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Novel Fuzzy Controller Based Shunt Active Power Filter For Solar Grid Integration

Dayanand Gangadhar Patil[1], Vinodkumar P. Patil[2]

[1]*PG Student, Dept. of E& TC Engg, GCoE Nagaon Tal. Dist.-Dhule, Maharashtra, India*
[2]*Assistant Professor, Dept. of E& TC Engg, GCoE Nagaon Tal. Dist.-Dhule, Maharashtra, India*
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ABSTRACT

In recent decades, solar energy has become one of the most important renewable energy sources. The Photovoltaic (PV) system when connected with the grid proves to be a boon to the modern society. Although various power quality issues arises such as voltage fluctuations, harmonics and flickers. Thus, the integration of solar energy could initiate problems for equipment in power system. In this paper, a novel fuzzy logic controller has been presented. Solar plant is integrated with the grid through it for minimization of harmonics generated by non-linear loads.

Keywords—PV system, power quality, fuzzy controller

1. INTRODUCTION

Increased production of goods per head, increased prosperity and urbanization, rise in per head consumption, and easiness in energy access are the factors that are responsible for the increase in the total demand of electricity by a significant extent. Having a look at the difference of electricity demand and supply, huge quantities of coal and furnace oil are being used. These usages need to be reduced, as these are leading to tremendous costs in the form of subsidies and increment in the country's dependency on imports. Renewable energy sources have the ability to make a noteworthy contribution in these areas. Due to all of these, renewable energy needs to be studied and utilised to a great extent [1]. Solar power has an exceptionally good potential for providing electrical energy that is free & non-polluting. Its effectiveness as an electricity supply source has encouraged ambitious targets for solar PV system in many countries around the world.

As the government is providing subsidy, more and more people are getting attentive towards the use of solar energy. According to the recent data available, as of 27 November 2020, renewable energy sources generates 136 GW out of total 373 GW. With the increasing demand, solar power installation is presumed to see a raise of approximately 360% by 2021.

Solar PV system can be implemented in two ways: One as "Off Grid" and the other as "Grid Connected". In the "Off Grid" solar PV, the PV system is stand alone and independent, means it is not associated with the main electric supply line or with the electricity distribution system. On contrary, "Grid Connected" solar Photovoltaic system is connected with main grid or the electricity distribution company. The major distinction between these two is the storage device. Off grid PV system uses batteries to store the extra amount of energy generated during off peak hours, whereas with Grid connected Photovoltaic system, surplus amount of energy can be sold to the electricity distribution company. Batteries prove to be a high cost element for the off grid connected system, making it quite expensive to use. Along with high cost, it is inefficient also as the battery loose energy with time. Off-Grid is usually required in more remote areas which are far from any electricity grid. Generation of electricity through photovoltaic-grid system encourages use of solar energy source, on the contrary part, PV generation leads to new initiatives for development and scheming due to several power quality issues [2]. When PV system is tied with the grid, the effect on power quality is being reviewed in this paper.

2. GRID CONNECTED PV SYSTEM

Photovoltaic (PV) cells also known as solar cells, converts energy of sun light directly into electricity. PV received its name from the action of transforming light energy (photons) to electricity (voltage), which is known to be the PV effect. Figure 1 displays simple illustration of grid connected PV scheme. The various components of the system are briefly described below:

