International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-11 Issue-5, January 2023

Primary and Secondary Control of Grid Connected Micro Grids using ANFIS Controller

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Abstract: ***The microgrid has been defined to cope with the large penetration of distributed generations (DGs). The microgrid is capable of operating in grid-connected mode (GC) and islanded mode (IS). In microgrid, distributed generations (DGs) are always connected to power network via power inverters. In the Grid Connected mode, DGs commonly acts as current controlled sources to retain a high grid-current quality and a fast dynamic response in the photovoltaic and wind generation systems. However, this current controlled DGs cannot work alone without the voltage/frequency support from utility-grid. Islanding occurs when a portion of a micro-grid becomes electrically isolated, yet continues to be energized by DGs connected to the isolated subsystem. In islanding mode, the inverter-interfaced DGs work as voltage-controlled sources. As system voltage and frequency are not determined by utility-grid, DGs should take care of the voltage/frequency stability. Moreover, the power sharing should be guaranteed according to their individual ratings to avoid circulating currents among DGs. The operation and control of existing utility networks are becoming more and more complex due to the increased interconnection of a DG systems with diverse characteristics. So this paper intends to address the above problems and come out with a proper control strategy using ANFIS controller that could be implemented for the successful operation of a microgrid.***

Keywords: ***Microgrid, Distributed generation, islanded mode, ANFIS Controller***

I. INTRODUCTION

Microgrid is a group of distributed energy resources (DER) and loads and within an electrical boundaries that acts as a single controllable entity with respect to the utility grid. The general architecture of a microgrid is shown in figure 1.1 A microgrid generally operates connected to the grid, but it can break off and operate on its in times power outages. Based on the operation of microgrids they are classified as: remote microgrids, grid-connected microgrids and networked microgrids.

Manuscript received on 30 December 2022 | Revised Manuscript received on 06 January 2023 | Manuscript Accepted on 15 January 2023 | Manuscript published on 30 January 2023.
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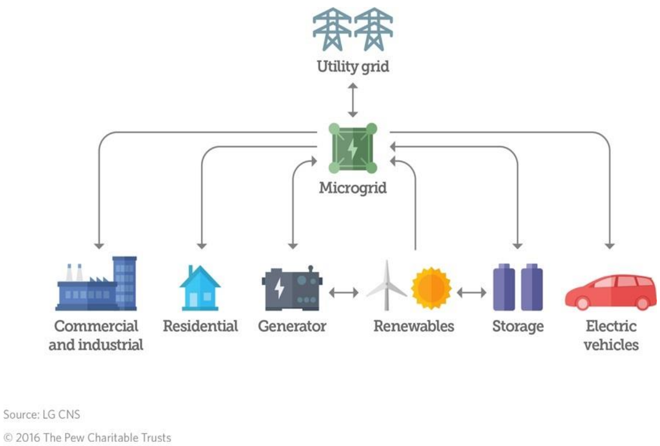

Figure 1: Structure of a Microgrid

Remote Microgrids – generally called as off-grid microgrids, these are isolated from the utility grid and operate in island mode.

Grid-connected Microgrids – They are area connected to the utility grid physically at the point of common coupling (PCC).

Networked Microgrids – called as nested microgrids, it consists of separate DERs and/or microgrids connected to the same utility grid and serve a large geographic area.

The development of the microgrid involves the use of different energy sources, modern converters, grid components, and protection system and communication system and bidirectional power flow management. When interconnection of a microgrid is concerned, switching from grid-connected mode to an islanding mode is a challenging task mainly because of mismatching in synchronization and transients.

Voltage and frequency control are the major functionalities of grid connected mode of operation through demand based power exchange. In island connection, MG is separated from main grid and having the supply to load from energy sources. Proper balance should be provided between demand power and input power in case of hybrid operating condition[14]. To control real power and reactive power, frequency and voltage drop characteristics have to be adapted.

Hierarchical control structure of a microgrid eliminates this issue by involving multiple levels of control. This paper explains various levels of hierarchical control strategies[2][13], which constitute primary control, secondary and tertiary control. The primary control is mainly based on the droop control, secondary control carries out the restoration of voltage and frequency performed by primary and tertiary control maintain the power flow between the micro grid and main utility[4][5].

The hierarchical controller improves the efficiency of the system and provide stability in both grid connected and islanded operation[3]. This paper analyses the primary and secondary control of microgrid. The work is implemented in MATLAB/Simulink software and results are compared in term of voltage, current, frequency, active and reactive power. And also controller performance is compared for two cases viz without controller, and with ANFIS controller.

II. OVERVIEW OF HIERARCHICAL CONTROL

Depending on the MG control structure, islanded and grid connected operation of MG is achieved. For different operating condition corresponding controllers should provide smooth operation. Hierarchical control is used to achieve the smooth operation of MG in grid connected and islanded operation[8]. Hierarchical control structure is shown in figure 2.1. Three control levels are used for obtaining the hierarchical control of the MG.

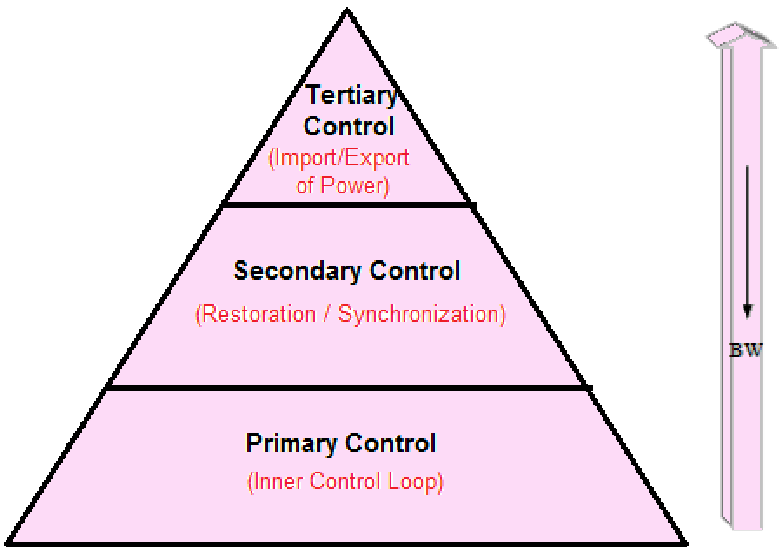

Figure 2.1: Hierarchical control structure

A. Primary Control

Primary control is also known as local control. It is applied to power electronic converters, inverters, synchronous and asynchronous generators. Primary control does not require any communication link. Primary control is the basic control strategy that controls different energy sources under normal working condition of the MG. Primary control uses a droop controller for providing the reference voltage to the inverter[15]. Depending upon the values of voltage and frequency in the inverter, droop controllers find the real and reactive power values of the inverter. Main aim of this primary control level is to achieve the reduction in circulating current by changing the frequency and voltage reference values that is given to the voltage and current control loops. [6]

