Harmonic Distortion Analysis of ANFIS controlled PV fed three phase Voltage Source Converter

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ABSTRACT

An increasing demand for power and polluting fossil fuels has made the focus to move towards renewable energy systems (RES). Inspire of providing a clean and green energy, the renewable source suffers from intermittency and low power levels which have made the boost converters indispensable. The POSLC offers a viable option which uplifts the voltage level in geometric progression increasing the gain in power series. The P&O based MPPT method have been applied to track the maximum power. A power output obtained from a solar panel is given to the super-lift converter and the boosted output from the converter is converted to AC through a three phase VSC, which is fed to the grid after proper synchronization. This work presents a model of micro grid system connection for PV with RL load driving through LUO converters. The main challenges accompanying the integration of RES includes harmonic distortions and voltage fluctuations. To alleviate these PQ issues and to improve the performance of the grid, an ANFIS based controller has been instigated. SVPWM technique has been tailored for PWM production of VSI. The effectiveness of the modelled system is verified using MATLAB/Simulink.

Key words: ANFIS, LUO converter, P&O based MPPT, RES

1. INTRODUCTION

The consumption of electricity is rapidly increasing in today's world. The running out of petroleum and the increased global warming due to carbon emission has made world to move towards RES. In most part of the world the electricity is produced using coal /oil/Natural gas. However, these sources are highly expensive and also hazards to environment. Hence, the utilization of RES for power production is trending today in all over the world. This RES includes wind/solar energy.

These are referred as clean energy sources. These are referred as clean energy sources because they offer emission free environment. Among the various RES, solar is considered as more effective system because of its huge availability nature[1]. So it is widely utilized in most of the countries.

Thus, the voltage produced by the solar system depends upon the series/parallel arrangement of solar cells. It too many solar cells were utilized for higher voltage application, its size becomes more complex. Hence, only less number of PV array should be utilized for energy production. As a result, the output obtained from PV is less which is not enough to fed the load. Hence, to improve the voltage level of output (ie. PV), boost converters were employed [28-30].

One among such converter is a Luo converter. This converter provides high power density with ripple content [25]. There are four different forms of LUO converter are examined[13]. Based on their boundary conditions and gains (voltage transfer), positive output super lift converter is chosen to enhance the output from PV.

Thus, to control the operation of proposed converter, controller has to be implemented. However, conventional PI controllers are failed to regulate the voltage across the DC bus under dynamic operating condition. Hence at this condition, AI controllers like Fuzzy/Neuro can be implemented to avoid unregulation. In fuzzy control technique, mamdani and Takagi–sugeno (TS) were reported. They are formulated on the basis of rules. But no standard method is available for rule base. Moreover, to minimize the error, membership functions(MFs) has to be tuned. Hence, to eliminate these limitations of both conventional and AI controllers, an hybrid AI controller (ANFIS) is proposed in this work for regulating the voltage level of Luo converter.

ANFIS is the combination of neural network (NN) and FLC. Hence, it provides dual advantage in a system. In [25] ANFIS controller is incorporated with several inverters and hence, the total cost was reduced.

In [26] ANFIS controlled UPQC is modeled and hence, its efficiency was increased. In this, TS control is implemented

for DC bus and thus, ANFIS enhances a better voltage regulation with lower complex while implementing.

In[27], ANFIS was implemented to control the operation of STATCOM. Thus, it exhibits higher accuracy and it achieves higher active power along with compensation of reactive power.

Hence, the principal objective of this proposed system is depicted as follows.

1. Regulation of DC link voltage of an inverter by ANFIS controller. Hence, it is designed in such a way to after higher efficiency during variation in either load/generated power.

2. To alleviate power quality problems occurred due to nonlinear/unbalanced loads.

3. To retain a balanced 3ϕ voltage at PCC even under unbalanced load, condition.

4. To maintain unity power factor (PF) and there by sustains both active and reactive power in phase under all conditions

2. SYSTEM DEFINITION

The schematic representation of the suggested system is defined in Figure. 1.
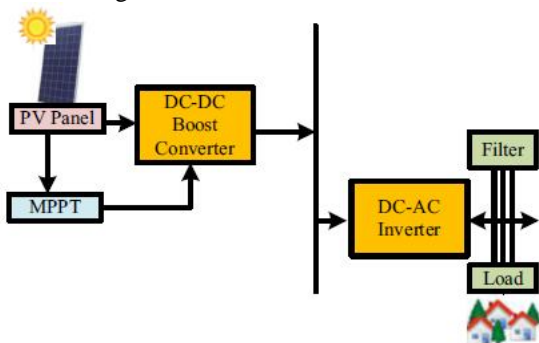
Figure 1: Schematic Representation of the suggested system

