ANFIS-GA Based Hybrid Control Method for Enhancement of DC Micro Grids Using Electric Spring

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Abstract

Due to the imbalance between supply and demand for electrical energy and the widespread use of Renewable Energy Sources(RES), the grid's stability is hampered and jeopardized. The intermittent and stochastic nature of RES is the root of the instability, and this issue can only be solved by using some form of load control rather than generation management. A technique known as demand-side management (DSM) has emerged as a way to consistently meet the demand for power by controlling the load rather than boosting supply.The electric spring (ES), which has a modest to moderate rating and can be used to directly commission voltage regulation at the customer's location, falls under the category of custom power devices.In this work, an effort is made to control the power consumption of the noncritical loads utilizing the proposed DC electric springs rather of moving them to different times of the day.The identification of the ANFIS parameters is suggested using a Genetic Algorithm (GA) based learning design process. The system under inquiry is thoroughly modelled, as are its control schemes. The other controllers like Artificial Neural Network (ANN), Model Predictive Controller (MPC) and Fuzzy Logic Controller(FLC) compares the performance of the ANFIS-GA controller with that obtained using optimized proportional-integral controllers. Through thorough simulation evaluations carried out in the MATLAB/Simulink environment, the ANFIS-GA control scheme's validity is confirmed. To back up the efficacy and precision of the suggested control technique, a study based on Matlab simulation results is carried out and presented.

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I. Introduction

Power generation from renewable energy sources close to the load centers would be an efficient solution to safeguard the environment and boost operational effectiveness. Power generation close to load centers reduces power loss during transmission while also requiring less investment in transmission and distribution networks. The idea of reducing generation resources to satisfy a concentrated demand in a small geographic area makes the overall structure resemble a microgrid, a small-scale electric grid. Compared to typical electricity grids, these micro grids are considerably smaller and require sophisticated operational methods. The main energy source for micro grids is renewable energy, which varies naturally.In order to meet the load requirement, the intermittent nature of renewable energy systems needs to be handled.Because ES has a lower energy demand than UPS, it may easily address the implications of distribution system instability brought on by oscillations caused by intermittency and emerging as a result of the bulk incorporation of RES in grid-tied solar roof-top systems.

The environment is being polluted as a result of the rising demand for electricity, which can only be met by fossil-based bulk generating sources. The cleaner version of the same, RESs, on the other hand, pollutes the electrical system itself. In this piece, the notion of ES as a tool comparable to the idea of DSM is explored. The effort concentrated on investigating different controllers that haven't been used with the ES. In micro grids, generation unpredictability is a significant issue that must unquestionably be resolved. A number of approaches, including the incorporation of storage devices, demand side management, generation scheduling, etc., can be utilized to address the unpredictability in the power provided to the loads. Finding a good solution is always difficult for engineers because there are so many options available.

The global decarbonization of the power industry is the cornerstone of the fight against global warming. To achieve this goal, the electric system's renewable energy penetration should be dramatically increased. In systems that significantly rely on renewable energy sources, this means that difficulties with grid stability, dependability, and power quality need to be taken into consideration. As distributed power is used more frequently, such as rooftop solar panels and charging huge fleets of electric vehicles, distribution networks may have over- and undervoltage issues. In the modern power network, where power generation is primarily dependent on load estimates, centralized control is used. To control voltage and power flow, flexible alternating current transmission systems are employed.

The standard single point control with STATCOM and distributed voltage control with ES are contrasted in the work by X. Luo et al. In order to decrease imbalanced loading in distribution systems, speed up demand side management, lessen voltage fluctuations in power systems, and enhance the performance of noncritical loads, Yan et al. (2017), Yang et al. (2018), and Zhang et al. (2019) used AC electric springs.Wang, et al. explain how non-critical loads can emulate the behavior of renewable generators in micro networks using renewable energy sources and use less energy when there is generation uncertainty (2018).In this study, J. Soni et al. used an electric spring to demonstrate how it might sustain voltage, reduce load power, and compensate for reactive power when used with building loads like central air conditioning systems.

A piece of power electronic equipment called the Electric Spring (ES) is used to improve system stability, reduce three-phase power imbalance, and boost power quality. The goal of the study evaluation is to use the DC series electric spring (DCSES) idea to reduce the amount of power supplied by the main grid during an RES generating shortfall.The new operational strategy where the load energy changes with the generation energy changes will be realized when ES adjusts the existing techniques of operation where the generated energy differs from the load energy. Future sustainable microgrids (MGs) need crucial elements like electricity produced by solar and wind sources. The intermittency, instability, and lack of prediction accuracy of RESs, among other characteristics, will be the source of the power imbalance between the generating side and the load side. The safety of the grid and the quality of the power being provided will also be affected.

These technological limitations have been taken into account by the development of the ES power electronic-based DSM approach. Three basic categories of AC ES technologies have been discussed in the literature thus far. The primary AC ES has been built to solely compensate reactive power at the point of common connection in order to manage its input voltage (PCC). For forthcoming distributed MG, the ES technology has been proposed to meet these requirements by shifting voltage variations to non-critical loads (NCLs) while keeping the voltage changes across critical loads (CLs) well below the bounds. NCLs can handle a wide range of potential, in contrast to CLs, which can only survive a narrow range. The transfer is made possible by ES's automated balancing of load demand and energy output.The so-called smart load(SL) is produced by combining ES and NCL.The renewable generating sources might not be reliable. Critical load (CL) will not function normally if the line voltage swings. To ensure that CL operates normally, the modification of ES transmits voltage variations to NCL. The imbalance brought on by the generation of renewable energy was resolved by the new operation strategy, which modulates the load energy in accordance with changes in the generation energy.A DCES changes the DC bus voltage and reduces harmonic and ripple content in the DC microgrid. It has battery storage in addition to filtering and reducing harmonics, allowing for a constant DC supply.

In this study, a model predictive controller-based electric spring is proposed. Solar panels serve as the DC power source for both critical and non-critical loads. The MPC technique is used for pulse generation. Simulation is carried out using the Matlab/Simulink program. The application of the suggested methodology is validated by comparing the different parameters to the ANN method and PI controller. The data collected clearly show that the main grid's reliance on the NCLs is reduced with the addition of ES. The effectiveness of the DCSES is assessed using a simulation model developed in Matlab/Simulink.An LMBP-based ANN controller is utilized to generate pulses for the DC-DC converter, reducing the DC micro-reliance grids on the main grid and ensuring that the NCLs entirely follow the profile of the IRES. This controller's performance is evaluated and contrasted with BESS. Voltage regulation, harmonics, and ripple are seen with PI and ANN controllers. The results are compared and discussed in subsequent meetings.

