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Harmonic Mitigation of PV Based Grid-Connected Hybrid System using ANFIS

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Abstract: ***Deriving quality power is the vital problem in power system network. The main focus of the paper is to reduce the power quality issues mainly the reduction of harmonics using source compensation technique. This paper proposes a grid integrated hybrid system with ANFIS. This hybrid system mainly consists of PV panel, inverters, fuel cell, batteries and filters. Based on working principle and characteristics of the proposed hybrid system, the composite control strategy about active power, reactive power and harmonic suppression is proposed. The composite control strategy are of two loops ie., a single closed-loop control response active power and reactive power, double closed-loop control responses harmonics. Both balanced source condition and unbalanced source condition for three phase system are developed by Simulink model. The balanced and unbalanced source performance is done by using ANFIS. PI controller and ANFIS are compared with their Simulink results. Simulation results shows the performance of ANFIS is better than PI controller.***

Key words: ***Power quality, ANFIS controller, Harmonics, PV, Inverter, Grid.***

I. INTRODUCTION

The power generation will produce excess amount of power demand in developing countries. In case of power systems, if the load is linear load then there will be no harmonics because the production of sinusoidal waveform at source side is same as loads side. For suppose if the non linear load is present more amount of harmonics will present, the sinusoidal waveform will fluctuate above and below the reference axis. Generally the voltage source inverters can be used for harmonic reduction and equal amount of reactive power sharing is minimized by the active power filter connected in parallel with the system for reduction of non linear load currents. The APF is classified into two types. they are Shunt and Series.

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Shunt APF is more preferred than series, shunt capacitor is used to compensate the lagging load current flow when inductive load is connected. shunt inductor is used to compensate the leading load current flow when capacitive load is connected.
Harmonics are the major issues power quality and they are caused by nonlinear loads such as converters, choppers, inverters etc. The nonlinear loads which produces harmonic currents are injected into the supply system. As it seem advantageous, the power obtained from PV panel to the inverter involved in the process of regulating various power quality issues. comparing harmonic filtering and pure filters from the both viability and economical point of view, harmonic filtering are more attractive than pure filters which reduces overall efficiency of the system. There are many techniques to mitigate these harmonic currents. One of the major technique is usage of filters. Here the filters are classified as active and passive filters. Resistor, Inductor and Capacitor elements comes under passive filters. Active Power Filters (APF) are made up of power electronic devices when compared to active filters and passive filters are simpler and cheaper were considered for harmonic mitigation .In passive filter, single tuned filter are most commonly used. It is very cheap and easy to design and creates a low impedance path for the corresponding designed order of harmonics and mitigates it.
XianyongXu, Lu Fang, Xianghu Xu, Xinjie Lu [1] proposed the composite control strategy about active power, reactive power and harmonic suppression. The hybrid system have an effective to improve power factor, supply active power for loads and suppress harmonics of micro-grid. Sen Ouyang1, Qingpai Ke1*, Wenjie Ma1 [2] proposes a new control strategy for PV grid-connected inverter with harmonic suppression is proposed. It makes the PV inverter not only can generate electricity, but also has harmonic suppression function. harmonic suppression strategy based on the virtual resistance method can suppress the voltage harmonics effectively. Wajahat Ullah Tareena,, Saad Mekhilefa, Mehdi Seyedmahmoudianb, Ben Horanb [3] presents the performances of the system is affected by grid-connected systems, several voltage and current harmonics. Active power filters (APFs), static var generators, and passive filters (PFs) are the effective solutions to these problem. Nguyen Duc Tuyen, Goro Fujita [4] proposes, to design the PV-APF controller the instantaneous power theory is applied, this paper presents reliable performances and by using maximum power point tracking, dc/dc boost converter to extract maximum radiation power and dc/ac voltage source converter act as an APF.

Zhang Lisheng, Li Quan [5] by using Fuzzy Logic Algorithm the Maximum Power Point Tracking (MPPT) of a PV system under solar radiation and variable temperature conditions are discussed. So, it is necessary to operate the PV system at any weather conditions with maximum efficiency by tracking its maximum power point. An Luo, Zhikang Shuai, Wenji Zhu [6] proposes reactive power is compensated dynamically to mitigate harmonics generated by nonlinear loads and the TCR , as well as suppress the possibility of resonance between the SVC and the grid.

