HARMONIC REDUCTION IN GRID SYSTEMS USING SINGLE-PHASE SERIES APF WITH PI AND FUZZY CONTROLLERS

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ABSTRACT

In this paper, the performance of a *single-phase Series Active Power Filter (SeAPF) without external power sources* ***is analyzed under two different control strategies:*** *Proportional–Integral (PI) Controller* ***and*** *Fuzzy Logic Controller (FLC)****. The SeAPF is developed to improve power quality by mitigating voltage harmonics, sags, and swells in the grid connected with non-linear loads. The proposed system is modeled and simulated in MATLAB/Simulink using Sim Power System Toolbox. Simulation results show that while the PI controller maintains the Total Harmonic Distortion (THD) of load voltage at*** *3.24%****, the Fuzzy Logic Controller significantly enhances the performance, reducing the THD to*** *1.63%****. The analysis confirms that the Fuzzy Logic-based SeAPF provides superior dynamic response, better harmonic compensation, and improved voltage waveform quality compared to the PI-controlled SeAPF. These results highlight the effectiveness of intelligent control techniques for active power filters in maintaining reliable power quality.***

Keywords- Active Power Filters, Harmonics, Power Quality, Single-Phase Series Active Power Filter, Voltage Sags, Voltage Swells, fuzzy logic Controller.

1. INTRODUCTION TO POWER GRID

An interconnected network used for delivering electricity starting from producers to consumers is termed as an electrical grid. The main components are generating stations which produce electrical power, high voltage transmission lines which carry power to demand centers from distant sources, and distribution lines which connect the individual customers. An AC-AC converter with approximate sinusoidal input current and bidirectional power flow can be grasped by coupling a PWM inverter and a PWM rectifier to the DC-link. Then DC-link quantity impressed energy storage element which is common to both the stages, i.e. an inductor for current DC-link or a capacitor for voltage DC-link. The PWM rectifier is been controlled in such a manner that a sinusoidal AC line current is been drawn, which is either in phase or anti-phase with the resultant AC line phase voltage [2].

Electric power quality is the extent to which the voltage, frequency, and waveform of a power supply system match to established specifications. Good power quality can be termed as a steady supply voltage that settles within the set range, steady ac frequency near to the rated value, and a smooth voltage curve waveform that looks like a sine wave. Generally, it is practical to deem power quality as the compatibility between output of an electric outlet and the load that is connected to it. Power quality is also used to portray electric power which drives an electrical load and the load's ability to task accurately. In the absence of proper

power, electrical loads may breakdown, fail too early, or not at all operate. Electric power can be of poor quality in many ways and the causes can be different [3].

The electric power industry mainly consists of electricity generation (AC power), electric power transmission and finally electric power distribution to an electricity meter placed at the site of the end user of the electric power. Then the electricity moves through the end user's wiring system until it reaches the load. The intricacy of the system to move electric energy from the production point to the consumption point in combination with disparities in generation, weather, demand and other factors offer many opportunities for the quality of supply to be compromised.

2. FUZZY LOGIC CONTROLLER

Fuzzy logic or fuzzy set theory was given by Lotfi Zadeh, a computer scientist at University of California, Berkeley, in 1965, for representing and manipulating data that is not precise and rather fuzzy or vague. In the beginning he was criticized by the professional community, but progressively, Fuzzy logic (FL) gained importance in the professional society and in due course emerged as a new order of Artificial Intelligence. The FL became a attractive area of research because it worked really well between significance and precision, that for a very long time humans have been doing manually. The fuzzy controller has got four main components: The rule-base, that holds the knowledge in the pattern of a set of rules that, describes the finest way for a system control. The membership functions are used to quantify knowledge. The inference mechanism states control rules which are relevant next to the present time and then decides which input of the plant should be enabled. The fuzzification interface modifies the inputs [6]