In this study, a ANFIS controller-based electric spring is proposed. Solar panels serve as the DC power source for both critical and non-critical loads. The ANFIS Controller which is trained by GA technique is used for pulse generation. Simulation is carried out using the Matlab/Simulink program. The application of the suggested methodology is validated by comparing the different parameters to the FLC, ANN, MPCmethod and PI controller. The data collected clearly show that the main grid's reliance on the NCLs is reduced with the addition of ES. The effectiveness of the DCSES is assessed using a simulation model developed in Matlab/Simulink. The results are compared and discussed in subsequent sections.

II. Design of ES

Similar to a mechanical spring (MS), an ES is a device that can be used to generate support voltage, store energy in electrical form, and attenuate electric oscillations. The source of the force acting on a ideal MS is,

$$F = -kx \tag{1}$$

Here, k →Spring constant
x →Displacement vector.

According to equation (1), the charge maintained in the electric spring is represented as,

$$q = \pm CV_c \tag{2}$$

Here, C→Capacitance in Farad
V_c→Potential acrosscapacitor.

The potential energy of the ES is provided by,

$$PE = \frac{1}{2}CV_c^2 \tag{3}$$

In its simplest configuration, an ES consists of a voltage block that generates a compensating voltage V_a and is connected in series with an NCL, Z_l. When the mains voltage V_S deviates from its reference value V_{S_ref}, ES can restore it using a variety of techniques. In potential boosting mode, Electric Spring generates a supportive voltage to raise the grid potential, and in voltage bucking (suppression) mode, it generates a suppressing voltage to lower the primary potential. The dynamic voltage restorer function of ES lowers electric oscillations.

Figure 1 depicts the simplified power circuit for the ES together with a voltage supply and transmitting lines. Following are the outcomes of applying KVL and KCL.

$$L_1\frac{di_1}{dt} = V_{in} - V_l - (R_1 * i_1) \tag{4}$$

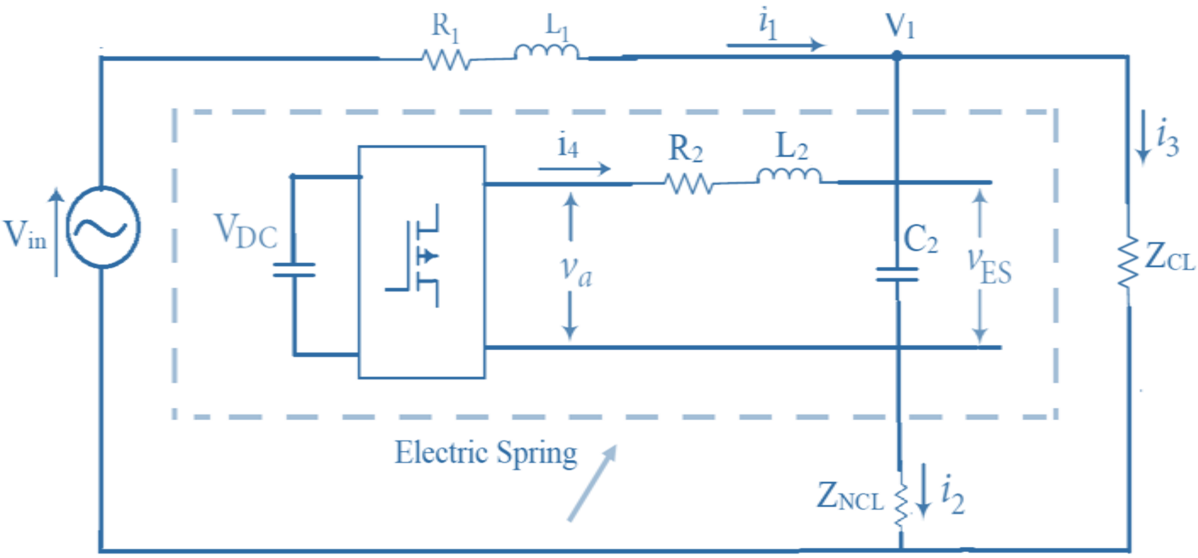


Fig. 1Equivalent Circuit of ES

$$L_2 \frac{di_4}{dt} = V_a - V_{ES} - (R_2 * i_4) \quad (5)$$

$$C_2 \frac{dV_{ES}}{dt} = i_4 + i_2 \quad (6)$$

$$i_1 = i_2 + i_3 \quad (7)$$

$$i_2 = \frac{V_l - V_{ES}}{Z_{NCL}} \quad (8)$$

$$i_3 = \frac{V_l}{Z_{CL}} \quad (9)$$

By resolving the aforementioned equations, one can obtain the state-space representation of an ES.

$$\dot{x} = A_e x + B_1 V_s + B_2 u \quad (10)$$

$$y = C_e x + D_1 V_s + D_2 u \quad (11)$$

The following matrices are used to calculate the coefficients of the equations above.

$$A_e = \begin{bmatrix} -\frac{Z_{NCL} Z_{CL} + R_1(Z_{NCL} + Z_{CL})}{L_1(Z_{NCL} + Z_{CL})} & 0 & \frac{Z_{CL}}{L_1(Z_{NCL} + Z_{CL})} \\ 0 & -\frac{R_2}{L_2} & -\frac{1}{L_2} \\ \frac{Z_{NCL}}{C_2(Z_{NCL} + Z_{CL})} & \frac{1}{C_2} & \frac{1}{C_2(Z_{NCL} + Z_{CL})} \end{bmatrix} \quad (12)$$

$$B_1 = \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \end{bmatrix} \quad (13)$$

$$B_2 = \begin{bmatrix} 0 \\ \frac{V_{DC}}{2\,L_2} \\ 0 \end{bmatrix} \tag{14}$$

$$C_e = \begin{bmatrix} \frac{Z_{NCL}\,Z_{CL}}{Z_{NCL}\,+Z_{CL}} & 0 & \frac{Z_{CL}}{Z_{NCL}\,+Z_{CL}} \end{bmatrix} \tag{15}$$

$$D_1 = 0 \tag{16}$$

$$D_2 = 0 \tag{17}$$

Where,

V_{in} →input or supply voltage
R_1 →Equi.Resistance of line (transmission)
L_1 →Equi. Inductance of line (transmission)
Z_{CL} →Critical load
Z_{NCL} →Non critical load
V_l →Voltage at the place of common coupling (PCC) (same as voltage across CL)
i_1 →line current
i_2 →current passing in the NCL
i_3 →current passing in CL
i_4 →current passing in ES
V_{ES} →voltage across C2, i.e., voltage across the ES
R_2 →Equi. Resistance of converter line (transmission)
L_2 →Equi. Inductance of converter line (transmission)
V_{DC} →DC link voltage (from solar panel)

III. Proposed Circuit Topology of ES

Figure 2 depicts the basic layout of the DCSES, and Figure 3 depicts the circuit for the proposed control strategy. Normally, the ES is connected through the NCL. The two primary compensating mechanisms employed by ES to alter the line voltage are inductive and capacitive modes. As the potential V_l exceeds its preset voltage V_{l_ref}, inductive mode for potential reduction,

V_{ES} lags behind i_0 by 90°, where i_0& V_0 are the current & voltage of the NCL, respectively. As soon as the potential V_l falls below the predetermined value V_{l_ref}, the electric spring in capacitive mode raises the line potential.