B. Secondary Control

Second level of control in the hierarchical control is secondary control. Secondary control is used for achieving power quality. By obtaining the points sets from the primary control, it reduces the deviations in frequency and voltage. Comparing to the primary control, secondary controller operates in slower time frame. By improving the power quality, system performance is improved. In grid connected mode, inverters collects the data of voltage and frequency from the main grid. Secondary control needs lower bandwidth communication because they have slower response time. [6]

C. Tertiary Control

Tertiary control is the third layer of hierarchical control technique. This control is responsible for providing reliable, economic and secure operation of MG in both grid connected and islanded mode of operation. Frequency and voltage control, reactive and active power control, restoration of the system, regulation are the basic duties of the tertiary control. [5] It has an important role in the island operating mode of the MG. During the transition from island mode to grid connected mode, tertiary control is used for providing synchronization. Next section explains the outline of proposed methodology.

III. OUTLINE OF PROPOSED METHODOLOGY

In this work, novel kind of control strategy is proposed which should work for both islanded and grid connected mode of operation of the MG. In island mode, MG controls to provide continuous voltage and frequency operation and in grid connected mode MG provide constant injection of real and reactive power. ANFIS controller is used for achieving the hierarchical control for the grid connected mode of operation. The block diagram of proposed system is shown in figure 3.1. The proposed system consist of solar, wind and fuel cell. These renewable sources are directly connected to the MG through DC-DC converter. Voltage Source Inverter is used to connect this renewable resources to grid. ANFIS hierarchical controller is used to provide control of the MG in both grid connected and islanded mode.

Retrieval Number: 100.1/ijrte.E74340111523
DOI: 10.35940/ijrte.E7434.0111523
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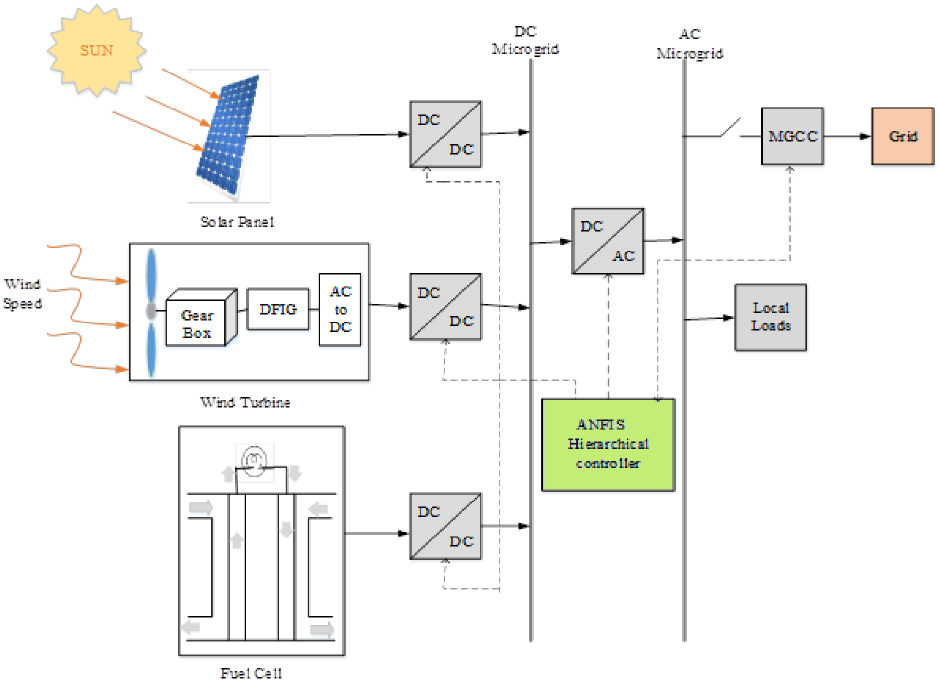

Figure 3.1: Block diagram of proposed system with three renewable resources

A. Modelling of Solar Photovoltaic system

A 40KW solar panel is used in the proposed system. Solar PV equivalent circuit is shown in figure 3.2. Parameter specification of the 40KW solar panel is shown in table 3.1. E_{PV} and i_{PV} are terminal voltage and current in the solar panel. Equations (1) and (2) shows the voltage and current outputs of the PV panel.

$$i_{PV} = \frac{(i_{sh} + K_{Sh}(t - t_r))s}{100} \quad (1)$$

$$i_{PV} = n_p\left(i_{ph} - i_{saturation}\left(e^{\frac{q}{AK}\left(\frac{E_{PV}}{n_s} + i_{PV}R_{series}\right)} - 1\right)\right) \quad (2)$$

Where, photocurrent, short circuit current and electron charge is represented as i_{ph}, i_{sh} and q respectively. K and K_{sh} are the Boltzman constant and temperature coefficient of short circuit current. Surface temperature and reference temperature are expressed in t and t_r.

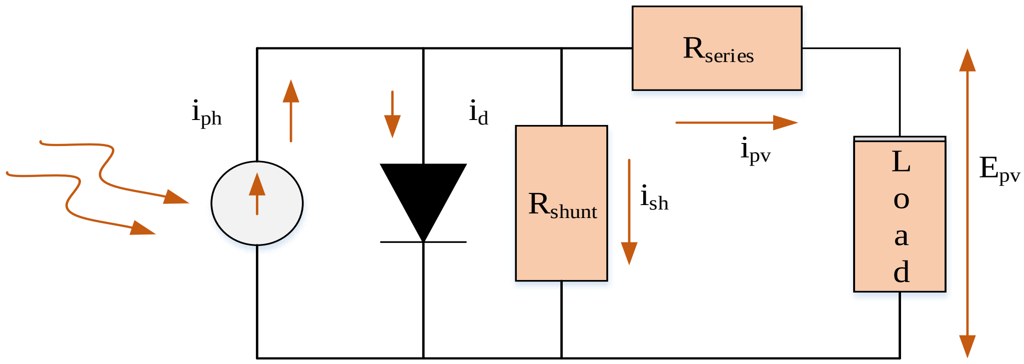

Figure 3.2: Equivalent Circuit of PV panel

Table 3.1: Solar panel specifications

Parameter	Value
Open Circuit Voltage (E_{oc})	403V
Charge(q)	1.602e^{-19}C
Factor of Ideality (A)	1.5
Short Circuit Current (i_{sh})	3.27A
Temperature coefficient of short circuit current (K_{sh})	1.7e-3
Boltzman Constant(k)	1.38e-23J/K
Reference Temperature(t_r)	301.18K
Silicon energy band gap(e_{gap})	1.1eV
No. of cells in series(n_s)	900
No. of cells in parallel(n_p)	40
Reverse Saturation Current(i_{rr})	2.0793e-6A
Solar Irradiance level	0-1000W/m