3. DESIGN OF PV SYSTEM

Solar cells together forms PV module. Usually they are organized either in parallel/series on the basis of its applications. Solar cell was symbolized as a current source (Is) with inverted diode and are arranged in parallel combinations. Thus each cell exhibits its individual series (R_s) and parallel (Rp) resistance. The Rs is due to interruption in the pathway of current and Rp is due to leakage current [10-13] and the same is represented in figure 2.
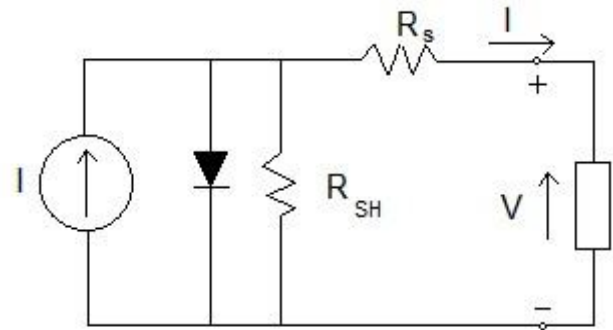
Figure 2: PV cell Model

However, in this projected model, R_s is very high. Hence, it is omitted and it has no significant role in the circuit.

The output current derived from PV is derived as

$$I = I_{sv} - I_d \tag{1}$$

But due to varying nature of weather, the PV gets affected. So an active tracking topology is indispensable to extract maximum amount of power from a PV module.

MPPT Algorithm

Thus, MPPT technique was adopted to obtain maximum of power from a PV module [2-9]. Among those, P&O topology is widely utilised in PV based system. It's mainly due to its higher efficiency and simplicity.

Thus, the flow chat of P&O technique is displayed in figure 3.
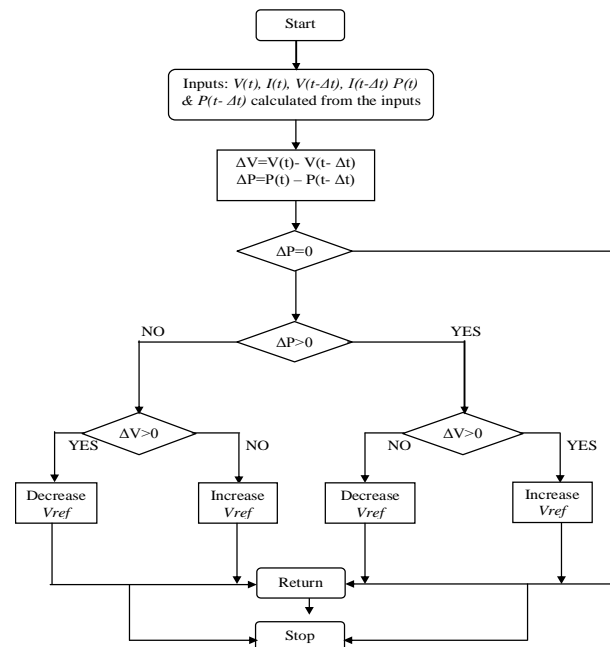
Figure 3: Flow chart of P&O technique

The switch S acts as a main switch and Si as a slave. These two switches (S, S1) operate in push-pull condition and its operation is depicted in figure 4 and 5.
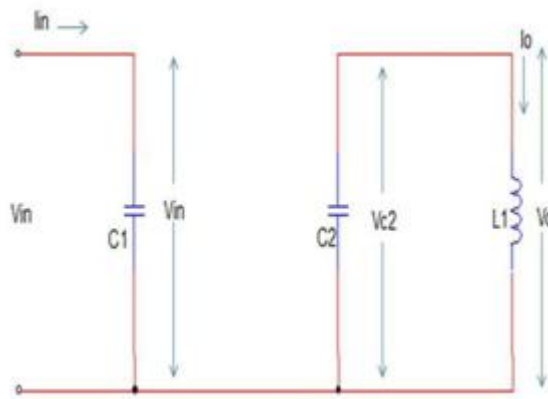
Figure 4: Circuit operation when switch is ON

When 'S' is in on condition, the voltage across the capacitor (C1) is V_{in} and the switch 'S1' remains off.