2.1 FUZZY LOGIC TOOLS

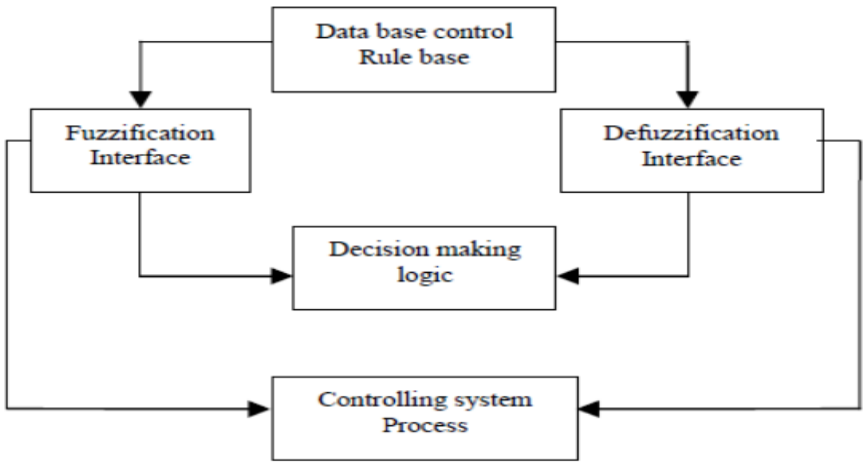

Fig.1 Fuzzy Inference System

2.2 Main Components of FLC

1. Fuzzification

- Converts crisp numerical input values (such as error e and change in error Δe) into **fuzzy values** using membership functions.
- Example linguistic terms: Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Large (PL).

2. Knowledge Base (Rule Base + Database)

- Contains a set of **IF–THEN rules** designed by expert knowledge or experience.

Example: IF error is Positive Small AND change in error is Negative Small, THEN output is Zero.

2.Inference Mechanism

Evaluates the fuzzy rules and determines the control actions based on the current fuzzy inputs.Uses methods like **Mamdani inference** or **Sugeno inference**.

3. Defuzzification

- Converts the fuzzy control actions back into crisp numerical outputs that can drive the system.
- Common methods: Centroid (most widely used), Mean of Maximum (MOM), and Weighted Average.

2.3 Advantages of Fuzzy Logic Controller

- Does not require an accurate mathematical model of the system.
- Provides **fast dynamic response** and robust performance under non-linear and uncertain operating conditions.
- More effective in reducing Total Harmonic Distortion (THD) compared to conventional PI controllers.
- Can adapt better to sudden disturbances like voltage sags and swells.

3. SIMULATION RESULT ANALYSIS

The proposed SeAPF is connected to a three-phase programmable grid source that utilises only a single phase and a nonlinear load. The programmable grid source block is particularly used to create sags and swells. Figure 2 below depicts the proposed SeAPF connected to a three-phase programmable grid source that utilises only a single phase and a non-linear load. The programmable grid source block is particularly used to create sags and swells in the line with programming time setting as discussed (Fig. 3). The total simulation time is set to 0.5sec. A sag condition is set from 0.1 to 0.2 sec, and a swell condition is set from 0.3 to 0.4 sec. For the remaining time, the system operates in normal operating condition.