B. Modelling of wind system

In the proposed work 50KW wind system is designed. Doubly Fed Induction Generator (DFIG) is used to convert mechanical energy into electrical energy. Output power equation of the wind system is expressed as follows.

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$$P_{output} = \frac{1}{2}\left(V_{ws}^{3} C_P \rho A \lambda \beta\right) \quad (3)$$

Where, wind speed, power coefficient, pitch angle, air density is expressed as V_{WS}, C_P, β and ρ respectively. λ and A are the tip speed ratio and area. Table 3.2 provides the specification of the wind system used in the proposed work.

Table 3.2: Specifications of the wind system.

Parameter	**Value**
Nominal output power ($P_{nominal}$)	50KW
Nominal mechanical output power (P_{output})	45KW
Nominal output voltage ($E_{nominal}$)	400V
Nominal DC output voltage ($E_{dc-nominal}$)	800V
Rotor resistance (r_R)	0.005pu
Stator resistance (r_S)	0.00706pu
Rotor inductance (l_R)	0.156pu
Stator inductance (l_S)	0.171pu
Mutual inductance (l_M)	0.9pu
Inertia constant (J)	3.1s
Number of poles (n_p)	6

C. Modelling of Fuel Cell

Equivalent circuit representation of fuel cell is shown in figure 5. 50KW PEM (Proton Exchange Membrane) fuel cell is used in the proposed work.
The output voltage of the fuel cell is determined using the following equation.

$$E_c = \left(-\frac{dE_c}{dt} + 1\right)\left(r_{activation} + r_{concentraion}\right) \quad (4)$$

$$E_{fc} = E - E_c - E_{activation} - E_{ohmic} \quad (5)$$

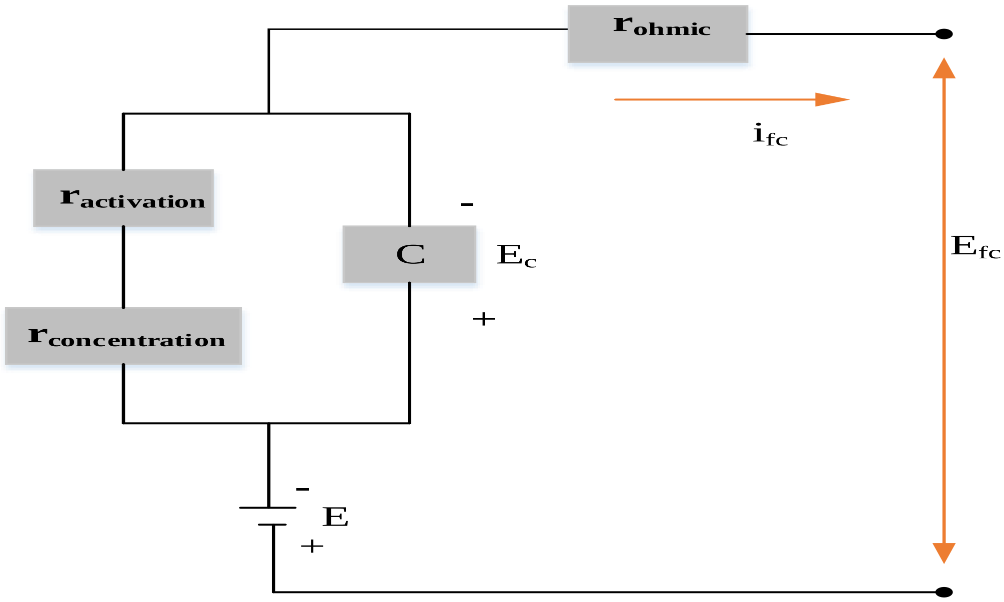

Figure 3.3: Equivalent circuit representation of the PEM fuel cell

Solar, wind and fuel cell are external energy resources that are supporting the MG in islanded mode of operation. Operating modes of MG and hierarchical control structure of algorithm interface ANFIS controller is explained in the next sections.

IV. WORKING OF ANFIS HIERARCHICAL CONTROLLER

Optimization algorithms, Fuzzy Logic (FL) and Artificial Neural Network (ANN) are the different artificial intelligence techniques that are used in wide range of application.[7] FL is mostly used because of its recognizing nonlinear relationship between given output and selected input. ANN improves performance by adopting a particular solution and also it has the neuron connection weight flexibility. Combining the FL and ANN techniques ANFIS controller is formed. Where, input preparation for FL is done by the ANN. Two input one output ANFIS architecture is shown in figure 6. In the ANFIS structure, membership function configuration and their parameters are selected automatically. Based on the fuzzy if-then rule it generate particular input output data. Two fuzzy rules are explained as follows.