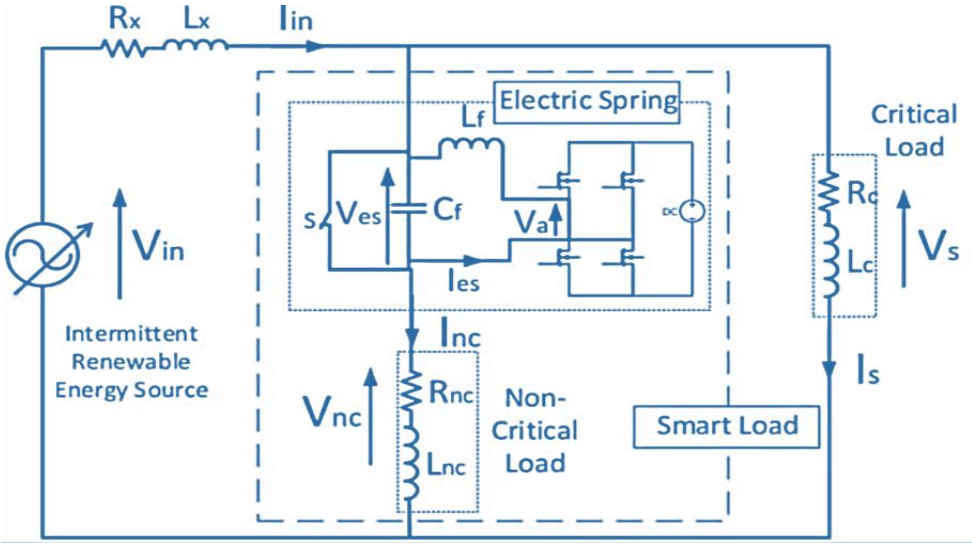


Fig. 2 Block diagram of ES

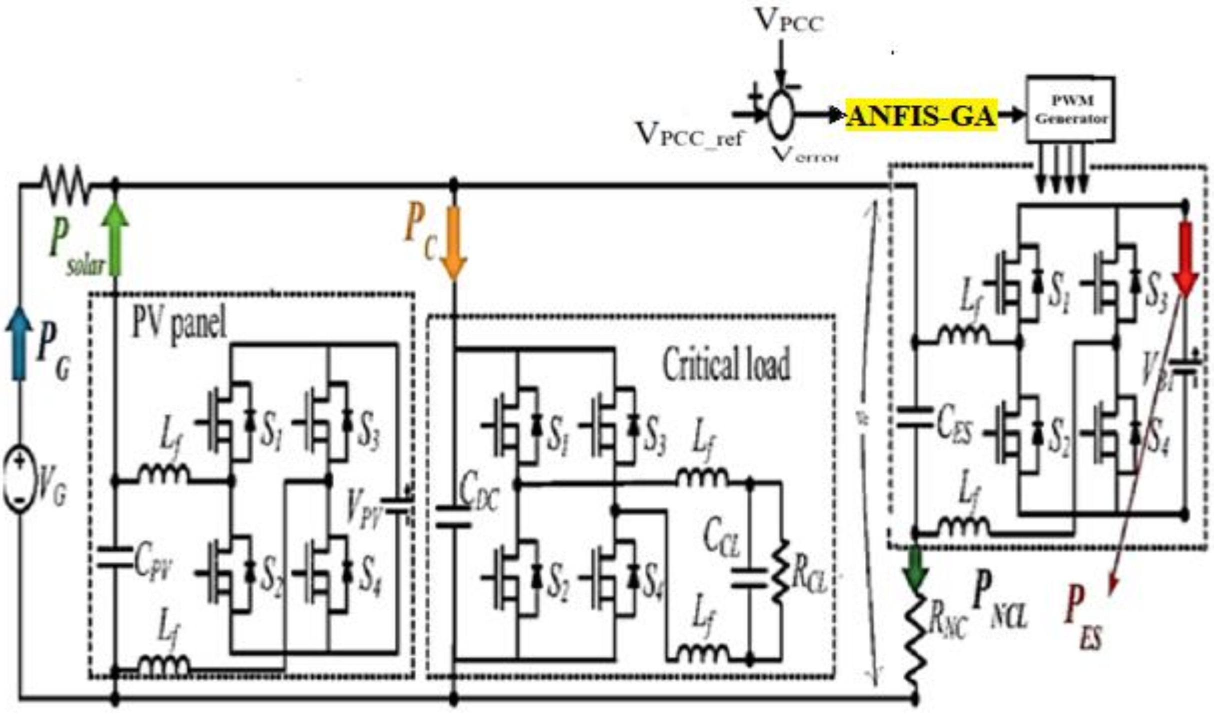


Fig. 3 Control circuit of Proposed ES

In the suggested circuit, a solar PV panel is treated as an unpredictable source of DC power. A battery storage system(BSS), a CL, NCL, ES, and GA trained ANFIS controller are all included. The ANFIS-GA controller is configured so that NCL obtains rated potential depending on the generation and below rated potential otherwise. The inductor L_f serves as a filter to decrease the DC's ripples. The burden on the battery unit can be reduced by making use of the irregular solar energy source.

IV. Control Techniques Applied for ES

Figure number 4 shows the general control schematic used in our research. In this study, we generate pulses for the DC-DC converter using the ANFIS-GA controller. Additionally, the suggested controller is evaluated using FLC, MPC, ANN and PI controllers.

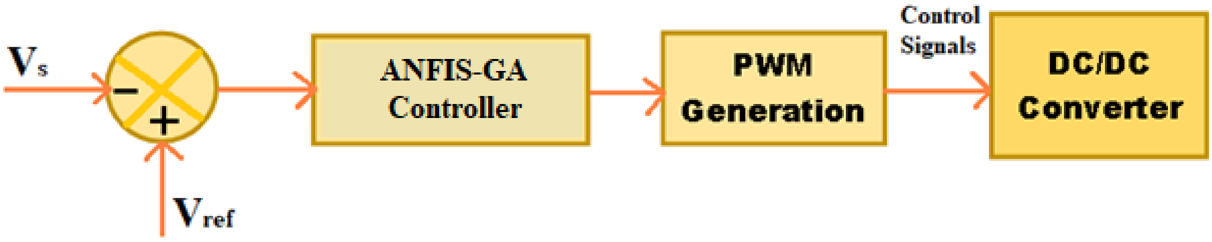


Fig. 4. Basic Control Circuit for ES based DC-DC Converter

(A) MPC Controller

Model predictive control is a feedback control method based on recurrently addressing optimal control issues. The flexibility of direct approaches for optimal control has increased in popularity, particularly in practical applications. MPC, a sophisticated approach to process control, controls a process using a set of constraints. MPCs have been employed in the process control sections of chemical and oil refineries since the 1980s. MPCs make use of dynamic process models, which are generally linear empirical models generated as a result of system identification. The main benefit of MP controller is that it lets you prioritize future time slots while simultaneously maximizing the one you have right now.