Rosa A. Mastromauro, Marco Liserre, and Antonio Dell'Aquila [7] presents survey on three of the main control issues for single-stage PVS: MPPT and current and voltage control.MPPT algorithms aims at maximizing the power extraction from the PV panels. It can be executed with low switching frequency or better performance can be obtained in case of floating-point implementation. Ding Ming, Wang Min [8] introduces the revolutionary approach of DGs, which will change the electric power systems operate along with their types as well as operating technologies. This paper discusses some definitions of DGs and their operational constraints which helps in understanding the regulations and concepts related to DGs. Suresh Mikkili and Panda A.K [9] discussed PI based fuzzy controller for 3 phase 4 wire shunt active filter reduces current harmonics. In [10-14] different topology of active power filters are proposed for reduction of harmonics in various balanced and unbalanced 3 phase 4 wire system.

This paper discusses the improvement of power quality by reducing current harmonics with hybrid harmonic filters in a PV hybrid system. Using the APF has advantage of suppressing harmonic current and reactive current. In this paper, the ANFIS and FLC are used for controlling the active filter. The results of filter and Total Harmonic Distortion (%THD) are analyzed by comparing conventional PI controller. The proposed method offers an efficient control and gives better dynamics response and the results are compared with different membership functions.

II. HYBRID SYSTEM

In this hybrid model ANFIS controller is used for better performance. The fuzzy rules and membership functions can be basically implements the neural network in a fuzzy neural hybrid model. As shown in Fig. 1, the micro grid photovoltaic generation inverter grid-Connected operating and harmonic elimination integrate device is mainly composed of Photovoltaic array batteries, Photovoltaic output filter, three phase voltage source inverter (VSI), output filter and passive power filters. Photovoltaic array batteries are connected to the DC Bus Capacitor through two diodes D_1 and D_2.DC side bus filter formed by L_f and C_f makes the DC side voltage more stable and smooth. Photovoltaic array batteries can be connected to DC side capacitor by the $K1$. The three-phase voltage source inverter is shunted to the power grid through the filter composed by L_4 and C_4. The capacitor C_3, inductor L_3 and the capacitor C_2, inductor L_2 are series connected to form the 5th and 7th single tuned passive powerfilter (PPF) respectively. These two groups of PPFs are connected to micro grid between the nonlinear load and inverter.

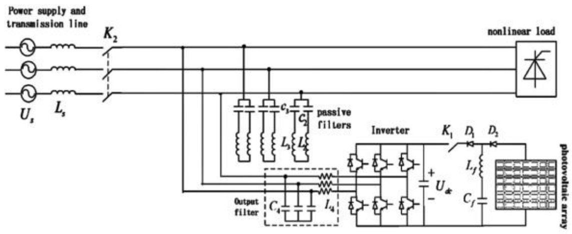

Fig 1. Structure of novel hybrid system.

By controlling $K2$, the photovoltaic generation system can operate in island operating mode or parallel running with the public grid. When $K2$ is turned off, photovoltaic generation enters island operating mode, and the nonlinear load is supplied by photovoltaic generation system. Meanwhile, when photovoltaic generation is connected to the micro grid through three-phase inverter, the active and reactive power can be compensated and the characteristic 5th and 7th harmonics can be suppressed by PPFS. When $K2$ and $K1$ are both turned on in the day time, photovoltaic array batteries is connected with DC side capacitor of the inverter. The nonlinear load is mainly supplied by public grid and photovoltaic generation system. PPFs are applied to eliminate the character 5th and 7th harmonics. When K1 is turned off at night, Photovoltaic array batteries is disconnected with the inverter, and the load only be supplied by the public grid. Thus, the three-phase VSI and PPFs form the hybrid active power filter (HAPF). The hybrid active power filter dynamically compensates the reactive power and eliminates the harmonics, according to real-time detecting the harmonic in power grid and the reactive power of the nonlinear load.

