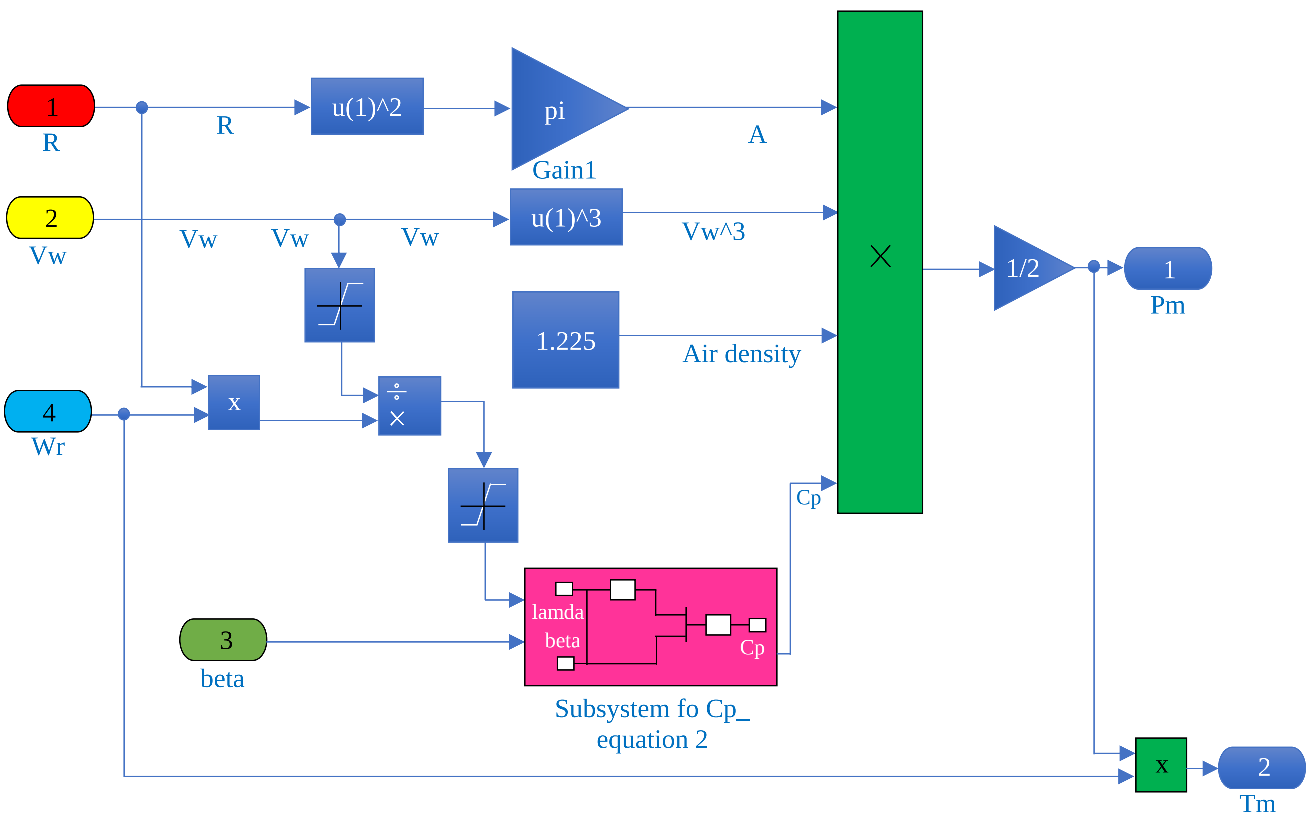

Fig. 2 Mathematical model of proposed wind turbine equations in Simulink

2.5. Modified 34-Bus Radial Distribution Network for Integration of Microgrids

In this paper, a test distribution system for a radial 34-bus system was modified. The test system was installed with Distributed Generation (DG) power sources and loads. Utilizing MATLAB Simulink, this system was created. This study considered critical loads, energy storage systems, and non-critical loads in addition to Distributed Energy Resources (DERs). The suggested MG can operate in both an island mode and a grid connection mode. At buses 3, 10, 22, and 30, respectively, the four microgrids are connected to the distribution network.

Bus 2,4,5,11,12,14,16,17,20,23,25,27,28,30,31 and 34 collectively connect 16 load locations. Figure 3 shows the flowchart of the proposed Microgrid control strategy. Figure 4 represents the modified radial distribution network, while Figure 5 is the complement implantation of the work in a MATLAB/SIMULINK. In the proposed grid-connected Microgrids, DER power and loads were controlled continuously based on the randomness of a load consumption profile and available power supply. The proposed ANFIS controller evaluates system requirements based on logical decisions and chooses the best reasonable action for optimal power dispatch.