This is achieved instead of a linear quadratic regulator by optimizing a constrained time horizon while just applying the current time slot before repeating optimizing (LQR). Additionally, MPCs have the ability to anticipate future events and take the appropriate countermeasures. This predictability is lacking in PID controllers. The MP controller's primary schematic is displayed in Figure 5.

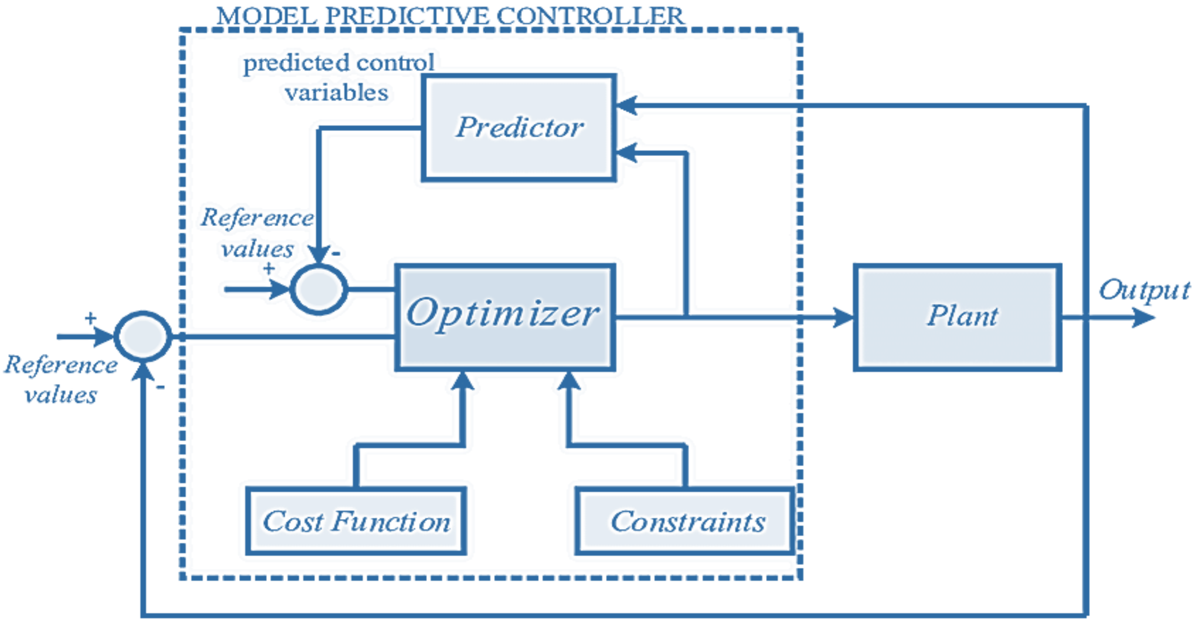


Fig. 5. General Structure of MPC Controller

(B) ANN Controller

ANNs are suitable as intelligent controllers to generate pulses to the converter due to their main firmness, exceptionally effective learning competency, ability to solve problems and generalize in pattern recognition and correlating, function optimization and approximation, and associative memories. It helps to support NCL under aberrant IRES by regulating the voltage and reducing the ripple content. The neural network is trained via the Levenberg Marquardt-based back propagation (LMBP) method. An I/p layer, two hidden layers, and an O/p layer were used to build the ANN. Each buried layer contains ten neurons.Figure 6 depicts the two-layer feed forward network that was used to train the network. Ten neurons make up the hidden layer, where Tansig activation function is used.

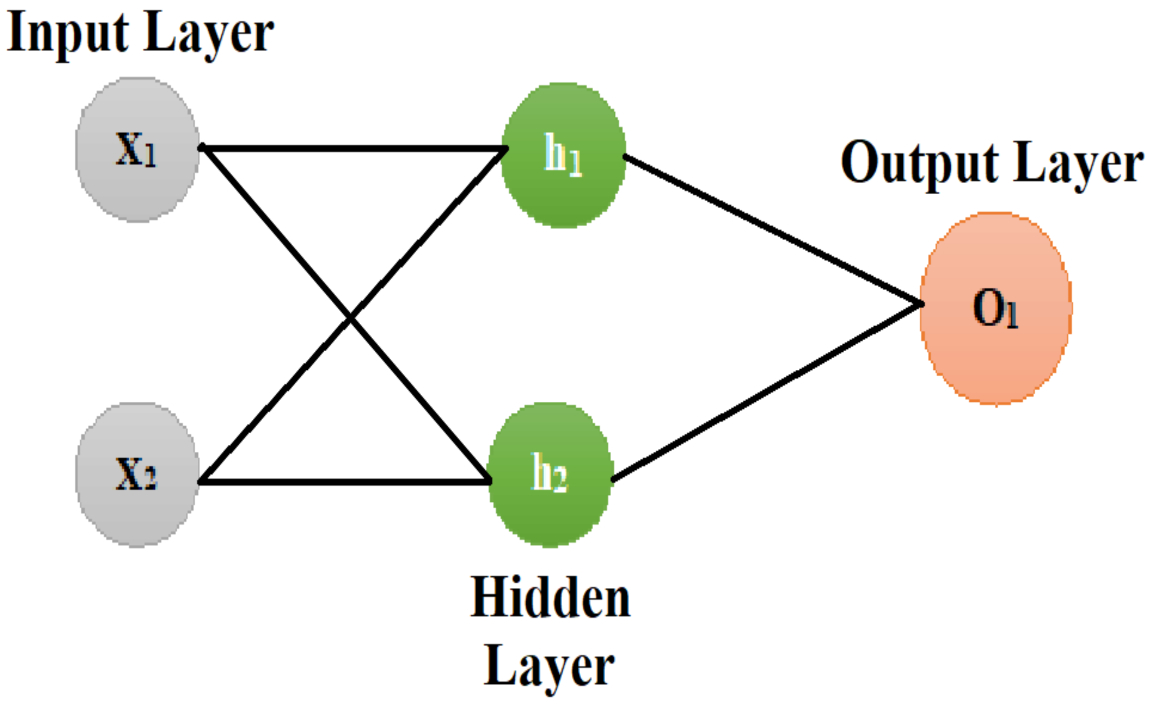
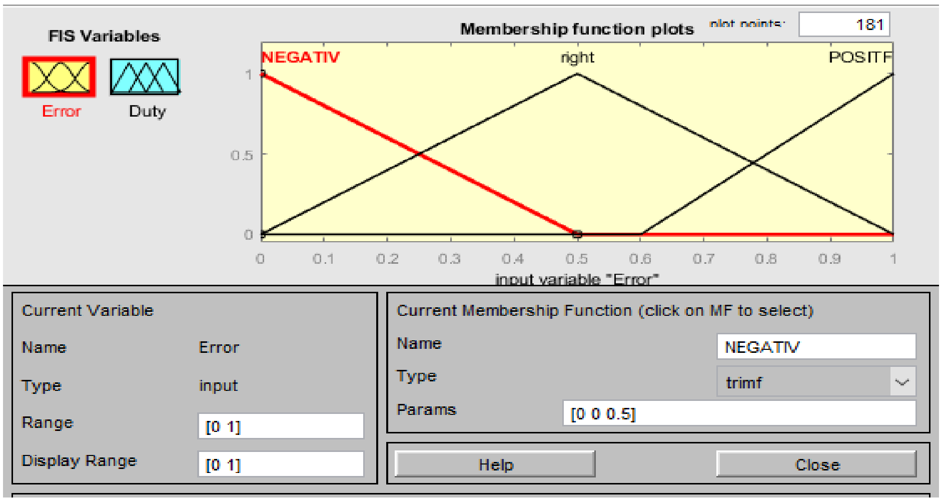