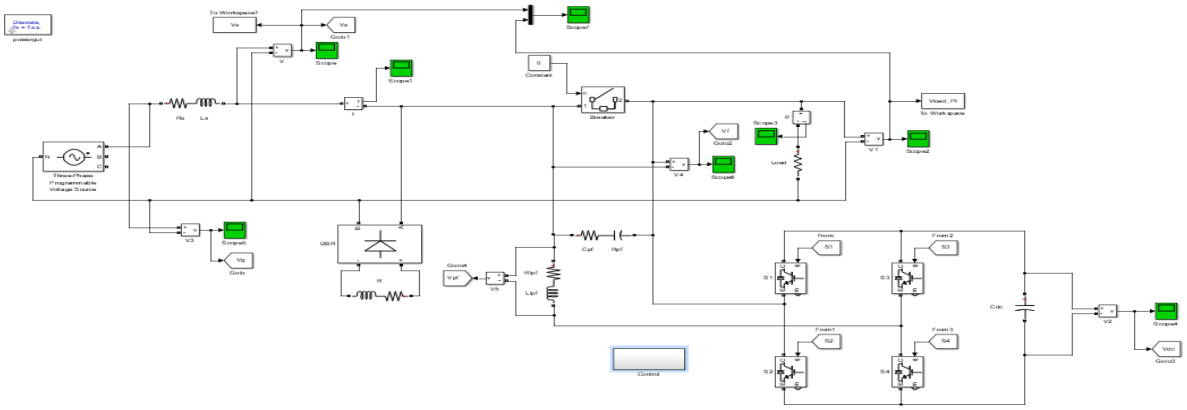

Figure 2 Proposed system of series active power filter with pi controller

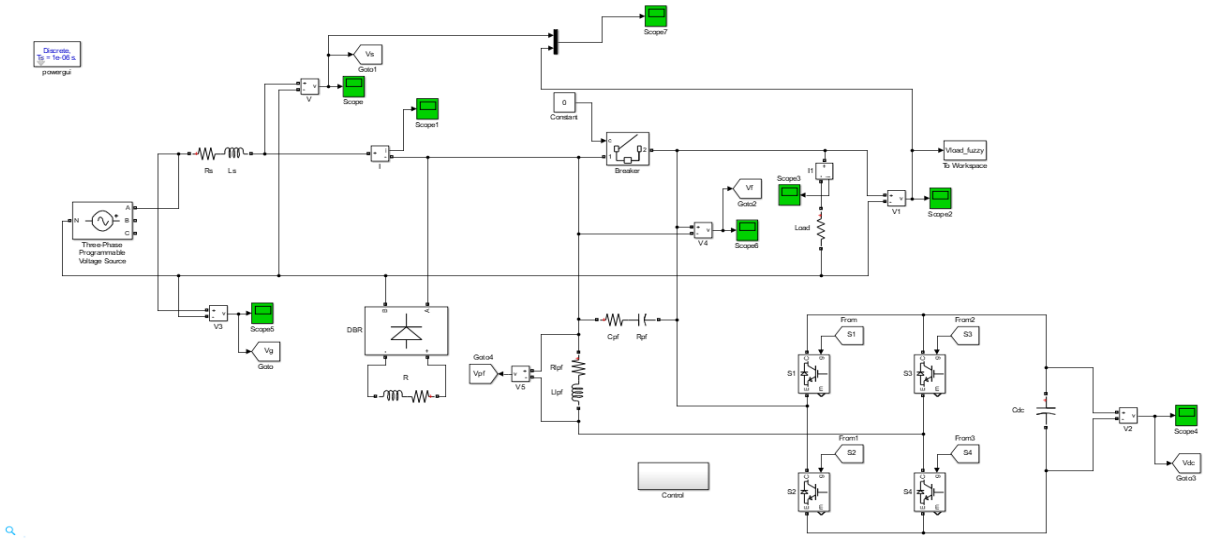

Figure 3 proposed system of series active power filter with controller

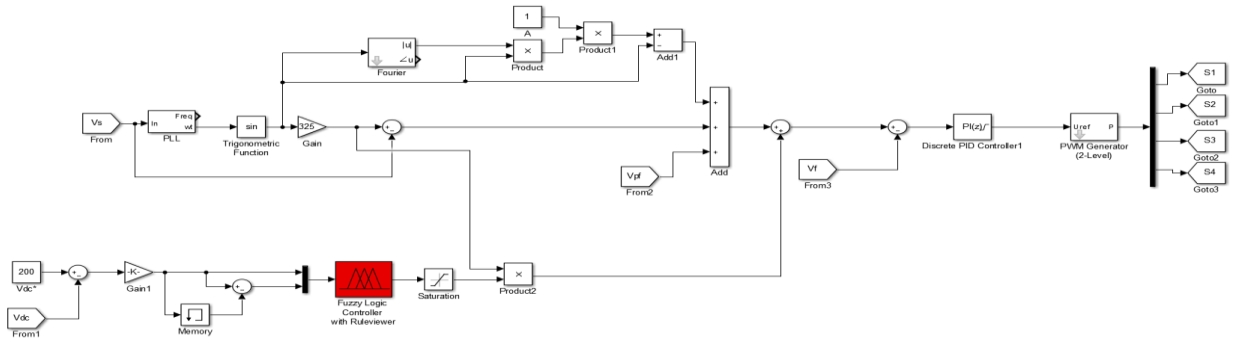

Figure 4 Proposed SeAPF control structure with Fuzzy Logic controller