When 'S' is in OFF condition and 'S1' remains ON, then the voltage across C2 is V_o.
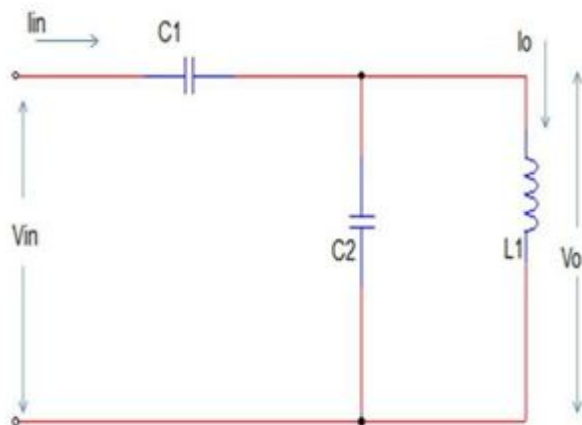
Where Therefore,

output voltage,

$$V_o = 2V_{in} \tag{2}$$

However under practical,

$$V_o = 2V_{in} - \Delta V_1 \tag{3}$$

$$V_o = 2V_{in} - (V_{D1} + V_{D2} + V_{S1} + V_L) \tag{4}$$

$$V_o = 2V_{in} - (2V_S + 2V_D) \tag{5}$$

Figure 5: Circuit operation when switch is OFF

From the above equations, it is concluded that due to some component losses, the output voltage will always be lower than twice of an input voltage.

Design of ANFIS controller

ANFIS operates by applying learning methods of neural network to fuzzy inference system. A two input one output ANFIS structure is considered as shown in figure 6. It consists of some set of rules and six distinct layer which makes it a multilayer network.
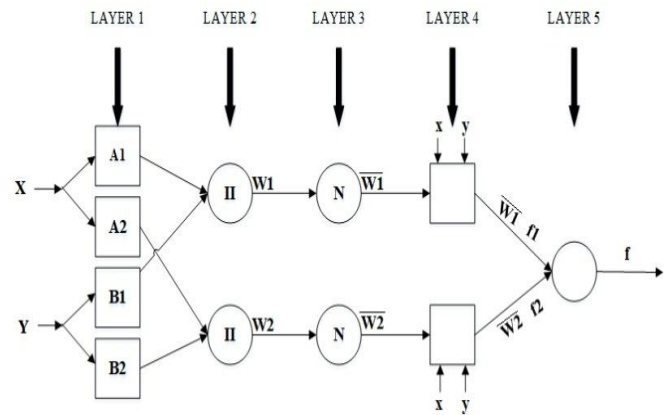
Figure 6: Sugeno type FIS structure with two input and two output

IF-Then Rules of Takagi-Sugeno model:

Rule 1 : *if z1 is A_1 and z2 is B1;*
Then F1= $a_1z_1 + b_1z_1 + c_1$

Rule 2 : *if z1 is A_2 and z2 is B2;*
Then F2= $a_2z_1 + b_2z_2 + c_2$

Layer 1: Acts as the input layer. Degree of membership of every inputs are computed using a Bell Membership function.

$$\mu_A z = gbell(z, a_i, b_i, c_i) = \frac{1}{1 + \left|\frac{z_i - c_i}{a_i}\right|} \tag{6}$$

Where

a_i; b_i; c_i - Parameter set

c   - Center of the function.

The parameters b and a are used to control the membership crossovers.

Layer 2: At the Fuzzification layer in the product node incoming signals are multiplied and firing strength of each rule is obtained as output.

$$w_i = \mu A_i(x) . \mu B_i(y) . i = 1,2 \tag{7}$$

Layer 3: Individual Rule's Strength is normalized in this layer. Output node(s) is the representation of proportion of firing strength of the ith rules to the summation of firing strengths of all rules.

$$\overline{w_i} = \frac{w_i}{w_1 + w_2} , i = 1,2 \tag{8}$$

Layer 4: This is a adaptive node which determines the consequent parameters using the following function.

$$\overline{w_i} f_i = \overline{w_i}(p_i + q_i y + r_i) \tag{9}$$

Normalized firing strength $\overline{w_i}$ is obtained from layer3 whereas p_i, q_i *and* r_i are the parameters of this node.

Layer 5: Finally, output of the system is the summation of inputs in a single node in this Rule inference layer.

$$Overall \ output = \sum_i \overline{w_i} f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{10}$$

The inputs to the fuzzifier section of ANFIS controller are change in error (ce) and error (e). The MF of the inputs are chosen as Gaussian MF and are categorized into 7 functions

namely (NL, NA, NM, Z, PM, PA, PL). The defuzzifier section generates the duty cycle (d) which is a linear signal in ANFIS model.