Fig. 6. Feed Forward Network used in ANN Controller

(C) FLC Controller

The fuzzy logic controller (FLC) is a method for automating language control procedures by developing a rule base that regulates the behavior of the system. FLC is one of the most well-researched solutions to distributed power optimization issues. Extensive study has been done on FLC functions to improve their ability to handle issues with expert systems. The basis for the microgrid was the development of a fuzzy logic controller for integration into the MATLAB/Simulink Fuzzy Logic toolbox.

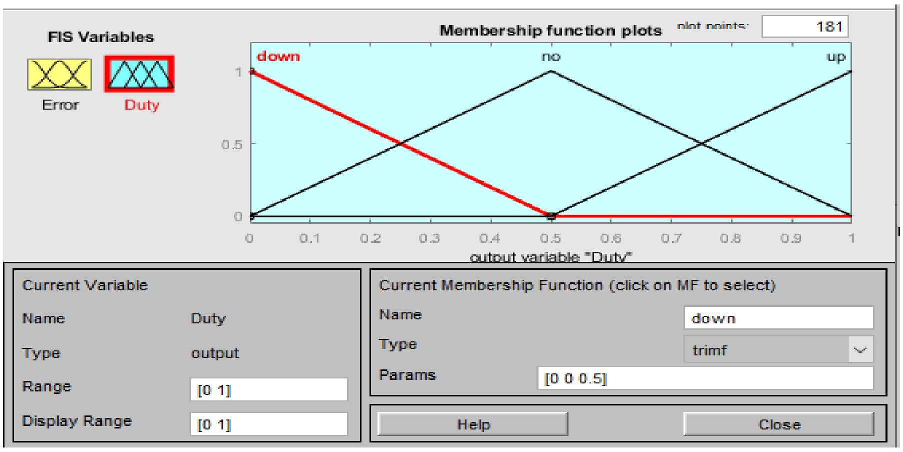
Figure 7 in this article displays the membership functions for input error utilized for microgrid control.As indicated in Figure 8, we took into account three linguistic variables (Negative, Positive, and Right) for the input "Error," and three linguistic variables (Up, Down, and No Change) for the output "Control." For the purpose of charging and discharging the battery, the fuzzy controller generated the proper switching pattern. The fuzzy logic controller was given four inputs to compare the DC bus voltage and a reference voltage. Figure 10 illustrates this by showing how it provides the duty cycle for the PWM block to send the signal to the DC-DC converter.



Current Variable
Name Error
Type input
Range [0 1]
Display Range [0 1]

Current Membership Function (click on MF to select)
Name NEGATIV
Type trimf
Params [0 0 0.5]

Fig. 7Functions for error signal membership.



Current Variable
Name Duty
Type output
Range [0 1]
Display Range [0 1]

Current Membership Function (click on MF to select)
Name down
Type trimf
Params [0 0 0.5]

Fig. 8Output membership function

(D) ANFIS Controller

The creation of a fuzzy logic (FL) and ANN idea for control concerns is a common study area today. This is due, among other things, to the fact that the theory of classical control frequently necessitates a statistical controller design. The accuracy of the mathematical modelling of the plant is often a barrier to controller coordination, especially for nonlinear and complex control difficulties. A better understanding of control as well as more effective control may ultimately result from the introduction of FLCs and neural controllers based on multi-layered NNs. Currently, FL and NN are working together to suggest and advance fuzzy NN (FNN); this combination is frequently referred to as ANFIS.

The ANFIS design is based on the Sugeno Model, which has five layers, two inputs, and one output. Each rule is given a weight that establishes its precedence. With training, the rules and weights can be adjusted to get the desired controller response while minimizing error. The first order Sugeno model can be expressed as,

If the inputs are e = A1 & e = B1, the outcome is u1.

If the inputs are e = A2 and e = B2, the output is u2.

As a result, the output is u = w1u1 + w2u2.

The inputs that have been fuzzified are A and B, and the chosen weight is w. Figure 9 shows the architecture of the ANFIS controller.

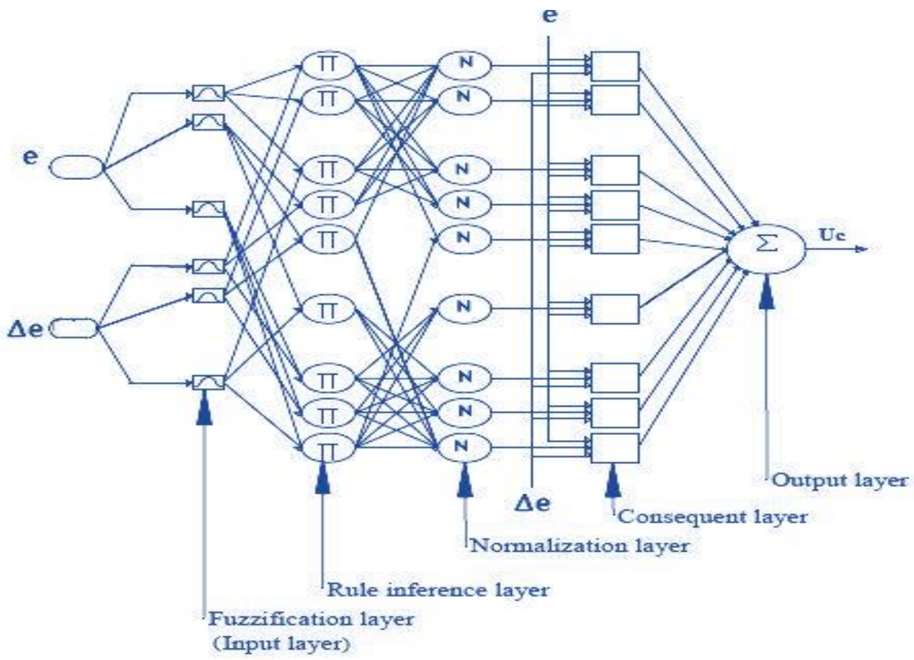


Fig. 9 Structure of ANFIS Model

V. Results and Deliberations

The results of the MATLAB/SIMULINK simulation simulations used to evaluate the effectiveness of the suggested control mechanism are shown in figures 10 through 21.[7] contains a list of simulation-related parameters.