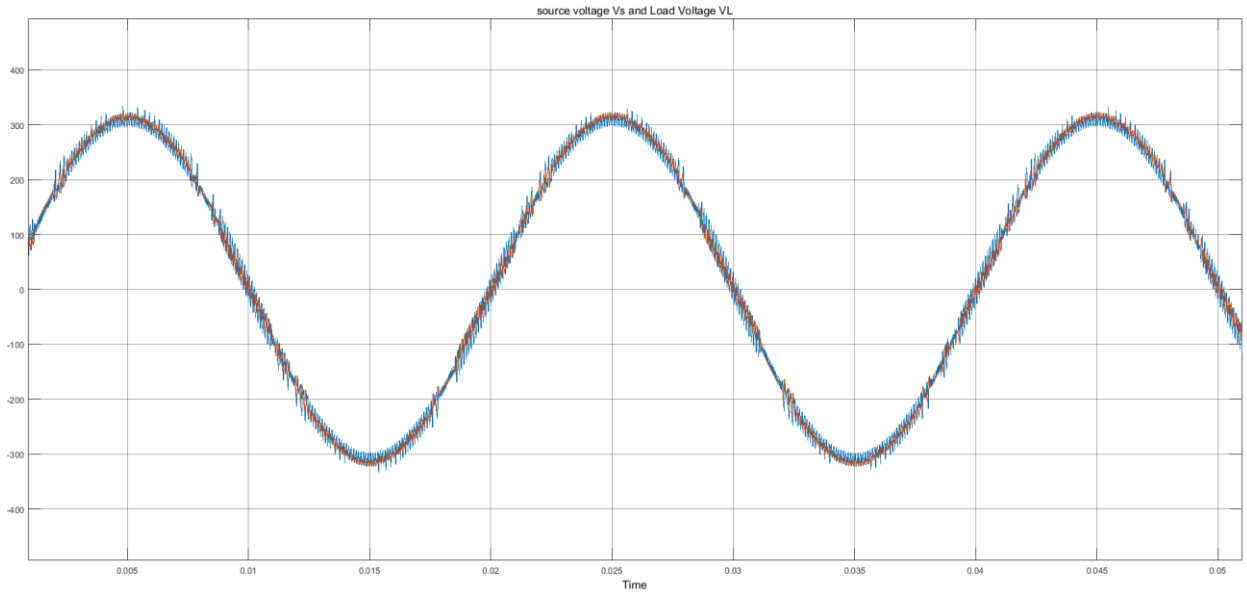

Figure 5 V_S and V_L during normal operating condition

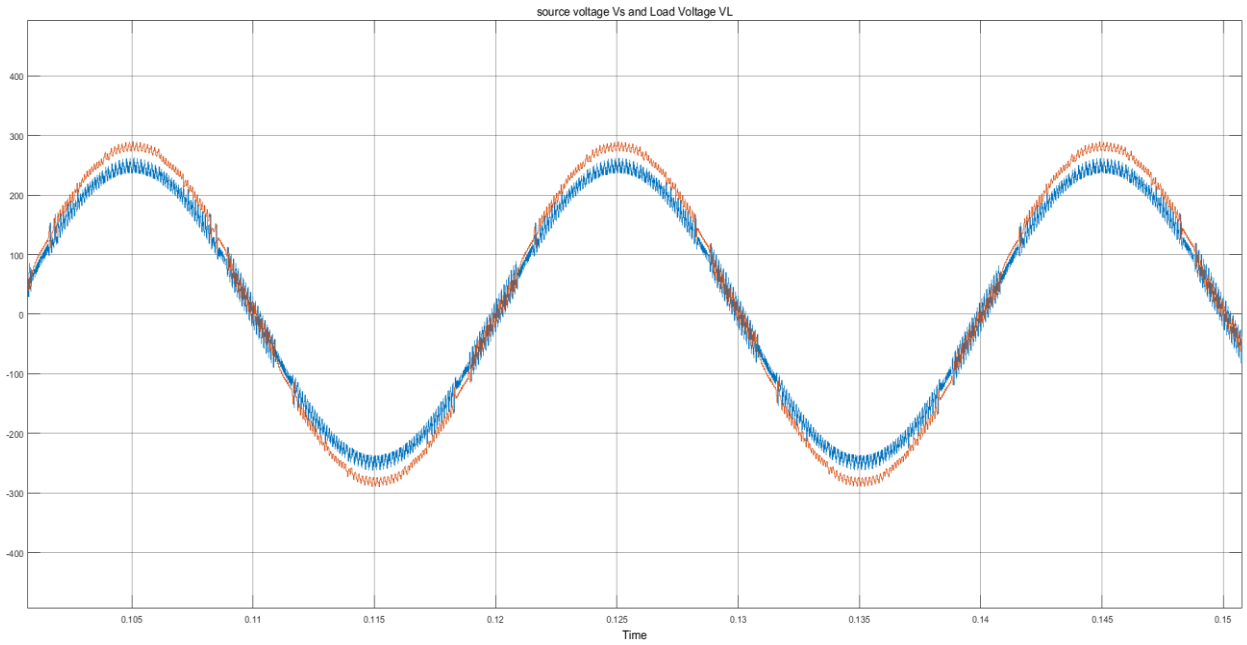

Figure 6 V_S and VL during sag operating condition

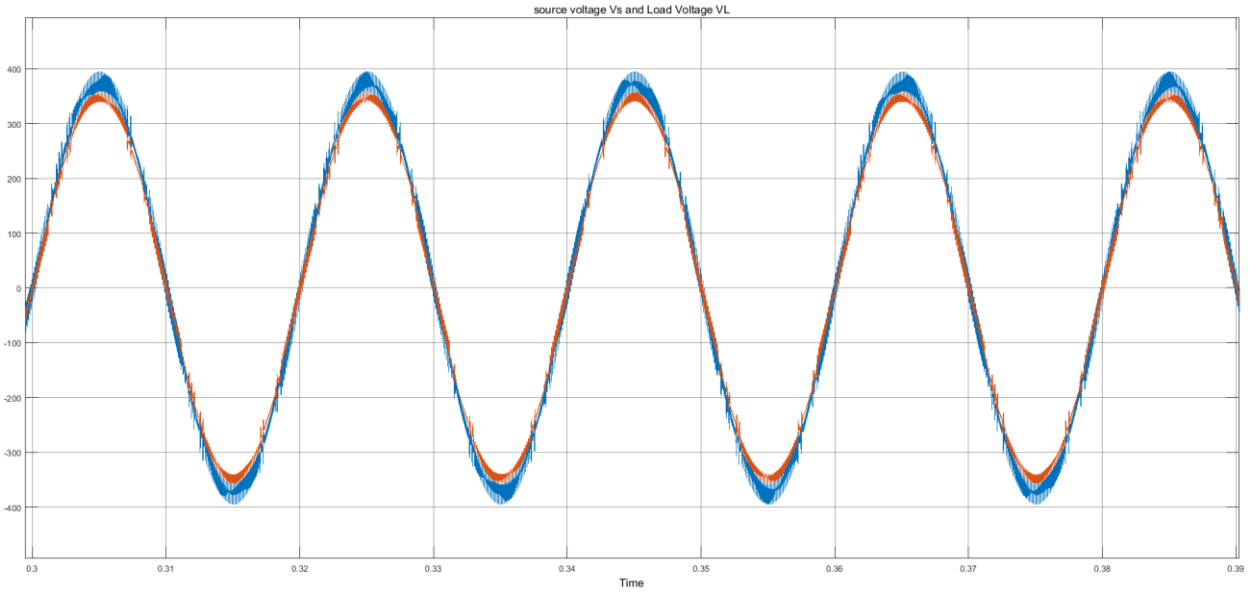

Figure 7 V_S and $V_L$during swell operating condition

The FFT analysis tool present in thePower GUI block of Simulink is been used for calculating the total harmonics distortion of the voltages.

Figure 8 shows the THD analysis of source voltage (V_S) which is about 5.37%.Figure 9 shows the THD analysis of load voltage (V_L) with PI controller and the value obtained is about 3.24% . Figure10 shows the THD analysis of load voltage (V_L) with Fuzzy Logic controller and the value obtained is about 1.63%.