The inputs are given to the ANFIS controller after being fuzzified using the fuzzy sets. To select proper set of rules which gives optimal output the neural network is trainned. Then the selected rules are fired to get the required control signal[31]. The structure of the ANFIS controller is shown in Figure 7.
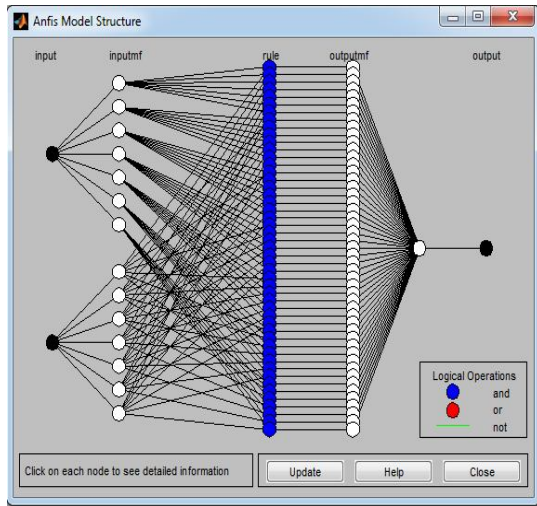

Figure 7: ANFIS Structure

The rule base of proposed ANFIS is depicted in figure 8a.
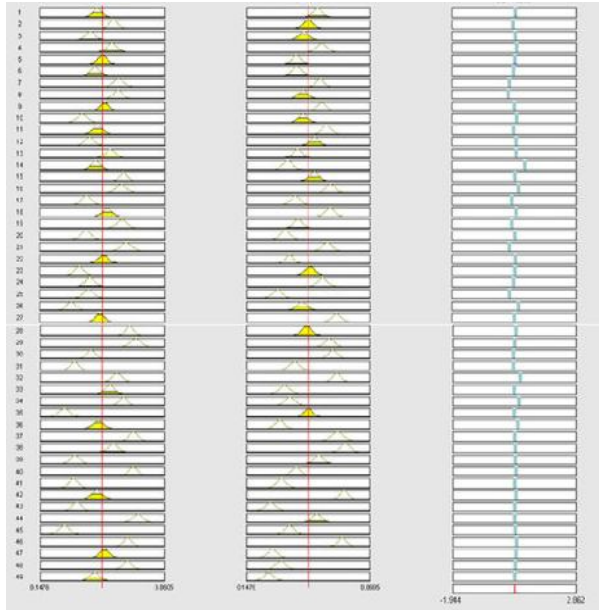

Figure 8a: Rule base - ANFIS

Figure 7 depicts the ANFIS model structure with two input neurons, four hidden layers viz., input membership function, membership function, rule base and aggregated output and one output neuron. The developed ANFIS controller is trained to select proper and optimal rules from the 132 fuzzy rules. Individually both the input neurons are connected to 7 rules

i.e., 7 by 7 rules is available for hidden layers. The e and ce are applied to the 1st hidden layer of the ANN. Optimal set of 49 fuzzy rules are identified and selected in the 2nd and 3rd layers. The 4th layer fires the most favorable rule out of 49 rules. Then the output is defuzzified at output neuron which in turn is used to generate the firing pulse for the converter.

Thus the surface view of rule base after training is illustrated in Figure 8b.
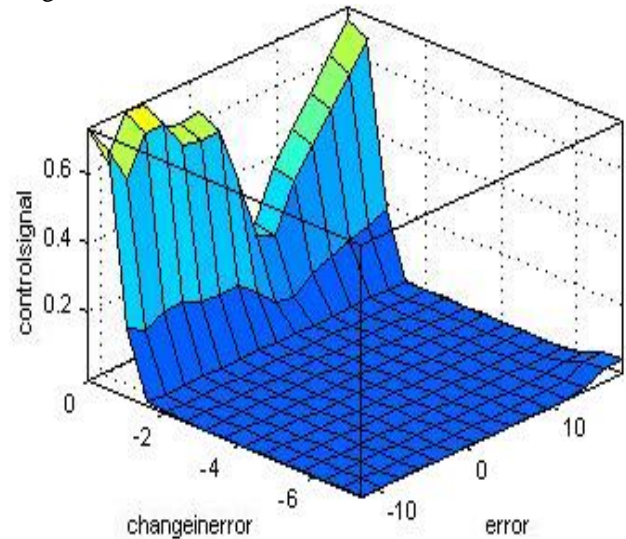
Figure 8b: ANFIS rule base surface view