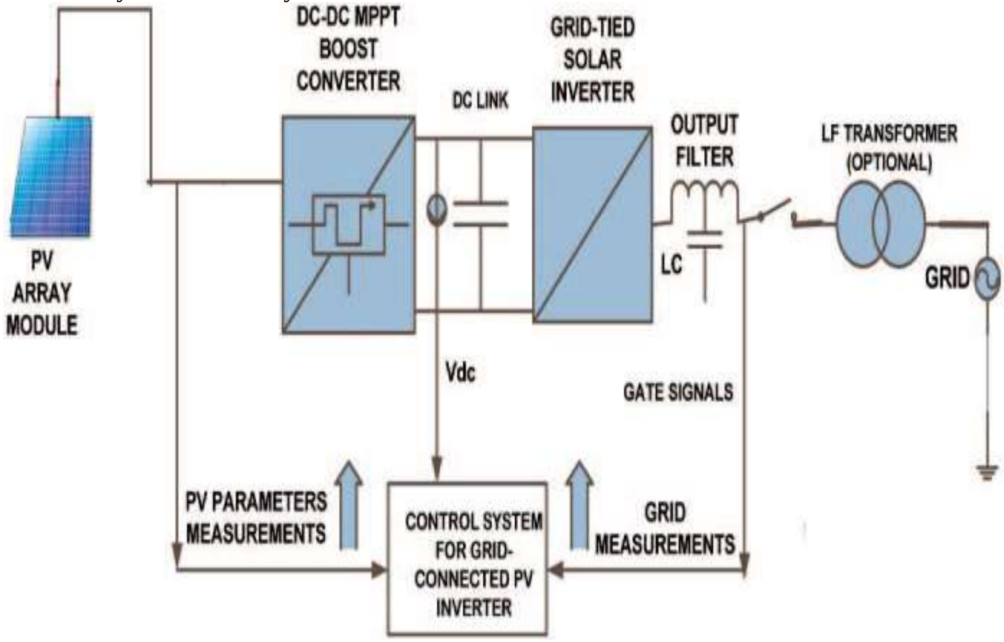

Fig-1. Simple illustration of Grid connected PV scheme

2.1 PV Arrays

The most important component of the photovoltaic (PV) system is the solar panels that generate electric power by the direct conversion of the sun's energy into electricity. The solar panels are mostly made with semiconductor material, with Silicon (Si) being widely used. Materials like Gallium (Ga) and Aluminium (Al) have better conversion properties and recently they are increasingly finding their application. The components of the PV system includes the electronic devices to interface the PV output and the AC or DC loads. Panels can be used independently, or a number of panels can be connected which forms arrays. Then as element of a complete PV system, more than one array is coupled to the electrical grid. With this modular structure, PV systems can be assembled to meet approximately any electric power requirements whether small or large.

2.2 DC - DC Boost Converter

Because of the unstable nature of the irradiance throughout the day, output voltage of the photovoltaic system varies. Boost converters are therefore needed to get a steady voltage at DC link [3]. By using Maximum power point tracker, operation of DC-DC step up (boost) converter is regulated to draw the highest power from Photovoltaic unit.

2.3 DC-AC Inverter

An inverter is one of the most important pieces of equipment in a solar energy system. Fundamentally, an inverter accomplishes the DC-to-AC conversion by switching the direction of a DC input back and forth very rapidly. As a result, a DC input becomes an AC output. It's the brain of a solar power system and serves primarily two purposes: Firstly, it changes the Direct Current generated from Photovoltaic Panels to Alternating Current in synchronization with grid which is used by the electrical appliances. Secondly, it ensures that solar power generated, is used at priority over grid supply.

3. FUZZY LOGIC CONTROLLER

Fuzzy logic controller was first introduced by Professor Zadeh Lotfi of University California Berkeley in 1965. Professor Zadeh Lotfi proposed a novel way of how to process a data which is not precise, with complex input. The idea of Zadeh's research was not fully utilized until the introduction and availability of modern high speed computers. Thereafter, fuzzy logic controllers attracted many researchers and control system engineers for application in control system analysis, as well as in the control algorithm for shunt active power filter applications. These controllers have advantages of simplicity in design because these do not need any accurate mathematical modelling, suitable for working with imprecise data of the system and it is also capable of working with non-linear data. Fuzzy logic controller is more robust than classical PI and PID controllers.