III. CONTROL STRATEGY OF THE HYBRID SYSTEM

As shown in Fig. 2, when the photovoltaic generation system is in island operating mode, the switch K_3 is turned to left and switch $K4$ is turned to upside in this control diagram. According to the output voltage $u_{pv}$and current signal $i_{pv}$of Photovoltaic array batteries, the DC side voltage V_e can be calculated by using maximum power point tracking control method (MPPT), and then the V_e is sent to the first normal ANFIS controller to get the current signal $i^*_d$of the d-axis. Its discrete control expression is shown as follows:

$$i^*_d(k) = i^*_d(k-1) + k_{p1}[V_e(k)-V_e(k-1)] + k_{i1}[V_e(k)]\text{….(1)}$$

The error Δi_d of the feedback current i_d and its reference current i^*_d is taken as the input signal of the third ANFIS controller. The output signal $i_{d1}$of the third ANFIS controller is considered as the active power reference current signal which the inverter needs to produce. In the same way, the error Δi_q of feedback current i_q and its reference current i^*_d is regarded as the input signal of the fourth normal ANFIS controller. And its output signal $i_{q1}$is as the reactive power compensation current. So there are only used Passive Power Filter (PPF) to filter the 5th and 7th harmonics. When photovoltaic generation system is connected to public grid:

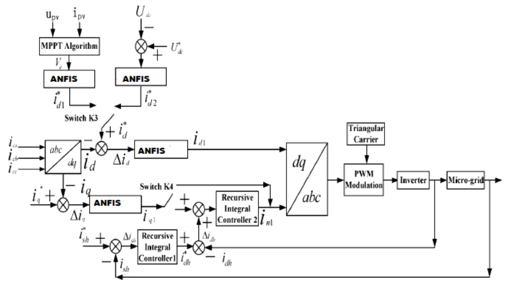

Fig 2. Control block diagram of the hybrid system

In the day time, the switch K_3 is turned to left and the K_4 is turned to underside. The control mode of active and reactive power is the same as island operating mode. The discrete control expression of the outer loop and inner loop are shown as follows:

$$i^*_{dh}(k) = i^*_{dh}(k-1)+k_{p10}[\Delta i_{sh}(k)-\Delta i_{sh}(k-N)]+k_{i10}[\Delta i_{sh}(k)] \quad \ldots(2)$$

$$i_{n1}(k) = i_{n1}(k-1)+k_{p12}[i_{q1}(k)+\Delta i_{dh}(k)-i_{dh}(k-N)-i_{q1}(k-N)]+k_{i12}[\Delta i_{dh}(k)+i_{q1}(k)] \quad \ldots(3)$$

At this time, PPFs are used to filter 5^{th} and 7^{th} harmonics; meanwhile, other harmonics are suppressed by active power filter.

At night, the switch K_3 is turned to right and K_4 is turned to underside.

The voltage error signal $\Delta U_{dc}$of the DC side capacitor issent to the second normal ANFIS controller. The output signal i^*_d of controller is took as reference current signal of the d-axis.Its discrete control expression is shown as follows:

$$i^*_d(k) = i^*_d(k-1)+k_{p2}[\Delta U_{dc}(k)-\Delta U_{dc}(k-1)]+k_{i2}[\Delta U_{dc}(k)] \quad \ldots(4)$$

At this time, the reactive power and harmonic control branches are the same as Grid-Connected operating control method in the day time.

IV. PROPOSED ANFIS CONTROLLER

The ANFIS has the advantage of both Fuzzy and Neural network . ANFIS is a type enhanced version of neural network that depended on Takagi-Sugeno fuzzy surmising framework. The frame work of fuzzy surmising is used to utilize a given informational index, The tool section capability of ANFIS develops a framework (FIS) in which parameter tuning is taking place. To obtain an enhanced design of ANFIS controller the information is generated from the PI controller, the same information is secured in the MATLAB workspace. At that point the ANFIS order window is opened by composing ANFIS supervisor in the principle MATLAB window. Now the recent information secured in workspace is arranged in the ANFIS order window so as to give an improved ANFIS design as in Fig.3.