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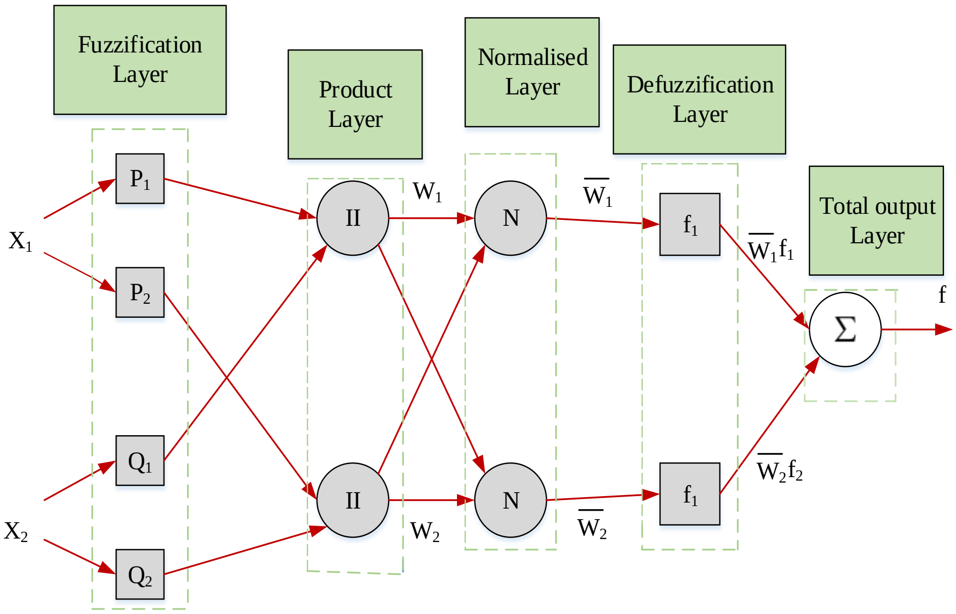

Figure 4.1: Basic architecture of ANFIS

First Rule: If X_1 is P_1 and X_2 is Q_1 then $f_1 = p_1x_1 + q_1x_2 + r_1$

Second Rule: If X_1 is P_2 and X_2 is Q_2 then $f_2 = p_2x_1 + q_2x_2 + r_2$

ANFIS controller consist of 5 operating layers as shown in figure 6. Each layer's output depend on the input (*j*) and product layer (*k*) values and are expressed as $O_{j,1}$.

First layer is the fuzzification layer. This layer is mainly responsible for transforming the given input values to fuzzy values. That fuzzified values should be suitable for the Fuzzy Interference System (FIS). Output of this fuzzification layer is expressed as follow

$$O_{j,1} = \mu P_j\left(X_j\right); j = 1,2 \tag{6}$$

Here, X_j represents the j^{th} node input.

Second layer consist of certain fixed rules. So this layer is called as rule base layer. This layer forms affixed nodes with fixed rules. Fuzzy values from the layer 1 is multiplied in this layer and firing strength is computed from this layer. Layer 2 output is shown in Equation 7.

$$O_{j,2} = W_j = \mu_{P_j}(X_1)\mu_{Q_j}(X_2); j = 1,2 \tag{7}$$

Third layer is similar to the second layer, this layer also consist of fixed nodes. Here also firing strength for each node is calculated by finding the ratio of the firing strength in i^{th} rule to the total addition of all the firing strength. Layer 3 output is shown in Equation 8.

$$O_{j,3} = \overline{W_j} = W_j\left(\frac{1}{W_1 + W_2}\right); j = 1,2 \tag{8}$$

Fourth layer is the consequential layer. Depending on the rules of consequential part, they calculate the output values.

$$O_{j,4} = \overline{W_j}\, f_j \tag{9}$$

Last layer consist of one single node that is used to find the sum of all the other layers from fourth layer. Output value of the fifth layer is expressed as follows.

$$O_{j,5} = \sum_{j=1}^{2} \overline{W_j}\, f_j \tag{10}$$

In these five layer, first and fourth layer are not fixed. The values in these layers can be changed and remaining layers are fixed. Depending on the data from the algorithm, values from the first and fourth layer are changed.

A. Overview of hierarchical ANFIS controller

ANFIS controller operates by providing control to the MG according to operating modes of microgrid[9]. Comparing to the conventional controllers, this hierarchical controller focuses to reduce the MG uncertainties and inaccuracies. It also consist of three control structures namely primary, secondary and tertiary. Block diagram of the ANFIS controller is shown in figure 4.2.

Three control structures are used to control the MG in different operating conditions. From ANFIS controller architecture (figure 4.1), three control levels are used. FL and ANN units are playing an important role in the ANFIS controller. [10]

To provide membership function ANN uses the reference and datasets are obtained by the change in values of frequency, voltage, active power and reactive power. ANFIS controller sends its output to the PI controller for providing switching signals to the inverter[12]. So coefficient of the PI controller is the output of ANFIS controller. . Power converters in the system are used to connect the renewable resources with the MG and utility grid. To transfer the energy between the renewable resources to the MG, converters have to synchronize the MG with power source[11].

So converters are operating in two different modes. They are grid feeding mode and grid following mode.