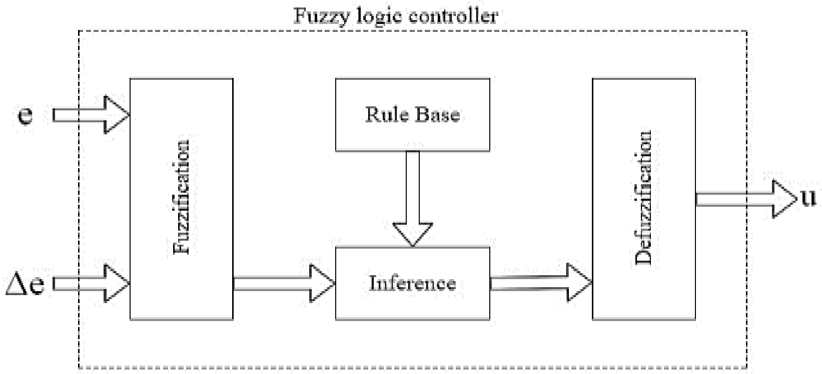

Fig-2 Internal structure of fuzzy controller

The internal structure of a general fuzzy logic controller is shown in Fig-2. It consist of four stages:

- Fuzzification
- Rule base
- Fuzzy inference
- Defuzzification

In real world, typical and rigid variables are present. For applying fuzzy inference, we linguistic variables values are required instead of classic and crisp. These linguistic values are expressed as a membership degree. The process of converting the numerical input into the linguistic values is known as Fuzzification process. The output variable is then controlled by a rule base in fuzzy logic system. These fuzzy rules are, IF THEN type rule with a condition and a resulting conclusion. Knowledge is captured by IF part which uses elastic conditions. Then an output in the form of linguistic variable is generated by the THEN part. Generating a relation between the input and output by applying fuzzy logic is called as fuzzy inference. For producing the fuzzy output set, fuzzy inference system is applied to the set of rules in fuzzy rule. The output of this system is also a fuzzy value which is required to be converted into a classic or crisp value. The process of getting this crisp value is known as Defuzzification. Error and change in error are the two inputs of FLC. Error is the difference in measured and reference value of the capacitor voltage. The output of the FLC is shown by control current Imax. Seven fuzzy sets are selected for converting numerical values of input to linguistic variables. Fuzzy sets are: Negative big (NB), Negative medium (NM), Negative small (NS), zero (ZE), Positive small (PS), Positive medium (PM), and positive big (PB).

FLC is characterized as:

- Seven fuzzy sets for each input and output.
- Triangular function is used for the sake of simplicity.
- Continuous universe of discourse used for fuzzification.
- Mandani's 'min' operator used for implication.
- Centroid of area method is used for defuzzification.

4. MODELLING AND SIMULATION

In this paper, a Mandani fuzzy controller was chosen and designed with linguistic term "if then". The linguistic variables for the rule base was selected as, positive big (PB), positive medium (PM), positive small (PS), negative big (NB), negative medium (NM), negative small (NS) and zero (ZE). The design of the proposed fuzzy logic controller is characterize as follows.

- Seven memberships function for each two inputs error (e) and its derivative (ɕe) are used.
- Seven memberships function for one output.
- Mandani implication in the design was used.
- Centre of area (COA) was used for the deffuzzification process.
- Triangular membership functions are used due to its simplicity

As it was defined for the linguistic rule variables, table 1 below shows the "if then" rules for the five membership functions selected for each of the input error (e) and the change of error (ɕe). For the two inputs, only twenty five possible rules are possible based on (7*7) =49 "if then" combinations.

Table-1 Fuzzy rule base table

ε /Δε	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fig-3 to Fig-6 shows the membership functions for error, change in error, output and surface view of the fuzzy logic functions.