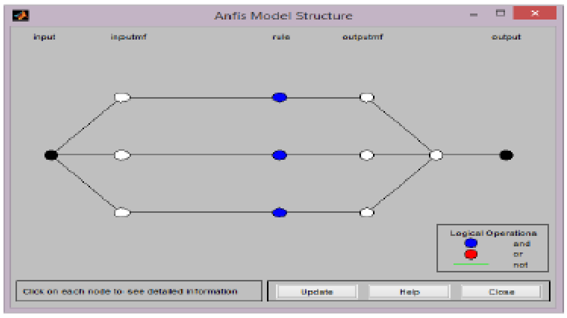

Fig.3. Optimized ANFIS Architecture

In Fig.4 shows schematic of the ANFIS based control architecture. In ANFIS architecture the node functions of each layer is discussed as follows:

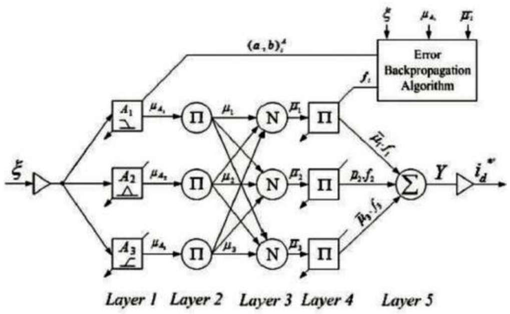

Fig.4. Schematic Of The ANFIS-Based Control Architecture.

The blunder between reference DC-connect voltage and genuine DC-interface voltage (ξ=Vdc*-Vdc) is given to the Neuro-fuzzy controller and a similar mistake is utilized to tune the pre-condition and ensuing parameters. The dynamic power current segment (id*') given by the control of DC-connect voltage, which is additionally adjusted to assess dynamic current segment infused from RES (iRen).

Layer I: This layer consists of input variables (membership functions), viz., input 1 and 2. This layer supplies the input values to the next layer, where i =1 to n. this is layer called as fuzzification layer. The triangular or bell-shaped Membership function can be used to decrease the calculation load as appeared in Fig. 5.

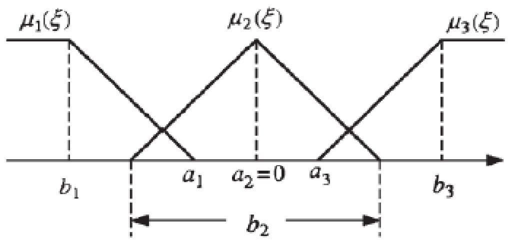

Fig.5 Fuzzy Membership Functions.

Layer II: Every hub in this layer is a hover marked as Π. which increases the approaching signs and acts as the inputs to the next layer. μi= μAiμBi=1,2,3,… But for our situation there is just a single info, then this layer can disregarded and the yield of layer 1 will straight forwardly go to the layer 3. This layer is membership layer.

Layer III: Every hub in this layer is spoken to as circle.

This layer computes the activation level of each rule and calculates each node.

$$\overline{\mu_i} = \frac{\mu_i}{\mu_1 + \mu_2 + \mu_3}$$

Layer IV**:** In this layer every node acts as node function

$$O_i = \overline{\mu_i}\,.f_i = \overline{\mu_i}\left(a_0^i + a_1^i \varepsilon\right) \; i=1,2,3$$

where the parameters (a^i_0, $a^i_1 \varepsilon$) are tuned as the capacity of info (ξ).In this layer the parameters are likewise alluded as ensuing parameters.

Layer V: This layer is likewise called yield layer or outer layer which registers the yield as given underneath: The output from this layer is increased with the normalizing element to get the dynamic power current part. This is layer called as Defuzzification layer.