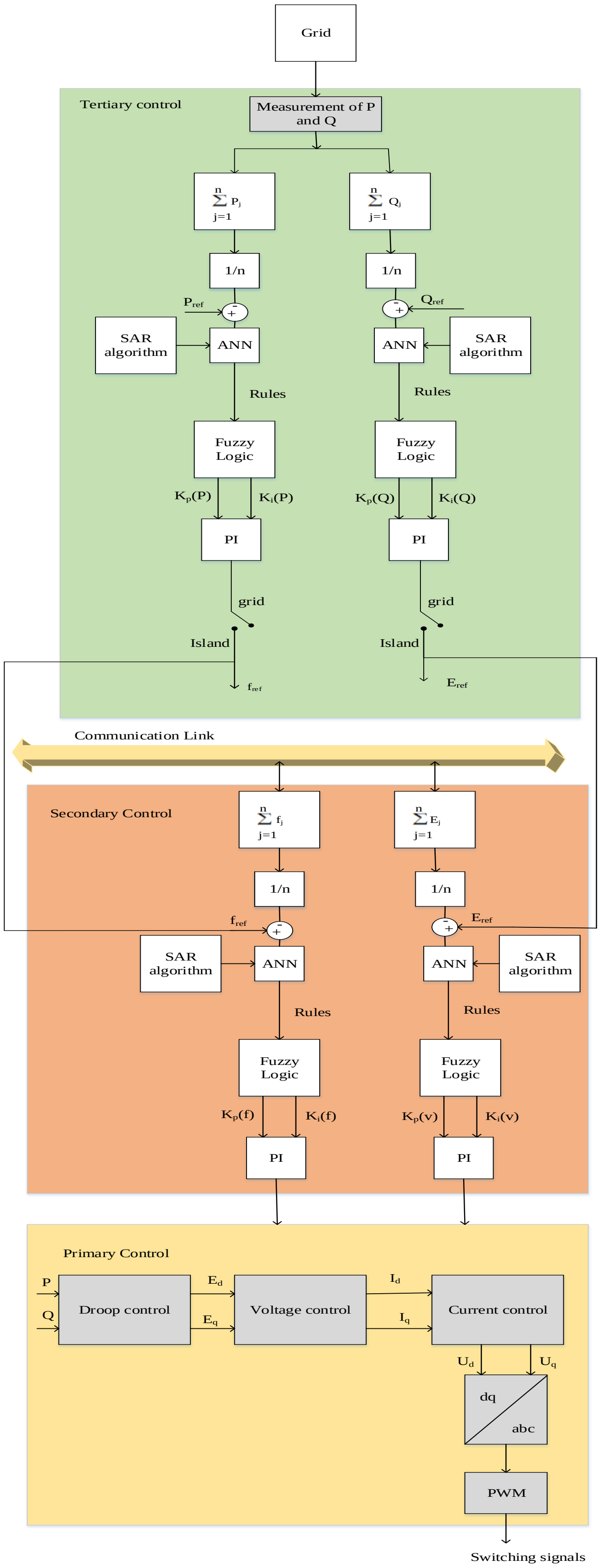

Figure 4.2: Hierarchical control structure of ANFIS controller

In grid feeding mode, converter transfer energy from the renewable source to the MG.

Converter controls the voltage and frequency at the point of common coupling and act as islanding operation. Controller is designed to maintain, frequency and voltage for both grid connected and islanded operation. And also it has to satisfy the power sharing between the renewable sources and different loads and control the power flow at PCC.

Three control strategies are used for controlling the stability in grid connected and islanded operating condition. Primary control gets the active (P) and reactive power (Q) from each renewable resources and supply that to the MG. For island mode of operation, using the droop control active power and reactive power is controlled[10]. Voltage and frequency control is used in the droop control. If primary control is not applied in converter then, when the grid is disconnected converter stops working and after it gets reconnected to grid it starts working. The frequency and voltage equations are explained as follows.

$$f = f_{ref} - \frac{\Delta f\left(P - P_{ref}\right)}{2P_{\max}} \tag{11}$$

$$E = E_{ref} - \frac{\Delta E\left(Q - Q_{ref}\right)}{2Q_{\max}} \tag{12}$$

To obtain the stability of voltage and frequency, secondary controller is used. In order to provide effective secondary communication, Low frequency communication is used. In the secondary control, frequency control and voltage control is used. Frequency control monitor both MG and grid frequency and control it to achieve stability of the system.

$$\delta f = K_P(f)\left(f_{MG,ref} - f_{MG}\right) + K_I(f)\int\left(f_{MG,ref} - f_{MG}\right) + \Delta f_G \tag{13}$$

$$\delta E = K_P(E)\left(E_{MG,ref} - E_{MG}\right) + K_I(E)\int\left(E_{MG,ref} - E_{MG}\right) + \Delta E_G \tag{14}$$

Active and reactive power obtained from the utility grid is compared with the reference value of active and reactive power and the reference voltage and frequency values are given to the MG. Output voltage and frequency equation of the tertiary control is easily understood using the following equations.

$$f_{MG,ref} = K_P(P)\left(P_{G,ref} - P_G\right) + K_I(P)\int\left(P_{G,ref} - P_G\right)dt \tag{15}$$

$$E_{MG,ref} = K_P(Q)\left(Q_{G,ref} - Q_G\right) + K_I(Q)\int\left(Q_{G,ref} - Q_G\right)dt \tag{16}$$

Search and Rescue (SAR) algorithm plays an important role on the ANFIS controller. Because it acts as a key point for the hierarchical operation of controller. It is used for finding the parameters of the ANFIS. In the ANFIS mode, two sets of parameters are adjustable. They are consequent and premise parameters. Consequent parameters fitness value is found by Least Square Method (LSM).

If steady premise parameters are not present, then the training convergence will get slower and the width of the search space will become larger. To reduce this type of problem SAR algorithm is used. SAR algorithm is used to optimize the weight and parameters of the ANFIS controller. Based on the Search and Rescue operation, SAR optimization algorithm is developed. Equation (18) shows the clue matrix that stores the position of the abandoned and hold clues.

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$$C = \begin{bmatrix} Y \\ X \end{bmatrix} = \begin{bmatrix} Y_{11} \cdots\cdots\cdots Y_{1N} \\ \cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots \\ Y_{M1} \cdots\cdots\cdots Y_{MN} \\ X_{11} \cdots\cdots\cdots X_{1N} \\ \cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots \\ X_{M1} \cdots\cdots\cdots X_{MN} \end{bmatrix} \quad (17)$$

Y and X are the human position matrix and memory matrix respectively. In the MN matrices, N is the problem dimension and M is the human number. For Mth human and 1st memory, position of the Nth and 1st dimension is represented as Y_{M1} and X_{1N} respectively. By connecting clues together, humans search and find direction. Social and individual phase are the two different searching procedure used in the search and rescue algorithm.

For each human, clue from the clue matrix is selected to model this social phase. The direction of searching is expressed in the following equation.

$$d_j = Y_j - C_r \quad (18)$$

Where, jth human position, jth human direction for search and rth clue position is represented as Y_j , d_j and d_j respectively. Individual phase is slightly different than the social phase. Here, searching process is not depend upon the position and collected clues. It searching around its current position. This phase also connect different clues and the j th human new position is expressed as follows.

$$Y_j^{'} = Y_j + R(C_r - C_l);\ j \neq r \neq l \quad (19)$$

For each human search, clue matrix is updated. Where, r, l and R is the random integer numbers and random number that is varied from 1, 2n and 0, 1. In the solution space, solution achieve from the individual and social phase is updated and it is modified if they are out of particular position. Then new position is formed for the jth human using the following equation.

$$Y_{j,i}^{'} = \begin{cases} \dfrac{Y_{j,i} + Y_i^{\max}}{2}, if Y_{j,i}^{'} > Y_i^{\max} \\ \dfrac{Y_{j,i} + Y_i^{\min}}{2}, if Y_{j,i}^{'} < Y_i^{\min} \end{cases} \quad (20)$$

After the solution is modified, it is updated and compared with the previous best solution. Final best optimal solution is given as a result. Search and rescue algorithm is used in the ANFIS controller for finding the parameters for ANFIS operation and also optimise weight value. Defining the membership function is the main and important function of ANFIS controller. The data set and training data for ANFIS controller is designed according to the need for the controller in the proposed work. Controller should work for both islanded and grid connected operation. So the SAR algorithm have to minimise the objective function for finding the weight values of ANFIS model. Operating modes of the MG with SAR-ANFIS controller is explained in below subsection.