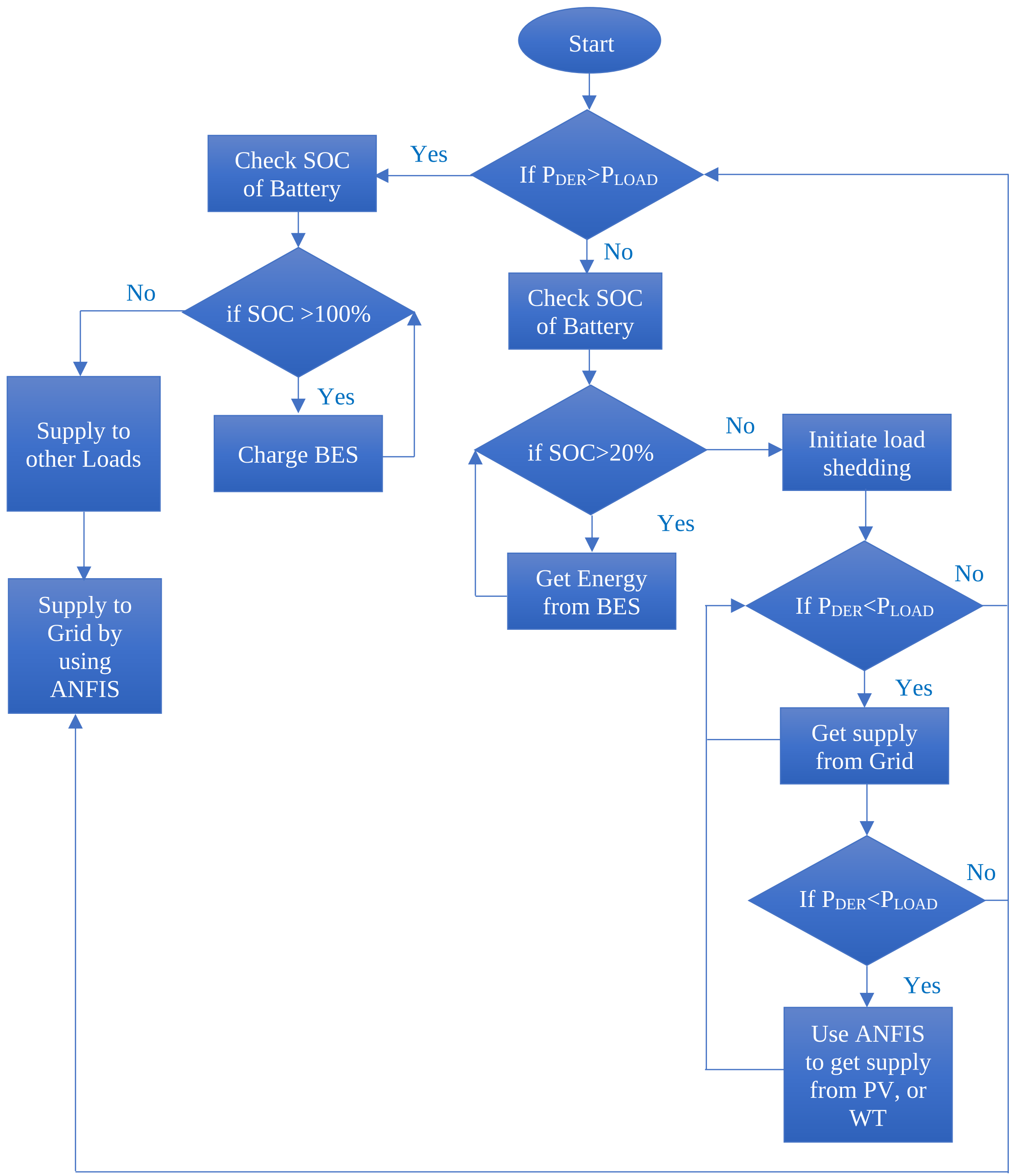

Fig. 3 Flowchart of grid-connected microgrids energy dispatching

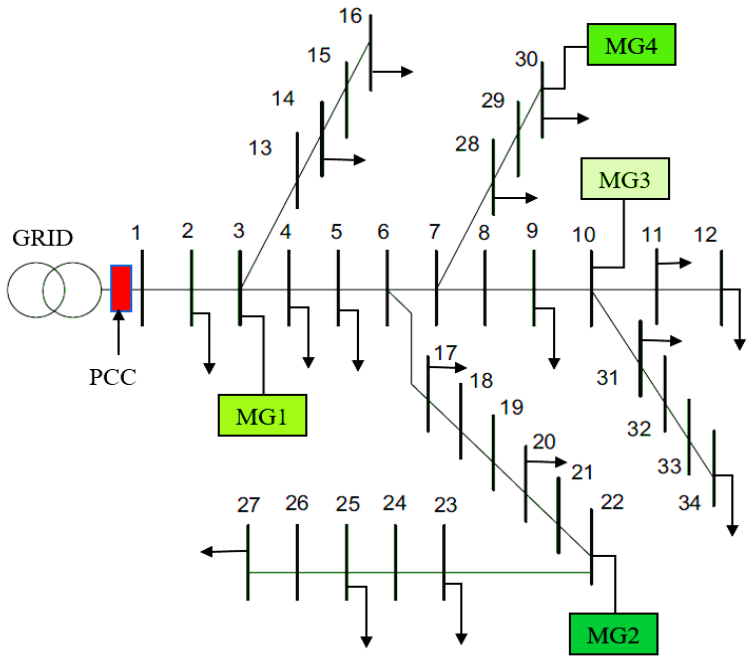

Fig. 4 Modified single line diagram of 34 buses radial distribution network [36]

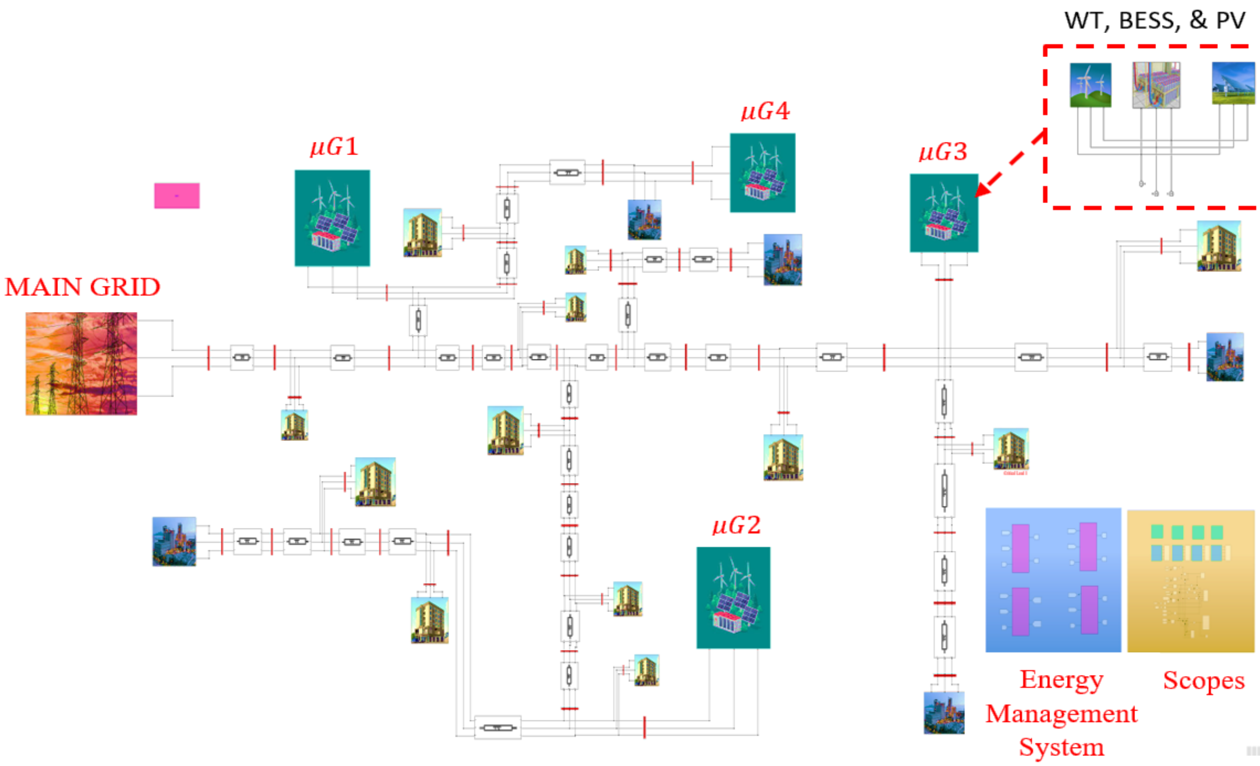

Fig. 5 Proposed Simulink 34 buses radial distribution Network with four Microgrids

3. Results and Discussion

As stated in the previous section, a 34-bus Radial Distribution Network (RDN) integrated four Microgrid was proposed in this study with the focus of evaluating the performance of coordinating multiple grid-connected Microgrids energy sources for optimal power dispatch using ANFIS. As detailed in section two of this paper, MATLAB/SIMULINK software was used to design, model, and simulate the system. For efficient solar energy harvest considering the temperature uncertainty, the PV plant boost converters were controlled with a Maximum Power Point Tracking (MPPT) controller to extract the maximum available power from the PV module. A signal builder was used to build the solar irradiance, having the maximum and minimum irradiance as 1200 (W/m^2) and 0 (W/m^2), respectively. The maximum irradiance was observed between the hours of 10:00h to 17:00h of the day, as shown in Figure 6. This was achieved using the MPPT in getting adequate power from the PV model based on the solar irradiance.