Thus the output of ANFIS controlled Luo converter is fed to the inverter. A 3Φ VSI is utilized here for DC/AC conversion and is depicted in figure 9.
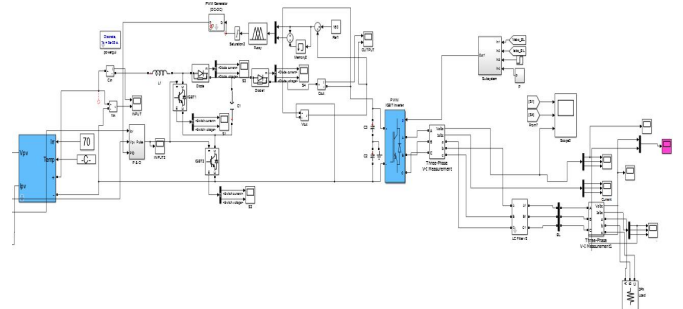
Figure 9: Simulation Circuit of Luo converter fed three phase VSC

Control of inverters

The efficiency of an inverter mainly depends upon the modulation approaches which controls the inverter[14-16]. In this design, SPWM technique has been tailored to control the inverter.

In this technique, the sinusoidal AC reference voltage (Vref) is compared with the triangular carrier wave (Vc) which governs switching states of an inverter. [17-19]. Thus, the switching state can be determined as follows

•When Vref> Vc, upper switches are on

• When Vref< Vc, lower switches are turned on [20-24].

4. RESULTS AND DISCUSSION

Thus the effectiveness of the suggested system under power flow management is power flow management is analyzed using MATLAB simulation. Thus the effectiveness, this model is analyzed under varying load condition.
The LUO converter I_{out} and V_{out} are given in Figure 10.
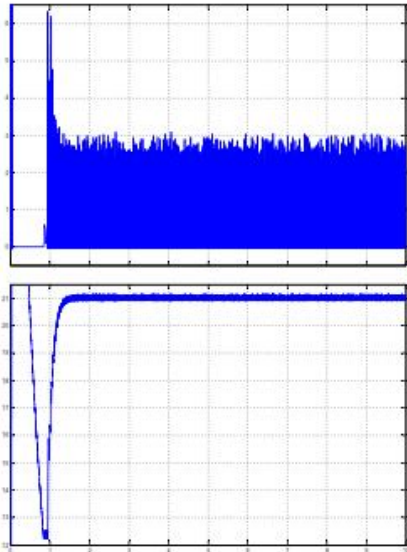
**Figure 10a:** LUO converter *Iout* and *V*out (with PI controller)
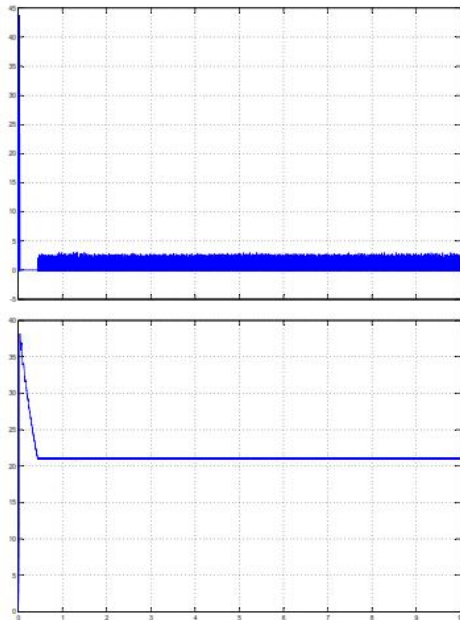
Figure 10b: LUO converter *Iout* and *V*out (with ANFIS controller)