V. RESULTS AND DISCUSSIONS

Here there are three cases discussed:

CASE:1 PV Array Battery Connected Proposed Hybrid System with PI Controller

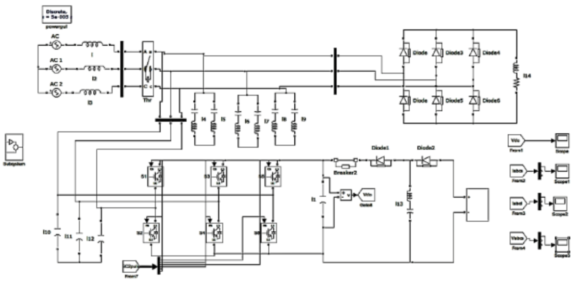

Fig.6 SIMULINK diagram of Photovoltaic Array Battery is Connected to the Proposed Hybrid System

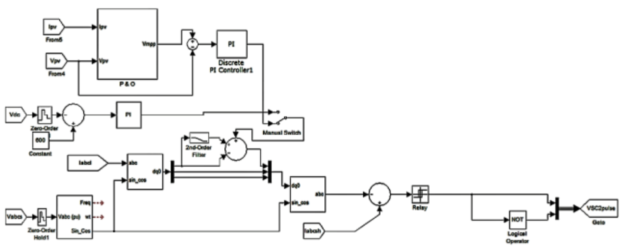

Fig .7 Controller subsystem with PI controller

When the PV array battery is connected to the proposed hybrid system, the simulation results are shown in Fig.8-10 I_{la}, I_{sa}, U_{sa}, U_{dc} is the load current, the grid side current, the grid side voltage, the DC side capacitor voltage of inverter respectively. Fig.8 shows current dynamic waveform of load and grid side, fig.9 shows Voltage waveform of grid side,fig.10 shows Voltage waveform of the DC capacitor

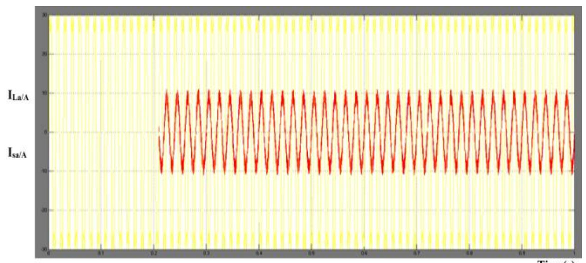

Fig 8.Current dynamic waveform of load and grid side

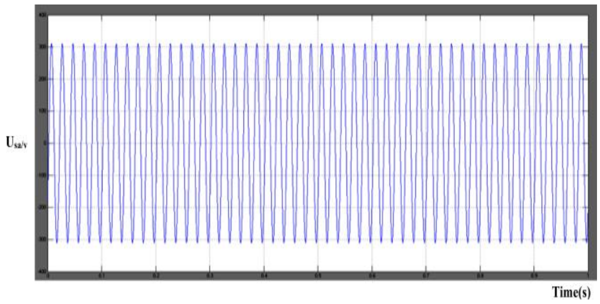

Fig 9. Voltage waveform of grid side

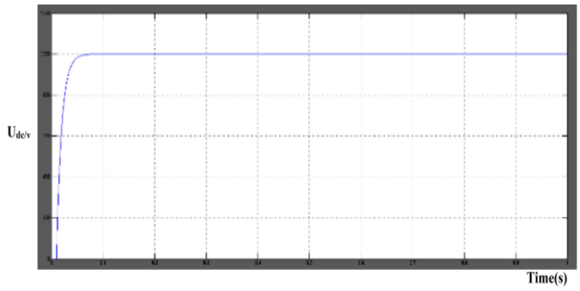

Fig 10. Voltage waveform of the DC capacitor

CASE:2 Proposed Hybrid System without PI Controller PV Array Battery

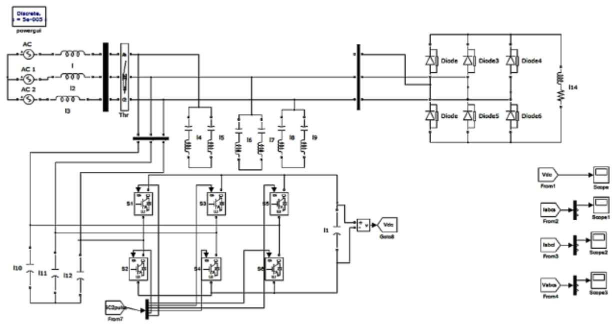

Fig 11. SIMULINK diagram of Photovoltaic Array Battery is not connected to the Proposed Hybrid System