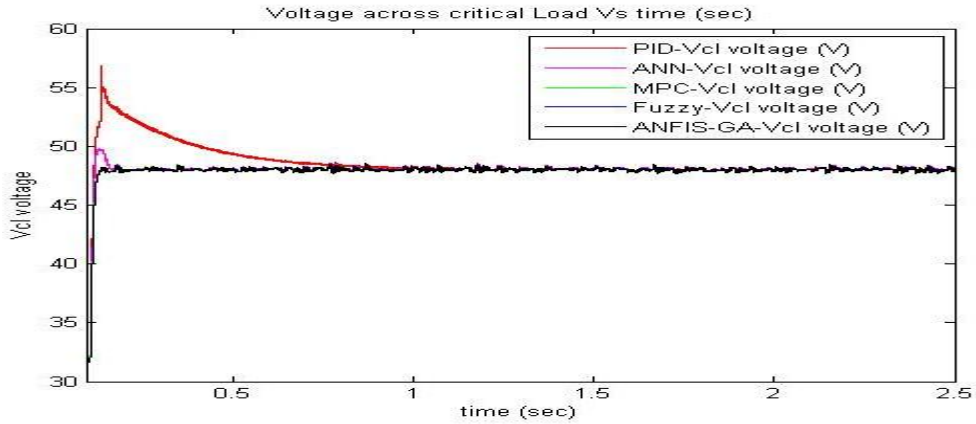


Fig. 10Voltage across CL for all types of Controllers

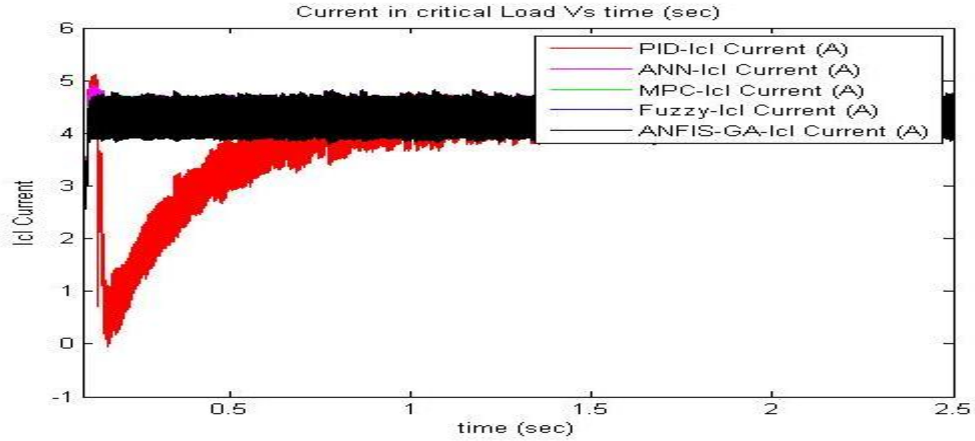


Fig. 11Current through CL for all types of Controllers

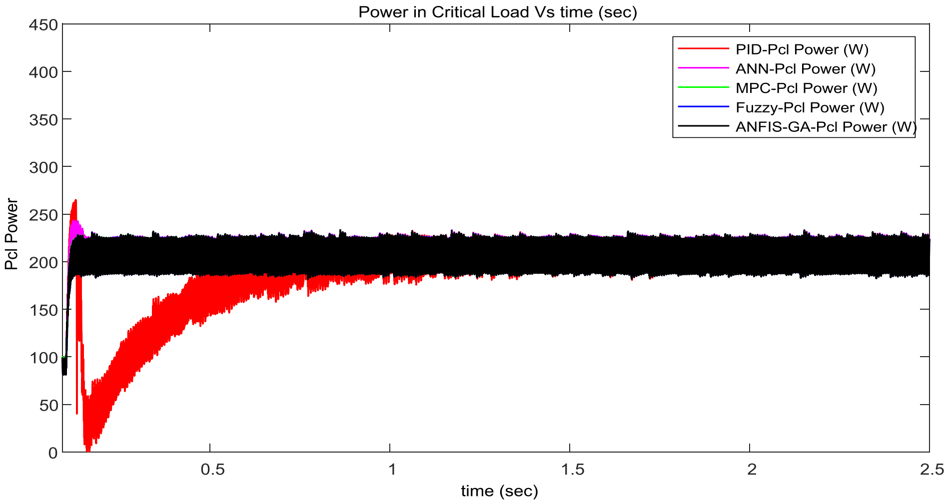


Fig. 12Power in CL for all types of Controllers

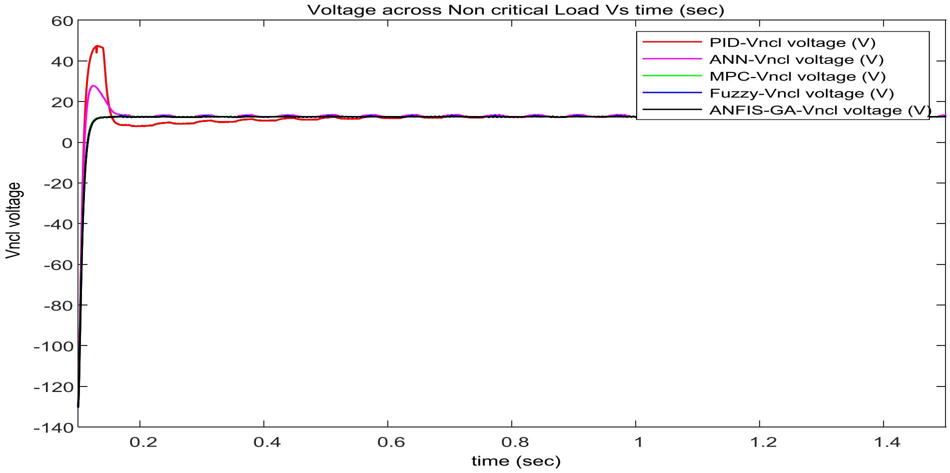


Fig. 13Voltage across NCL for all types of Controllers

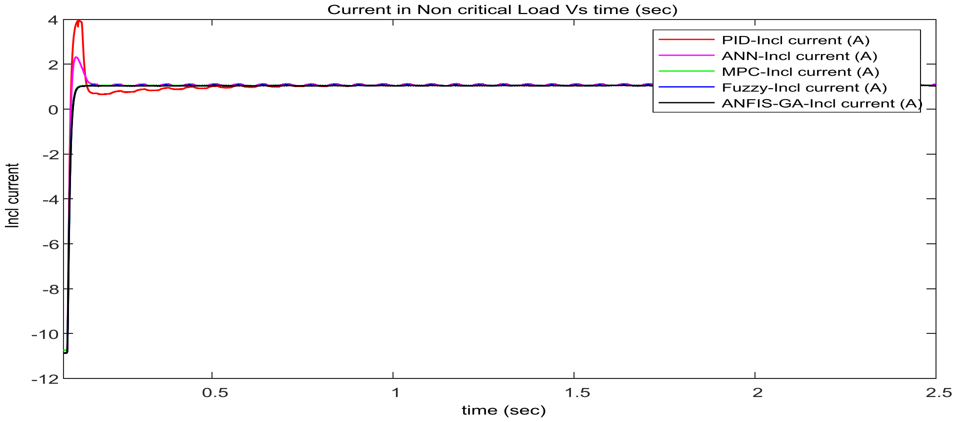


Fig. 14Current in NCL for all types of Controllers

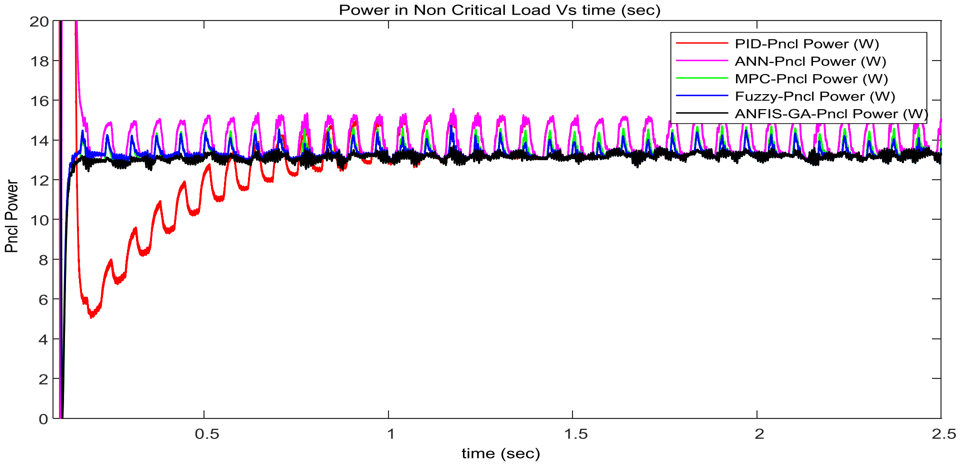


Fig. 15Power in NCL for all types of Controllers

Figures 10 to 15 show the voltage, current, and power output across critical and non-critical loads using different controllers. Figures 10 to 12 show the CL graphs, while Figures 13 to 15 show the NCL graphs. Figure number 16 shows