As stated earlier in this paper, the four (4) Microgrids, each consisting of a Photovoltaic (PV), Wind Turbine(WT), and Battery Energy Storage System, were integrated into a 34-bus network at buses 3, 10, 22, and 30 respectively. The results of how each microgrid-distributed generators (DGs) dispatches Power dispatch in the various grid-connected Microgrids are shown in Figures 7, 8, 9, and 10. In evaluating system performance based on the dispatching of the above-mentioned energy sources, some operational conditions scenarios were considered:

- When enough power is available, total power generation (P_{MG}) should be equal to system load demand power (P_{LD}).
- Under conditions of excess power, the power generated (P_{MG}) is more than the system load demand power (P_{LD}) connected in the network.
- During shortage power circumstances, total power generation (P_{MG}) is lower than load demand power (P_{LD}) realized in the system.

The main power considered in this paper is the power generated by the Wind Turbine(WT) since the PV power depends mostly on sunlight; therefore, the ANFIS controller was used to dispatch available power sources based on the load demand power (P_{LD}) connected in the network.

As can be seen from all the Microgrids results presented in Figures 7, 8, 9, and 10, the grid power and battery storage power are shared during the peak demand period of the day, that is, the hours of 06:00 to 10:00h and 18:00h to 20:00h with the grid supplies maximum power of 2.5MW while the battery supplies between 1MW to 1.5MW power in Microgrid one (1). In Microgrids one and four, the PV plants supply 0.25MWp power between the hours of 10:00h to 17:00h, using the MPPT control technique in harvesting the maximum available solar irradiation to produce the necessary power required as indicated in Figures 7 and 10, but the PV plants in Microgrids two and three starts generating power at the 09:00h of about 0.04MWp until the hours of 10:00h to 16:00h where maximum power of those plants was recorded to be 0.12MWp and 0.25MWp respectively.

The proposed ANFIS controller was utilized to manage pitch angle by adjusting the blade angles to keep the rotational speed of the wind turbines within the ideal range, hence maintaining optimal speed for the wind turbines and ensuring continual power output of 4MW throughout the day since there are no fuel input costs and also pollution free. The batteries in Microgrid two and three could supply power of 4000kW during peak demands, as shown in Figures 8 and 9. For the battery to store energy, the excess power generated is therefore stored in the respective available battery storage systems.

In this study, excess power detected in any of the Microgrid with low storage capacity, with the aid of the ANFIS controller, that amount of power detected is sent to another Microgrid that has enough storage capacity, and that power is therefore stored for use during peak power demands without losing it. In Microgrids one and four, power from the radial distribution network(RDN) was realized from the wind turbines of approximately 1.4MW, which were stored between the hours of 00:00h to 06:00h before the grid power started to supply power where the storage power increases to about 1.5MW and 2MW respectively during the peak hours after the grid starting supplying power. However, between the hours of 00:00h to 06:00h, 10:00h and 17:00h, and 20:00h upwards, even when the PV plants supplied power during 10:00h and 17:00h, a constant power of 1.2MW was maintained.

In addition, with the battery storage systems in Microgrids two and three, there was 1.2MW of power that was supplied to these storage systems when only the wind turbines (WT) were supplying power between the hours of 00:00h and 06:00h before the grid started supplying. The excess power from these sources was sent to the two storage systems, and a 2MW power was realized. This 2MW power was constantly maintained even though the PV plants supplied power. This was achieved because of the use of the proposed ANFIS controller, which was used to control the charging and discharging of the batteries that were used in this work, as well as ensure the sharing of power among the multiple grid-connected microgrids in the modified 34-bus radial distribution network as shown in Figure 4.