When the PV array battery is not connected to the proposed hybrid system, the simulation results are shown in Figures 12-14. At this time, the proposed hybrid system is equivalent to a pure shunt active power filter, passive power filter and loads, which are parallel connected to the public power grid. From Figure 12 to Fig.14, it can be seen that the harmonic current is greatly reduced, the voltage and current of power grid has same phase. The DC capacitor voltage of the inverter is 700V in Fig. 14. At this time, The DC side capacitor through the IGBT diode rectifier from the grid toobtain energy, so the proposed hybrid system is slower thanwhen the DC side capacitor through the PV system to obtain energy about 0.4S. That is to say, the dynamic adjustment speed of the proposed hybrid system is slower in case2 than in case 1.

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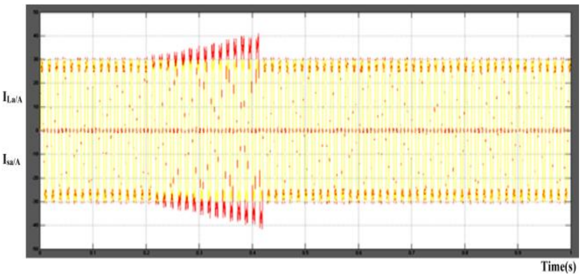

Fig.12 Current dynamic waveform of load and grid side

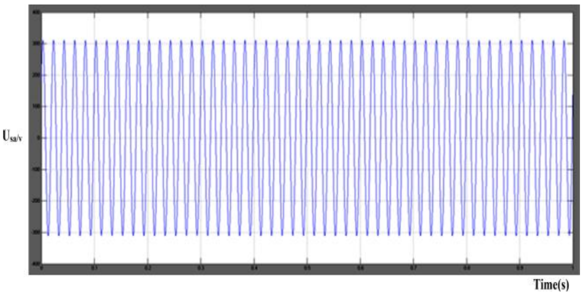

Fig.13 Voltage waveform of grid sideTime(s)

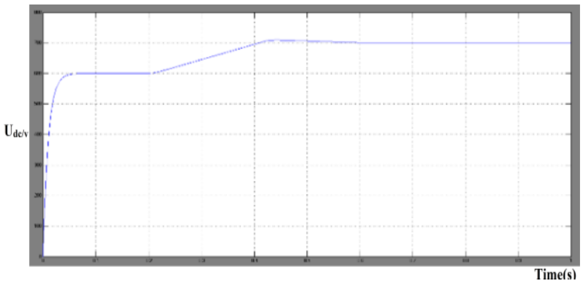

Fig .14 Voltage waveform of the DC capacitor

CASE:3 PV Array Battery Connected Hybrid System with ANFIS Controller

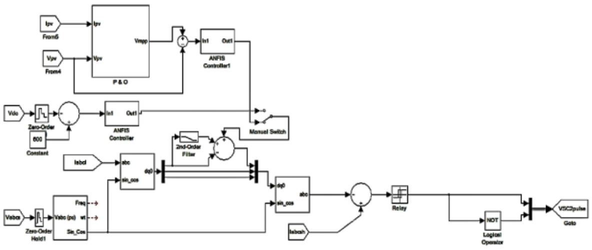

Fig. 15 Controller subsystem with ANFIS Controller

When the PV array battery is connected to the proposed hybrid system, and PI controller replaced by ANFIS controller. The simulation results are shown in Fig.16-17.I_{la}, I_{sa}, U_{sa}, $U_{dc}$is the load current, the grid side current, the grid side voltage, the DC side capacitor voltage of inverter respectively. Fig.16 shows current dynamic waveform of load and grid side, fig.17shows Voltage waveform of grid side. When compared to existing system grid current having less THD in proposed system. These are shown in figures fig 18 and 19.