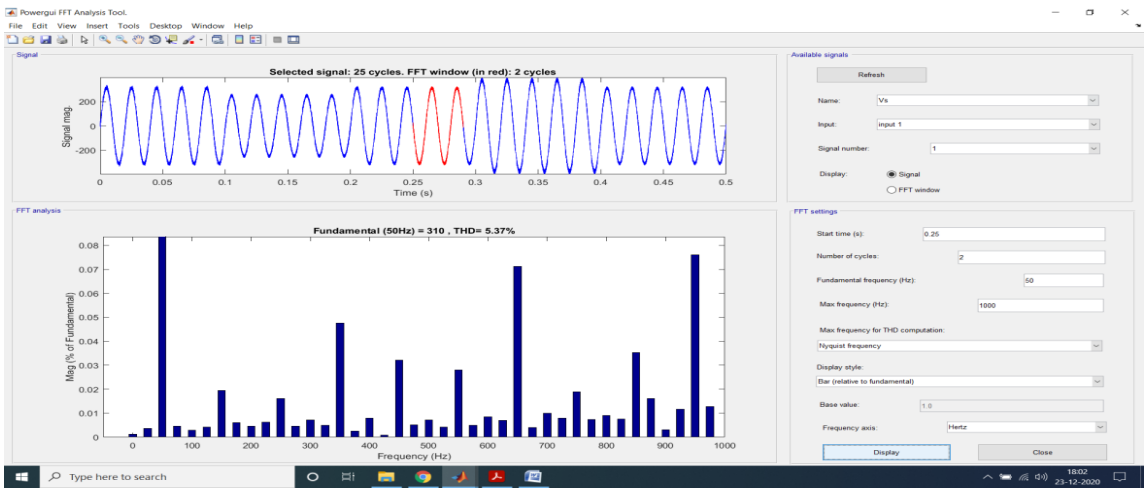

Figure 8 THD of source voltage (V_S)