B. Operating modes of MG

In this paper MG with three renewable system is considered. Hierarchical SAR-ANFIS controller is used for finding the stable operation of MG in its different conditions of operation. Basically MG consist of two operating conditions. They are Grid connected and Islanded operating condition. Overview of Islanding operating condition and use of SAR-ANFIS controller in that particular condition is explained in the following subsections.

C. SAR-ANFIS controller in grid connected operating condition

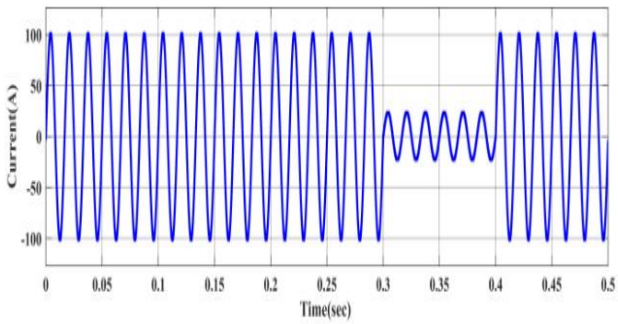
MG has to resynchronize with the grid, when the grid is connected back to the system.[1] By assigning the voltage phasors at the MG and switch which connect the grid with MG and load, synchronization is achieved. Two compensator are added in the real and reactive power controller for achieving the voltage and phase errors. These error values are reduced by providing particular voltage phasors to the controller. The switch get closed after these errors are zero and then grid connects to MG. The results and discussions for the proposed work is explained in the next section.

V. RESULT ANALYSIS

Proposed work is implemented in Matlab/Simulink working platform. Results are taken under three cases of hierarchical control strategies like case (i) without controller, case (ii) with ANFIS controller and case (iii) with SAR-ANFIS controller (proposed). Results of voltage and current analysis are taken under both grid connected and islanding modes of operating conditions. The simulation results and corresponding result explanation is detailed in following three sub cases.

A. Case (i) Without Controller

1) Voltage and Current Analysis (without controller)



(a) Grid Current (Grid Connected Mode)

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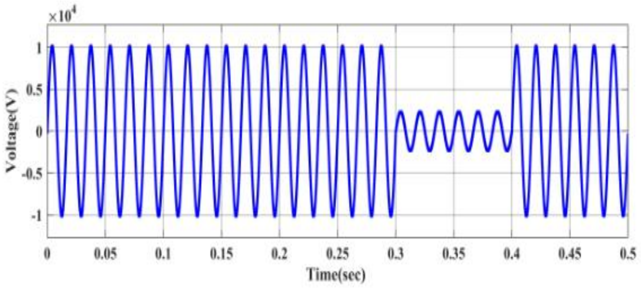
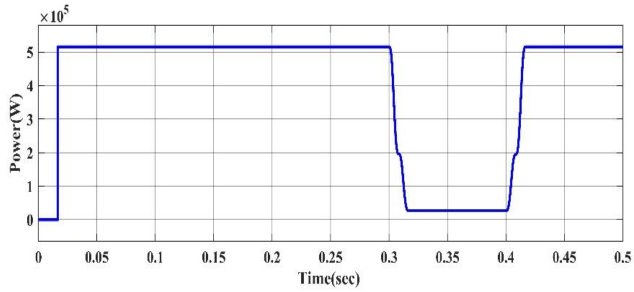


(b) Grid Voltage (Grid Connected Mode)

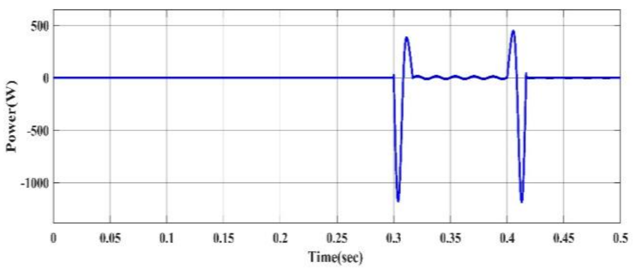
Figure 5.1: Voltage and Current Analysis (without controller)

Figure 5.1 shows the voltage and current results of grid connected mode without controller operation. In figure 5.1 (a) and (b), grid connected mode of current and voltage results are given respectively. Voltage and current are getting disturbed during the time duration of 0.3 to 0.4 seconds. Here, Grid connected voltage varies from -1×10^4 V to 1×10^4 V whereas voltage drop occurs in the range of -0.25×10^4 V to 0.25×10^4 V for 0.3 to 0.4 seconds. Likewise, Grid connected current varies from -100 A to 100 A whereas current drop occurs in the range of -25 A to 25 A for 0.3 to 0.4 seconds. mode voltage varies from -7000V to 7000 V whereas voltage drop occurs in the range of -0.25 V to 0.25 V for 0.3 to 0.4 seconds. Likewise, Islanding current varies from -68 A to 68 A whereas current drop occurs in the range of -25 A to 25 A for 0.3 to 0.4 seconds.

2) Power Analysis (without controller)



(a) Active Power



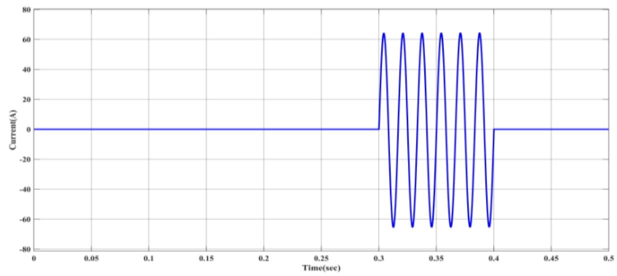
(b) Reactive Power

Figure 5.2: Power Analysis (without controller)

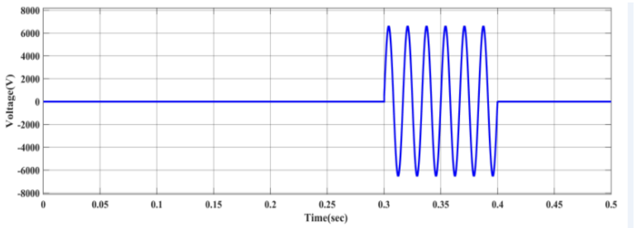
Figure 5.2 shows the active and power analysis under the absence of controller. Here, the power variation occur within the time duration of 0.3 to 0.45 seconds for both active and reactive power analysis. Both active and reactive power flow are maintained constant without any oscillation for remaining time period except 0.3 to 0.45 seconds.