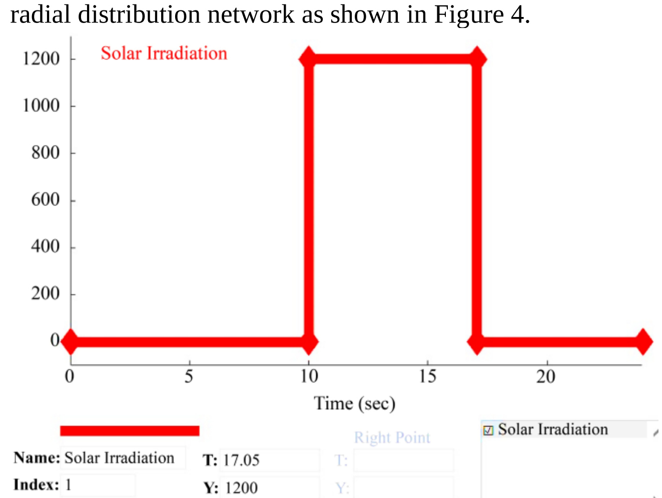

Fig. 6 Proposed solar irradiance

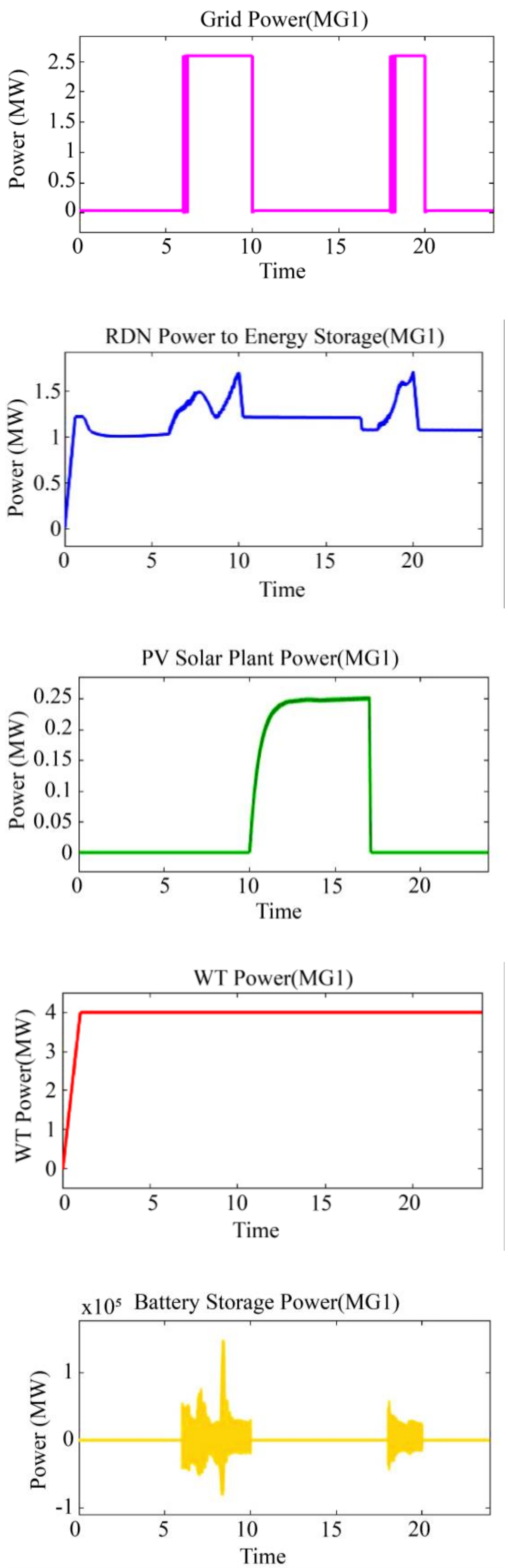

Fig. 7 Grid-connected Microgrid 1 Power dispatch

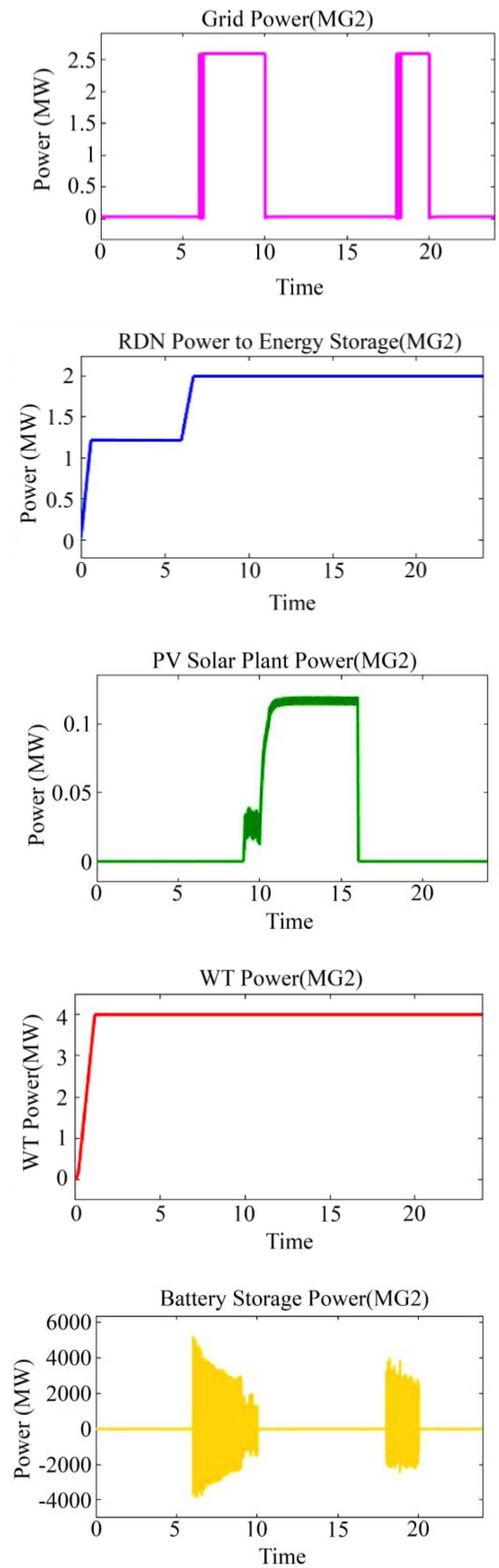

Fig. 8 Grid-connected Microgrid 2 Power dispatch

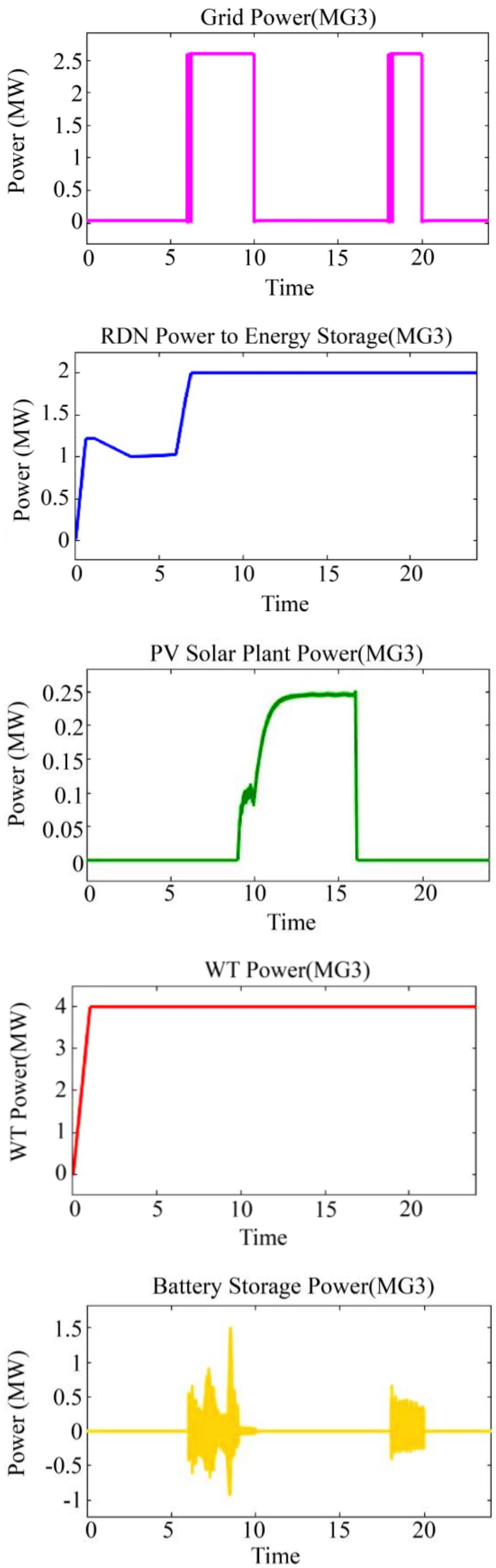

Fig. 9 Grid-connected microgrid 3 power dispatch

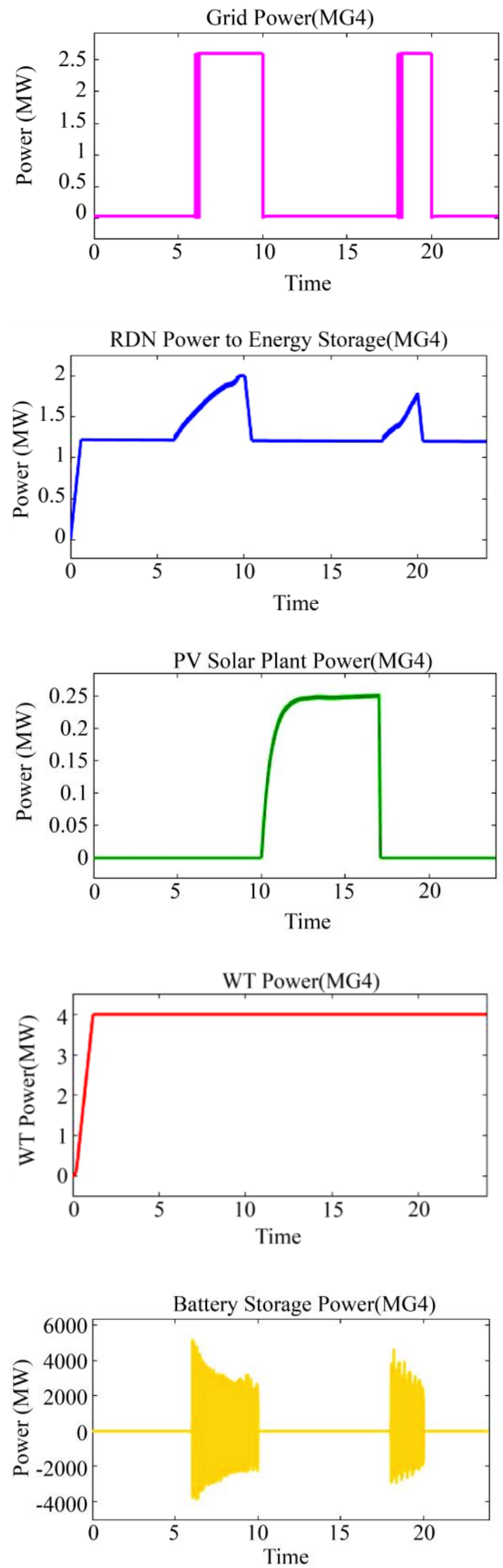

Fig. 10 Grid-connected microgrid 4 power dispatch

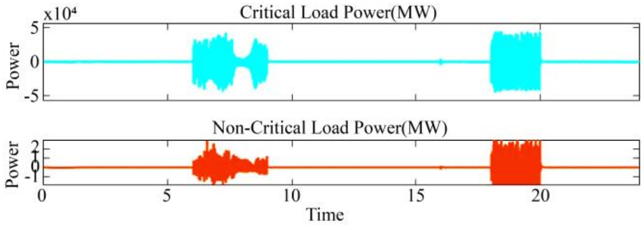

Fig. 11 Power to critical and non-critical load