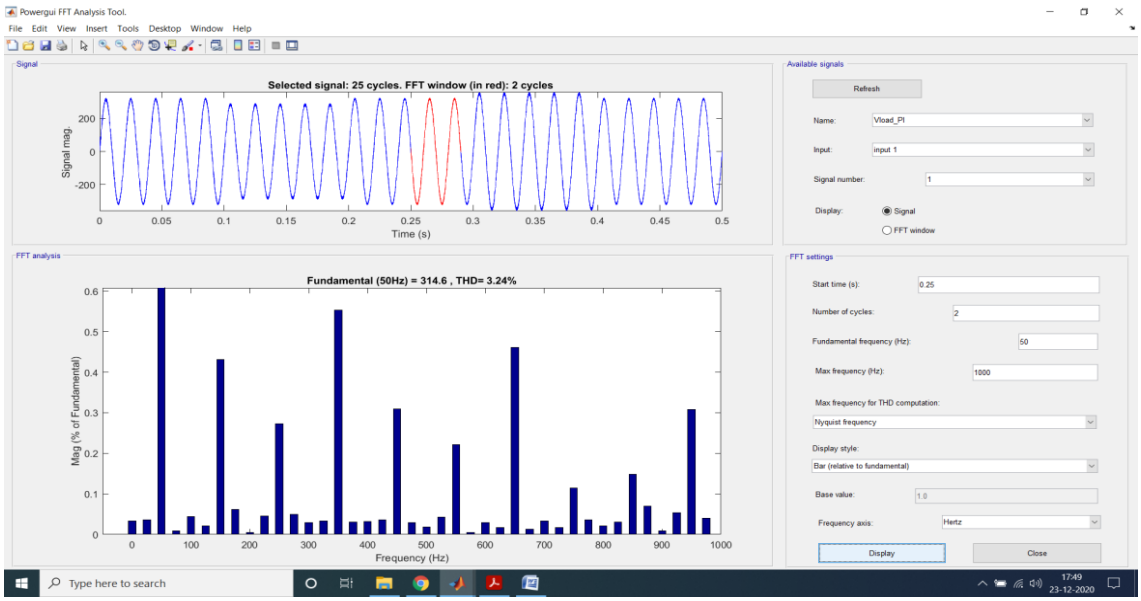

Figure 9 THD of load voltage (V_L) with PI controller

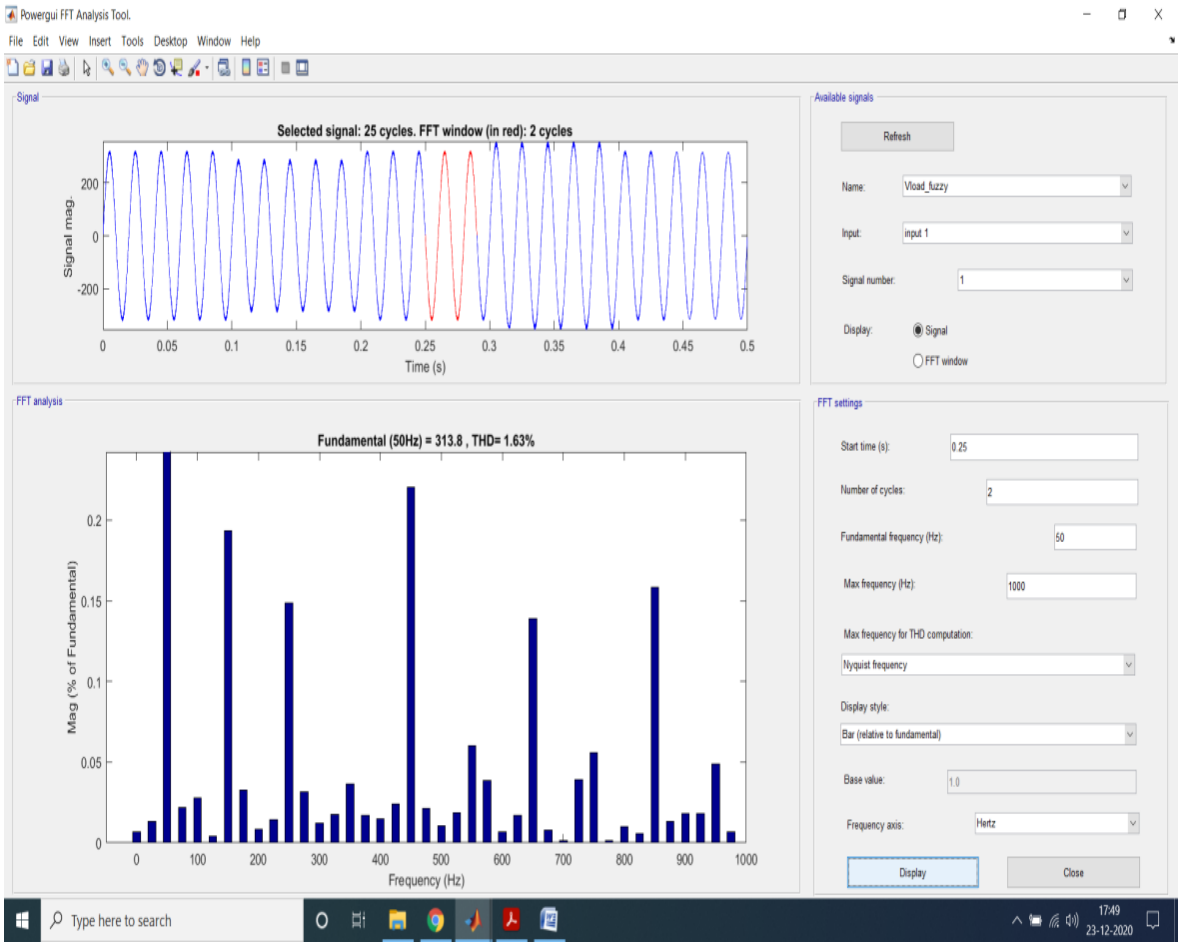

Figure 10 THD of load voltage (V_L) with fuzzy controller

4. CONCLUSION

This dissertation shows the analysis and comparison of the series active power filter connected to a single-phase grid. The voltage compensation during sag and swell is achieved with injection and absorption of voltage from the line. The control strategy is based on a PLL circuit that synchronizes the control signals with the Power Grid and thereby obtaining the compensation voltage. During the steady state operation, the SeAPF compensates the Power Grid voltage harmonics making the load voltage sinusoidal. The FFT analysis tool is used for THD analysis of the source voltage (V_S), load voltages (V_L)with both PI and fuzzy logic controller.The THD with fuzzy controller is maintained at 1.63% and with PI controller is maintained at 3.24%. However, both the controllers improve THD of the voltage when compared to the source voltage (V_S) THDwhose obtained value is 5.37%. Hence it can be concluded that the fuzzy controller has the least THD when compared with other controllers.

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