B. Case (ii) With ANFIS Controller

1) Voltage and Current Analysis (with ANFIS controller)

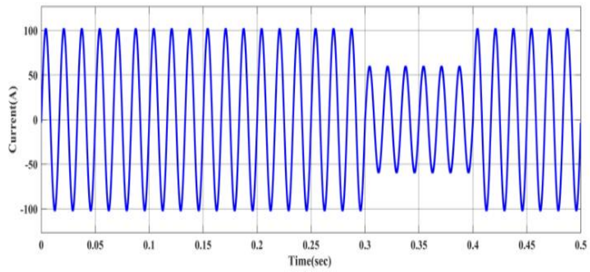


(a) Output Current

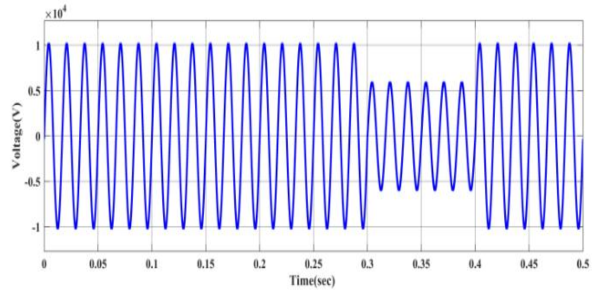


(b) Output Voltage

Figure 5.3: Output of ANFIS Controller



(a) Grid Current (Grid Connected Mode)



(b) Grid Voltage (Grid Connected Mode)

Figure 5.4: Voltage and Current Analysis

(with ANFIS controller)

In order to overcome the voltage and current deviation within the range of 0.3 to 0.4 seconds, ANFIS controller based hierarchical control strategy is applied. After the application of ANFIS controller, amplitude of voltage and current under grid connected mode of operation is enhanced to dominate the deviation process. For that purpose, controller generates current and voltage in the range of -62 A to 62 A and -6500 V to 6500 V respectively for 0.3 to 0.4 seconds as shown in In figure 5.3 (a) and (b), . In figure 5.4 (a) and (b), grid connected mode of current and voltage results are given respectively. Voltage and current generation getting disturbed in the time duration of 0.3 to 0.4 seconds.

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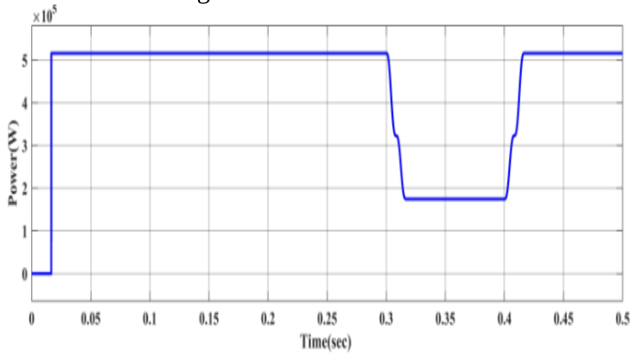
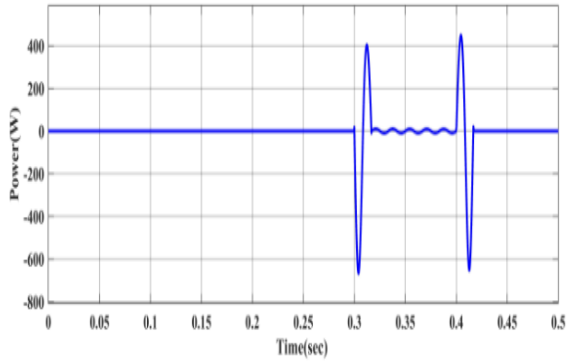
Here, Grid connected voltage varies from -1×10^4 V to 1×10^4 V whereas voltage drop occurs in the range of -0.6×10^4 V to 0.6×10^4 V for 0.3 to 0.4 seconds. Likewise, Grid connected current varies from -100 A to 100 A whereas current drop occurs in the range of -60 A to 60 A for 0.3 to 0.4 seconds. in the range of -37 A to 37 A for 0.3 to 0.4 seconds.



(a) Active Power

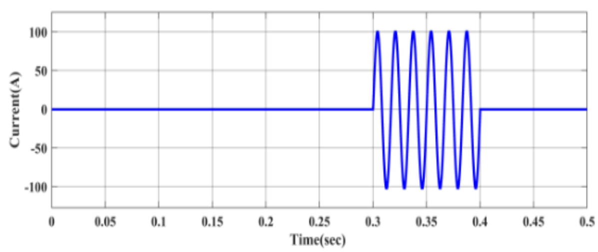


(b) Reactive Power

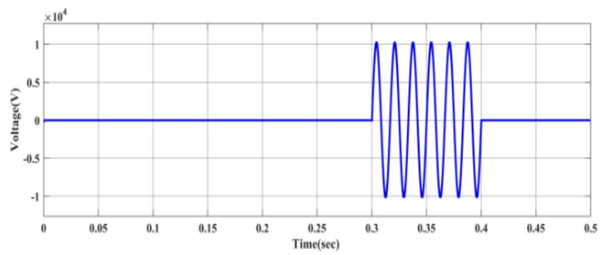
Figure 5.5: Power Analysis (with ANFIS controller)

Figure 5.5 shows the active and power analysis under the absence of controller block. Here also, the power variation occur within the time duration of 0.3 to 0.45 seconds for both active and reactive power analysis. Both active and reactive power flow is maintained as constant without any oscillation for remaining time period except 0.3 to 0.45 seconds.