the power oscillations of the ES for each of the controllers. It can be observed that the oscillations are minimum for the proposed ANFIS controller as compared with the other types.

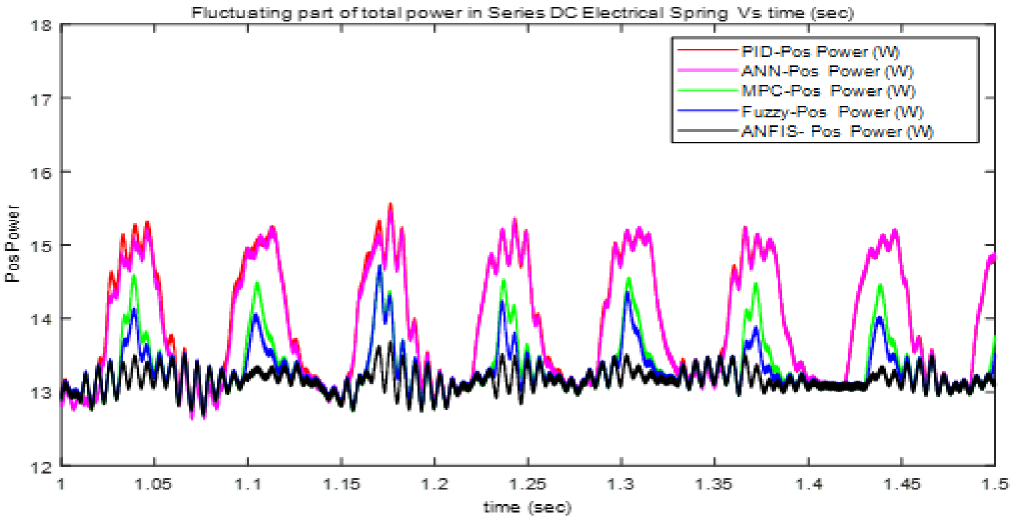


Fig. 16Power Oscillations across ES for all types of Controllers

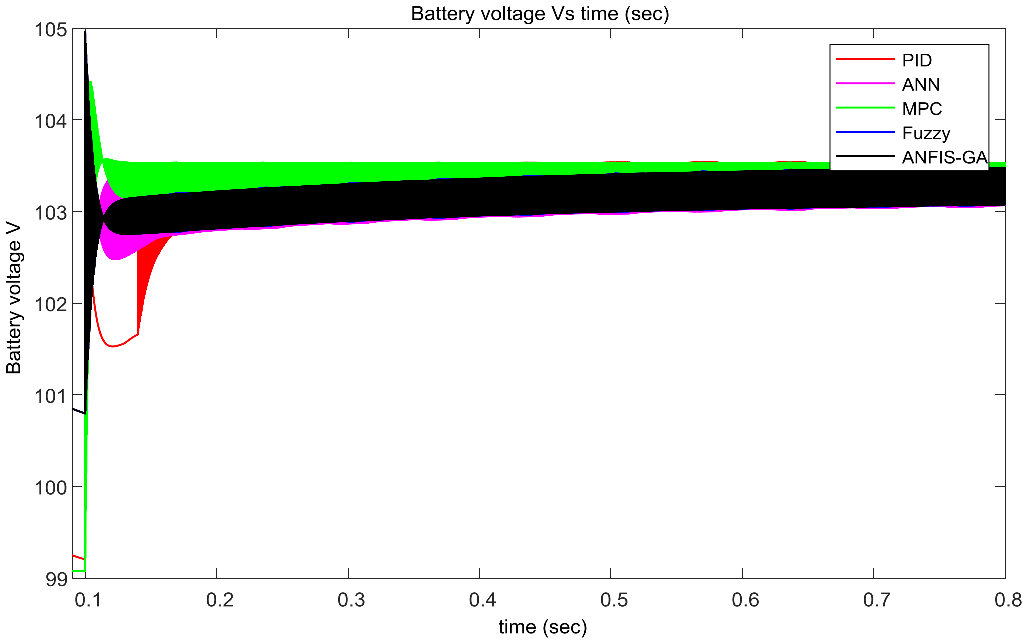


Fig. 17Voltage across the Battery Storage for all types of Controllers

Figure number 17 shows the voltage across the energy storage element battery for the various controller types employed in this paper. The figures 18 to 20 show the regulated quantities as a result of the ES and other controllers. The output voltage across the DC bus is shown in figure 18. Figures 19 and 20, respectively, depict the current and power in the DC bus of the suggested control approaches.