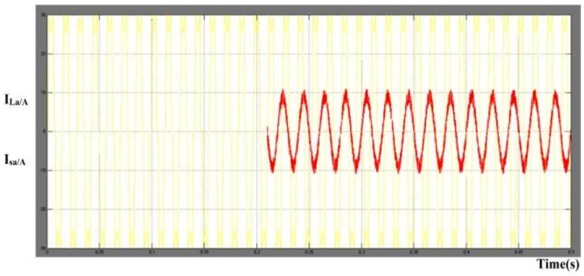

Fig.16 Current dynamic waveform of load and grid side

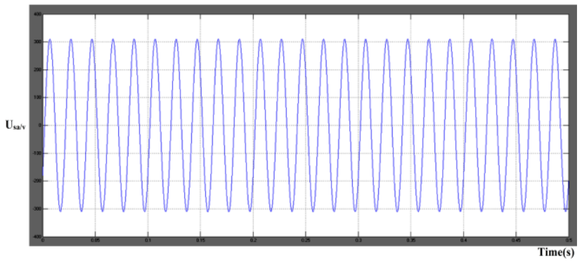

Fig 17. Voltage waveform of grid side

VI. COMPARISON OF RESULTS

From Table. 1 it conforms that the THD value is much more reduced in the case 3.

Table.1 Comparison of THD

	Parameters	Results
Case 1 **PV Array Battery Connected Proposed Hybrid System with PI Controller**	**THD**	**19.86%**
Case 2 **Proposed Hybrid System without PI Controller PV Array Battery**	**THD**	**25.52%**
Case 3 **PV Array Battery Connected Hybrid System with ANFIS Controller**	**THD**	**10.52%**

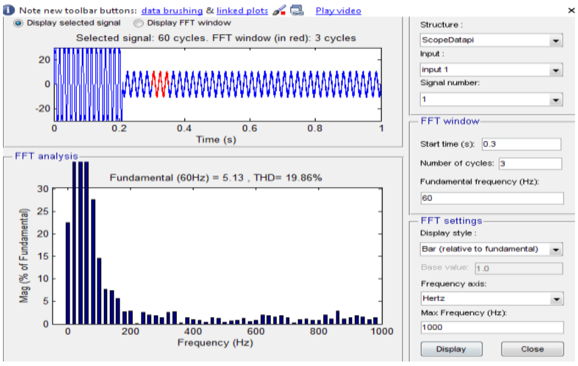

Fig .18 THD of load current is 19.86% (with PI controller)

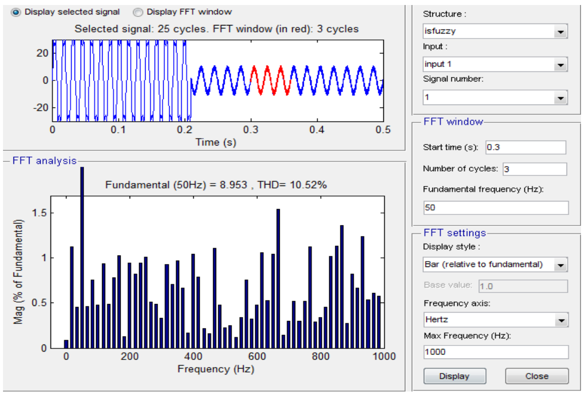

Fig 19. THD of load current is 10.52%(with ANFIS controller)

The figure 18 shows the pictorial representation of THD by FFT analysis .this figure depicts that THD value with PI controller is 19.86 % . when the PI controller is replaced by ANFIS the THD value is got reduced into 10.52 %. It witnessed that the proposed hybrid system of ANFIS controller has the less percent of THD.

VII.CONCLUSION

In this paper the discussion of the new hybrid filter topology and controlled strategy of ANFIS control technique has been clarified by using Simulink environment. From the results, the hybrid power filter is better than the active power filter current compensation . here two controllers are employed and the THD value are lesser with the PI controller the THD value is 19.86%.With the ANFIS the value of the THD is 10.52 %. Of load current. ANFIS has a better performance compared to PI. Hence, it can be concluded that non-linearity of load is compensated by use of Shunt APF the with ANFIS Controller harmonics to a large value to provide multiple of fundamental frequencies of sinusoidal output current and also to provide only real power at the distribution system the reactive power is compensated.

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