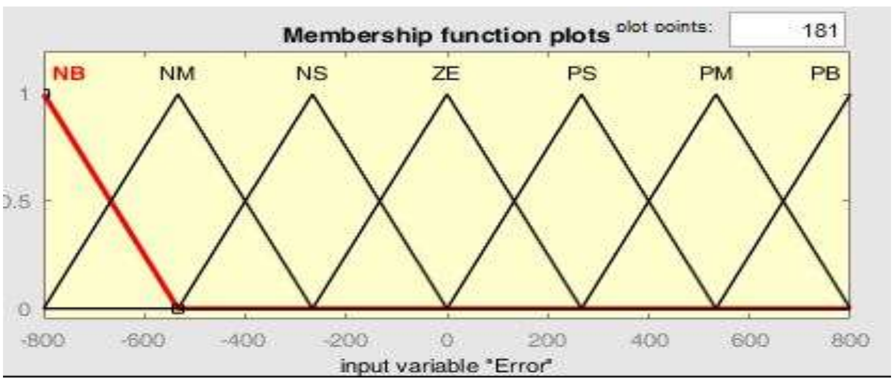

Fig-3 membership functions for error

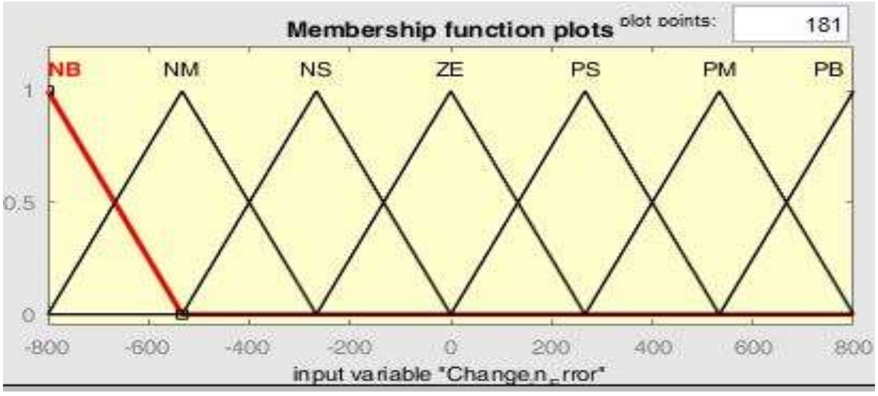

Fig-4 membership functions for change in error

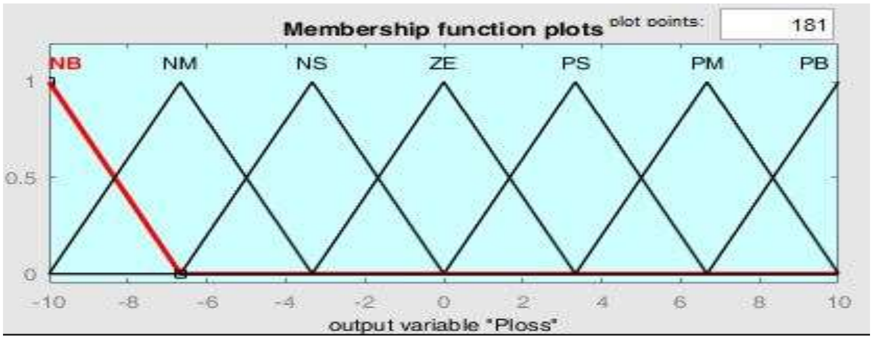

Fig-5 membership functions for output

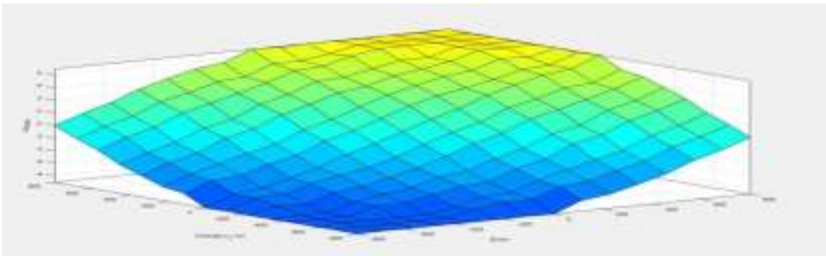

Fig-6 surface view of the fuzzy logic functions.

The data was collected from the plant and a replicate model was modelled in the MATLAB Simulink. The model was analyzed for the harmonics. Figure 7 shows the three phase voltage and current waveform at the point of common coupling(PCC). As can be seen from the figure the voltage waveform is slightly distorted whereas it shows a large amount of distortion in the 3 phase current waveform.