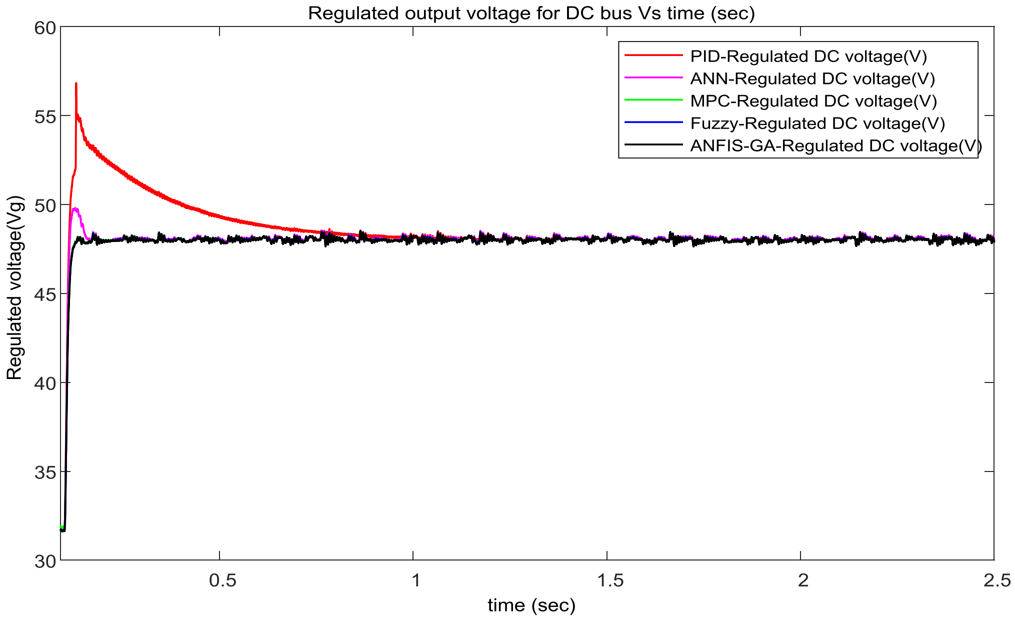


Fig. 18Regulated Output Voltage across DC Bus

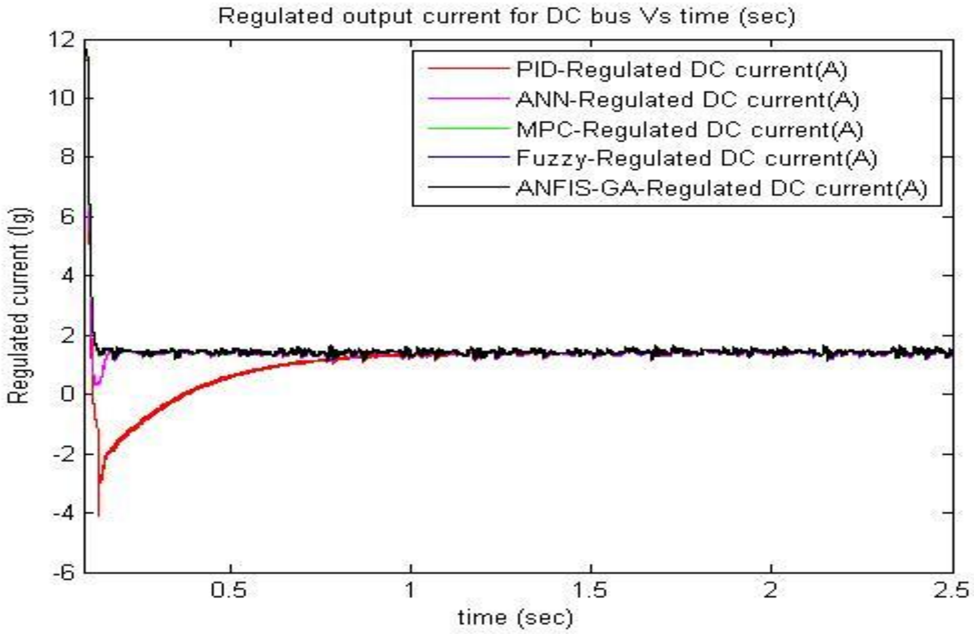


Fig. 19Regulated Output Current in DC Bus

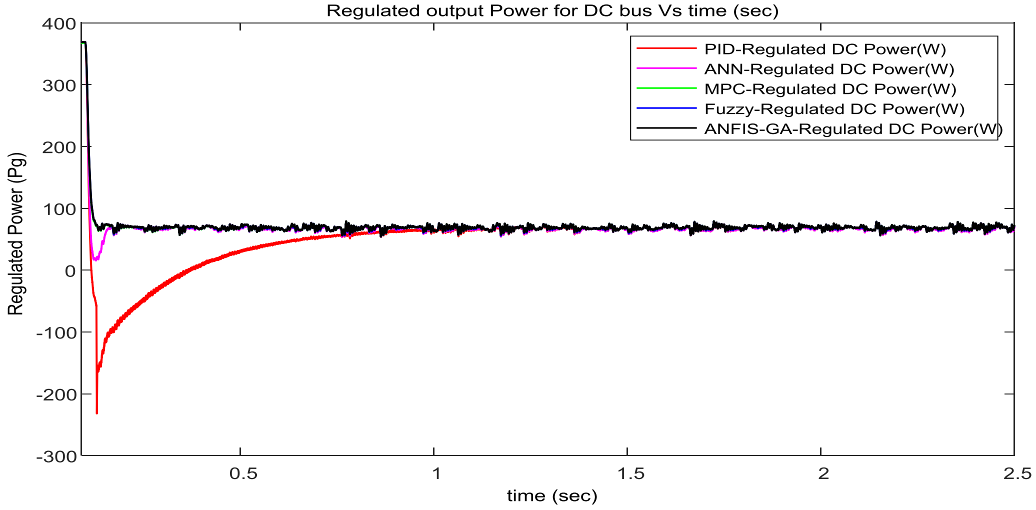


Fig. 20Regulated Output Power in DC Bus

VI. Conclusion

Distribution networks will face considerable voltage shifts that are intolerable for the bus supplying essential loads as a result of the intermittent nature of renewable energy sources and variations in demand. This study provides a successful voltage control method for crucial bus voltage support in a distribution system utilizing ES. This paper proposes a novel control strategy to solve the aforementioned issue in the context of a DC microgrid. The effectiveness of the strategy is highlighted by the results, which show the proposed ANFIS-GA controller to be effective in fixing the issues outlined.The suggested controller offers greater voltage management, less ripple, and harmonic suppression when compared to the FLC, MPC, ANN controller, and conventional PI controller. The simulation was carried out using MATLAB/Simulink, and the outcomes demonstrate the dependability of the suggested controller. We can infer that the ES topology under consideration can control the intermittent nature of the RES in the DC microgrid.

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