C. Case (iii) With SAR-ANFIS Controller

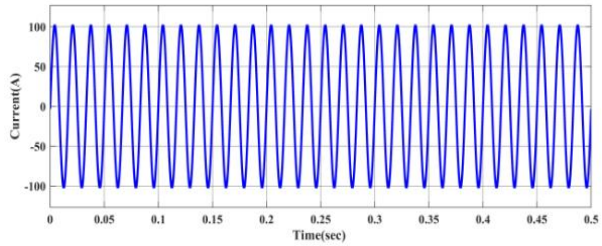


(a) Output Current

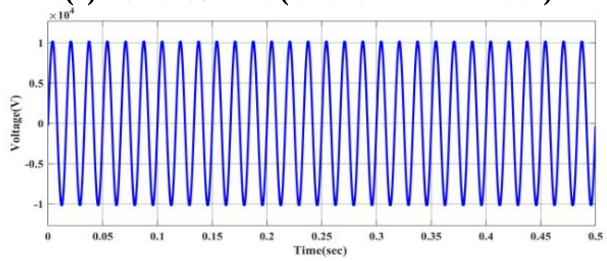


(b) Output Voltage

Figure 5.6: Output of SAR-ANFIS Controller



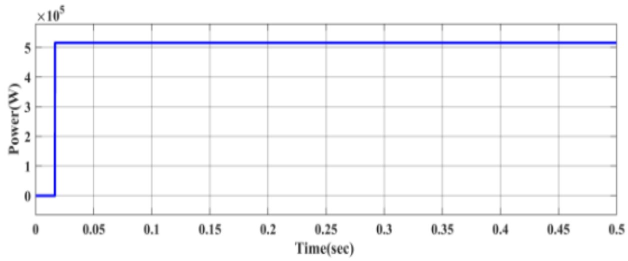
(a) Grid Current (Grid Connected Mode)



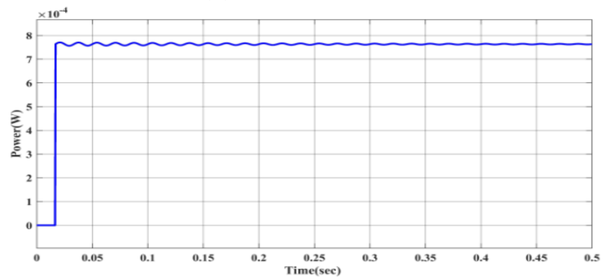
(b) Grid Voltage (Grid Connected Mode)

Figure 5.7: Voltage and Current Analysis (with SAR-ANFIS controller)

In order to overcome the voltage and current deviation within the range of 0.3 to 0.4 seconds, SAR-ANFIS controller based hierarchical control strategy is applied. After the application of SAR-ANFIS controller, amplitude of voltage and current under both grid connected and islanding mode of operation is enhanced to dominate the deviation process. For that purpose, controller generates current and voltage in the range of -100 A to 100 A and -1×10^4 V to 1×10^4 V respectively for 0.3 to 0.4 seconds. In figure 5.7 (a) and (b), grid connected mode of current and voltage results are given respectively. Voltage and current generation getting disturbed in the time duration of 0.3 to 0.4 seconds. Same is occurred for islanding mode of voltage and current results also. Here, Grid connected voltage varies from -1×10^4 V to 1×10^4 V whereas grid connected current varies from -100 A to 100 A with no deviation in for 0.3 to 0.4 seconds.



(a) Active Power



(b) Reactive Power

Figure 5.8: Power Analysis (with SAR-ANFIS controller)

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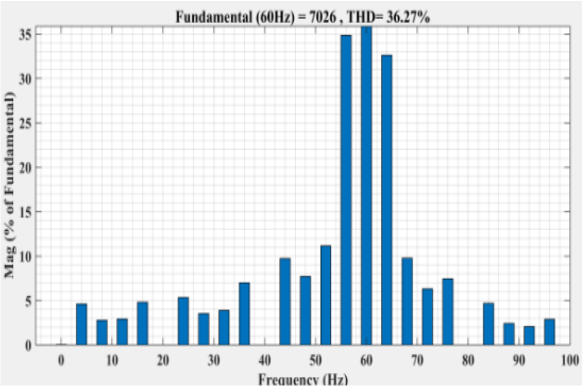
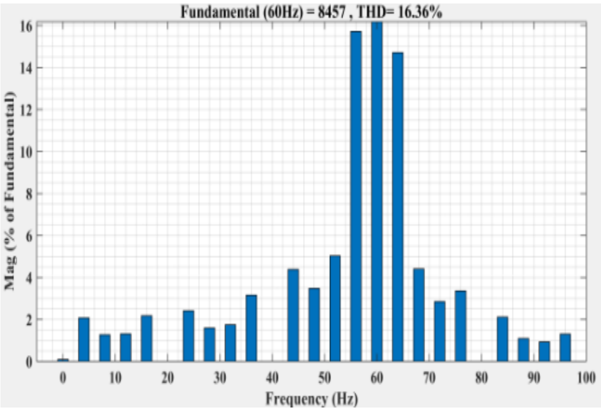
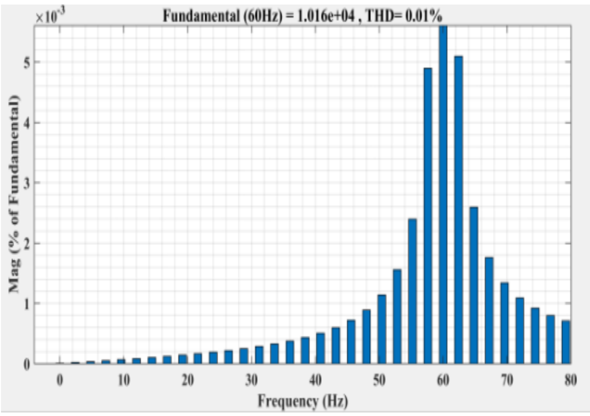


(a) Without Controller



(b) With ANFIS Controller



(c) With SAR-ANFIS Controller

Figure 5.9: THD Analysis

Figure 5.8 and 5.9 shows the power and THD analysis of proposed work respectively. Both active and reactive power is calculated with respect to time variation and there is no deviation within 0.3 to 0.45 seconds while using proposed controller. Likewise, THD values of comparative analysis is shown as 36.27%, 16.36% and 0.01% for without controller, with ANFIS controller and with SAR-ANFIS controller respectively. From this analysis, it is proved that the proposed hierarchical control strategy performs better than other comparative methods.

VI. CONCLUSION

Control of micro grid is difficult because of the changes in the outcomes of RES. For the sake of optimizing micro grid control, development of hierarchical control strategy became vital concept in recent days. In this work, hierarchical control strategy is developed while integrating RES with micro grid. Combination of ANFIS controller and SAR algorithm is used for the development of hierarchical control strategy. With the help of Matlab/Simulink implementation, results like current, voltage, THD, active and reactive power are calculated. From this analysis, it is proven that the proposed work given better controlling performance than conventional models.

DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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DOI: 10.35940/ijrte.E7434.0111523
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