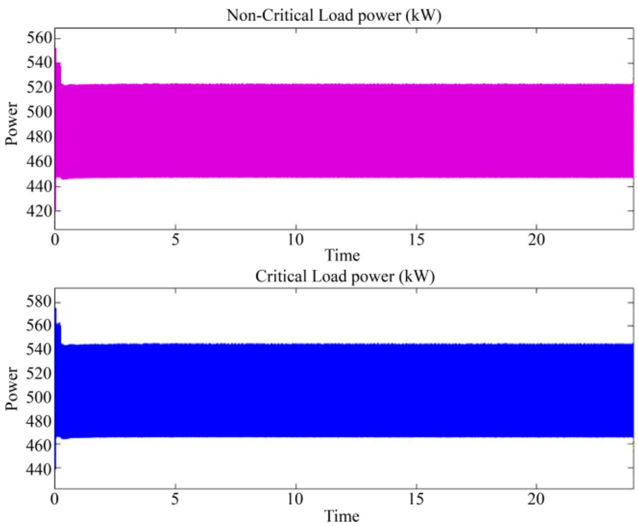

Fig. 12 Non-Critical and critical load power

It must be emphasized that, during the simulation, all the system loads were connected to evaluate the optimal power sharing in the proposed 34-bus radial distribution network. As mentioned earlier in Section 2.5, 16 load points were considered in this paper. These loads are classified into non-critical loads and critical loads. The ANFIS controller was used to manage the energy available and share based on the load demand on the system. The power to the various loads was mostly considered during peak hours of the day to meet the necessary power demand. Figure 11 shows how power was shared with critical and non-critical loads at buses 30 and 23 in the system during the peak hours of the day. It was realized that 5MW and 2MW power were supplied to critical and non-critical, respectively. Figure 12 also shows the power flow to other Non-Critical and Critical Loads, indicating that the controller can supply adequate power to the above-mentioned loads based on demand.