Figure 10a and 10b describes depicts the performance of PI and ANFIS controller in the suggested system. From the analysis, it is proven that ANFIS exhibits better regulation in terms of voltage. Simultaneously, the tracking capability of ANFIS is high which can observed from its reduced settling

time than that of PI controller under varying load condition. From the graph view, it is observed that the setting time (T_s) of ANFIS is only about 0.5s where as in PI, it is about 1sec. conversely, there is no undershoot while implementing ANFIS. Figure 11 shows that the voltage from the inverter which remains in balanced condition and is sinusoidal irrespective of the nature of the applied load.
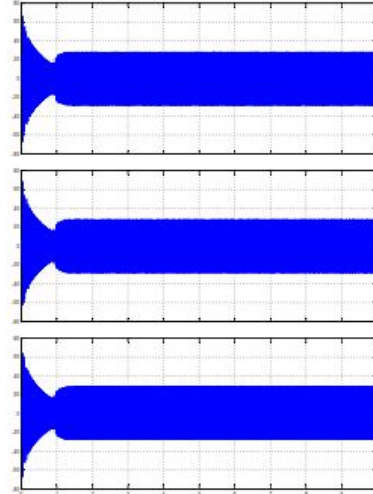
Figure 11a: System response under PI controller
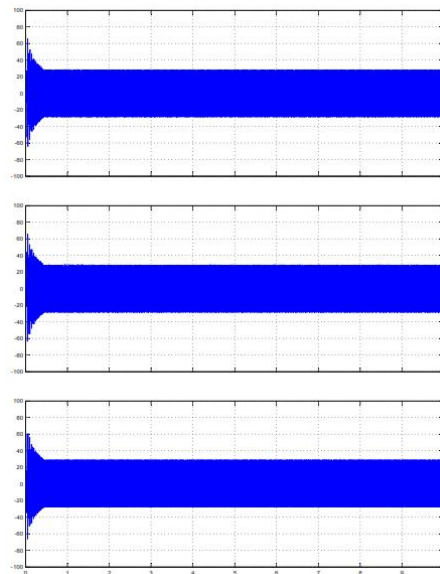
Figure 11b : System response under ANFIS controller

While integrating RES with grid, the power quality measures play a major role. Thus, the harmonic distortion has to be measured to ensure the efficiency of the system. Thus, from the figure 12a and b, the THD of the system under different controller were observed. From the THD analysis, it is seen that ANFIS exhibits 2.37% of THD where as it is about 7.22% for PI controller. Hence, it is concluded that ANFIS will suppress the harmonics present in the system to a considerable limit.
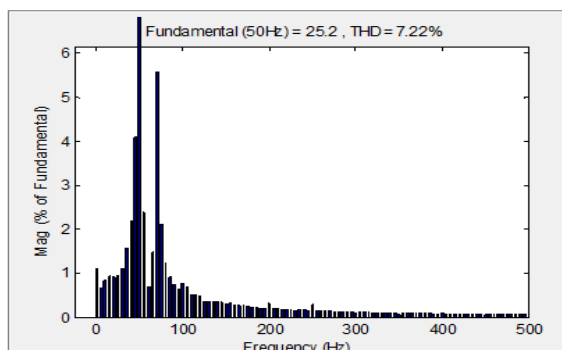
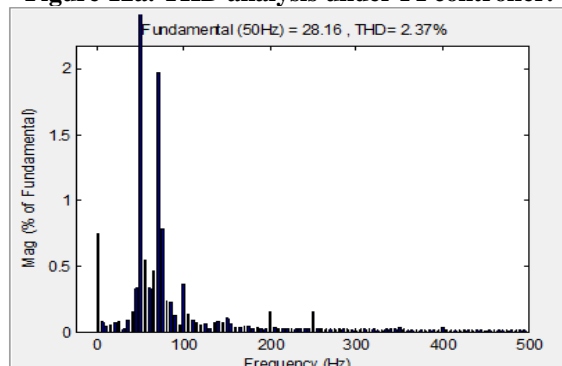**Figure 12a. THD analysis under PI controller.**

Figure 12b: THD analysis under ANFIS controller

Finally, from all these, it is concluded that the suggested system can appropriately responds to all variations in load with improved power quality performance.

5. CONCLUSION

This study made an attempt to design micro grid application for industry/ rural area. In this perception, this work formulated an efficient system using PV source along with LUO converter. In this system, a constant power is supplied to load by maintaining constant irradiation and temperature value. Thus, under these operating conditions, the output voltage obtained using LUO converter is incorporated to AC load through VSI. SPWM topology is incorporated to produce PWM signals. From the analysis, it is concluded that Luo converter can be successfully implemented for such micro t grid applications. Thus, the outcomes of this work can be concluded as follows:

• Simulation results portrays that the proposed ANFIS controller shows an improved performance in terms of regulation of DC link voltage with quick dynamic response.

• Comparative study of ANFIS controller over PI controller have been demonstrated.

• The control scheme of an inverter was established using SPWM and thus it reduces the THD of system within 5% stipulated limit.

• The suggested control structure can be generalized for all type of RES without any change in control scheme.

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