3.1. Comparison of Proposed Work and Existing Researches

In this paper, the coordination of power dispatch of multiple grid-connected Microgrids in a 34-bus network successfully enhanced the optimal distribution network operation as proposed. The proposed ANFIS controller works effectively in controlling and dispatching available energy sources based on increased or decreased load demand to enhance reliable power supply. The results of the multiple microgrids power-sharing using the proposed controller are presented in Figs. 7, 8, 9, and 10 and discussed in section 3 of this paper. The result reveals that the proposed method outperformed some works identified in the literature in that signals generated are clear with few or no signal spikes compared to results presented in Figure 13 of work done in [16], [32]. In other research works, where authors consider load switching and coordinating power management of subgrids in a Multi-Renewable AC-DC Microgrid, the results obtained were presented in Figures 13 and 14 in references [15], [16] considering the power of wind, DC side power flow into AC side and the output of battery in grid-connected mode. Other research also presented a new paradigm for energy scheduling for the efficient and effective operation of isolated and grid-connected microgrids, which was carried out in [5]. The results are shown in Figure 15 of [5] based on hourly optimal expected loads for grid-connected MG under DR. With these few comparisons of existing research as compared with the result presented in this proposed work; it is clear that the proposed technology of power sharing in this manuscript outperform the works found in literature confirming that real-time implementation of this technology will go a long way to mitigate wastage of excess power generated with multiple microgrids thereby enhancing reliable power supply in radial distribution networks.

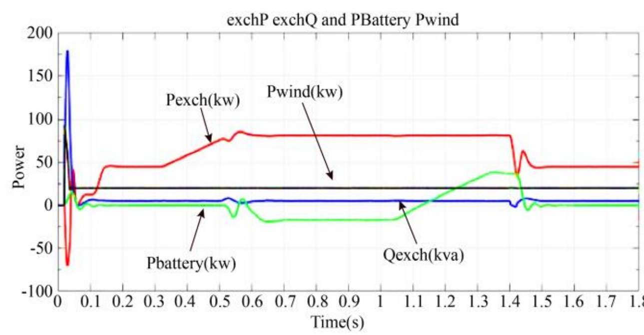

Fig. 13 Power in grid-connected mode[16]

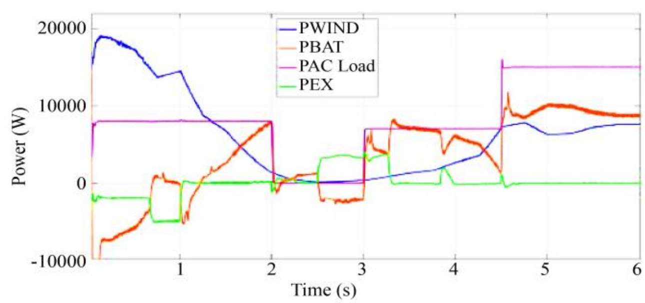

Fig. 14 AC Subgrid power balancing [15]

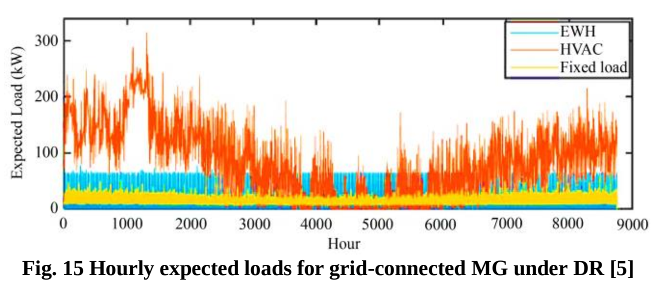

Fig. 15 Hourly expected loads for grid-connected MG under DR [5]

4. Conclusion

This article presents the coordination of multiple grid-connected Microgrids in a 34-bus Radial Distribution Network (RDN) with four Microgrids, each consisting of a Photovoltaic (PV) plant, Wind Turbine (WT) generator, and Battery Energy Storage System (BESS) using a lithium battery for power saving. ANFIS controller is implemented for organizing the battery charging and discharging and also controlling the dispatch of the various energy sources depending on load demand during the day. Design, modeling, simulation, and data training were done using MATLAB/SIMULINK software. This paper solves the problem of the challenge faced in dispatching multiple Microgrids with renewable energy sources integrated into distribution networks and enhances optimal power supply to customers. Implementing an adaptive control system capable of transferring excess power from one microgrid with insufficient storage capacity to another microgrid with adequate storage capacity was successful. MPPT controller was used to harvest the available PV model power. The proposed system operates in both grid-connected mode and Islanded mode. Uncertainty of temperature on the PV model was considered during the simulation with solar irradiance signal built using a signal builder. It is found that the proposed technology succeeds in coordinating multiple grid-connected microgrid power sources and was effective in power dispatch using ANFIS controller for optimum usage of power generated and distributed.

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