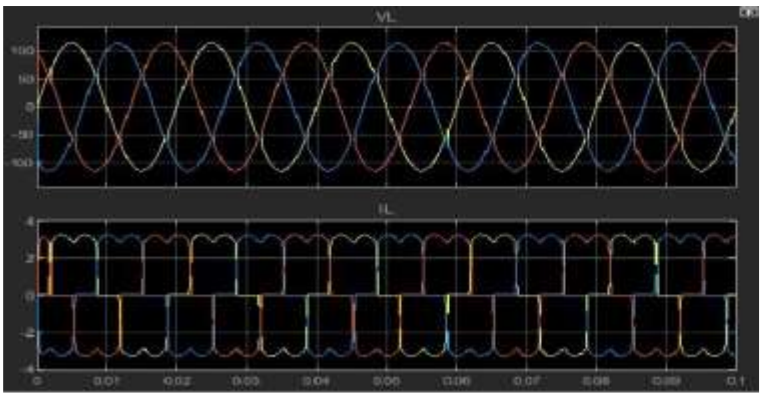

Fig-7 Three phase Voltage and current waveform at PCC

4.1. Analysis of Voltage Distortion

In this simulation, THD for voltage (THDv) of Photovoltaic-grid integration is shown as FFT analysis in figure 8 and 9. Figure 8 demonstrates the voltage harmonics caused at the PCC near the load. Figure 9 shows the THDv generated at the source end. This phenomenon of THDv has occurred due to the integration of the photovoltaic system in the grid.

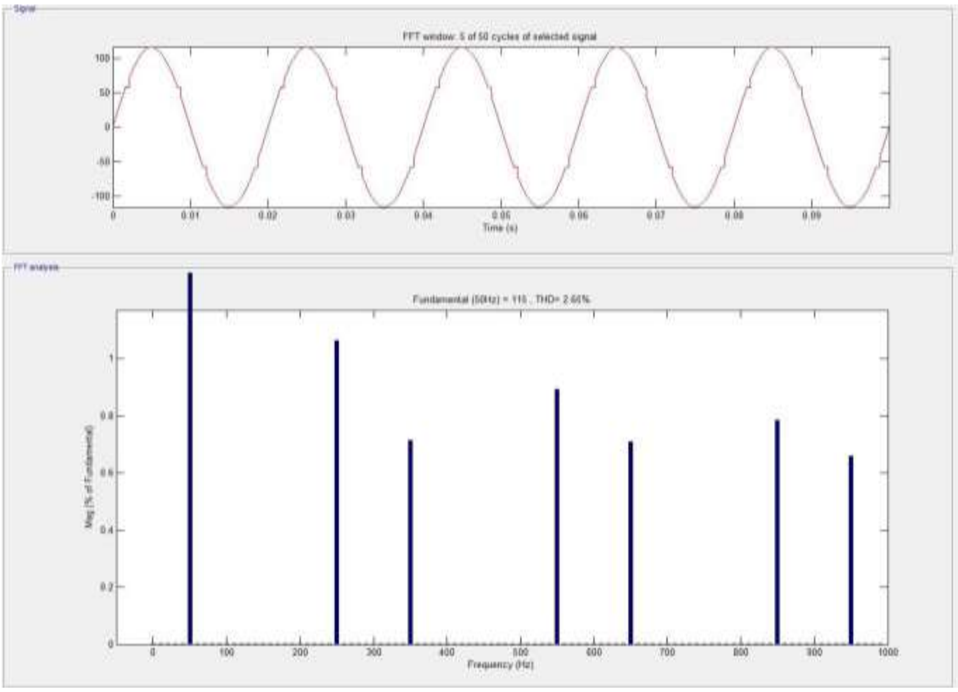

Fig-8 FFT Analysis of source current

As can be seen through the figures, THDv at the PCC is analyzed to be 2.65% and that at grid source end has come to be negligible.

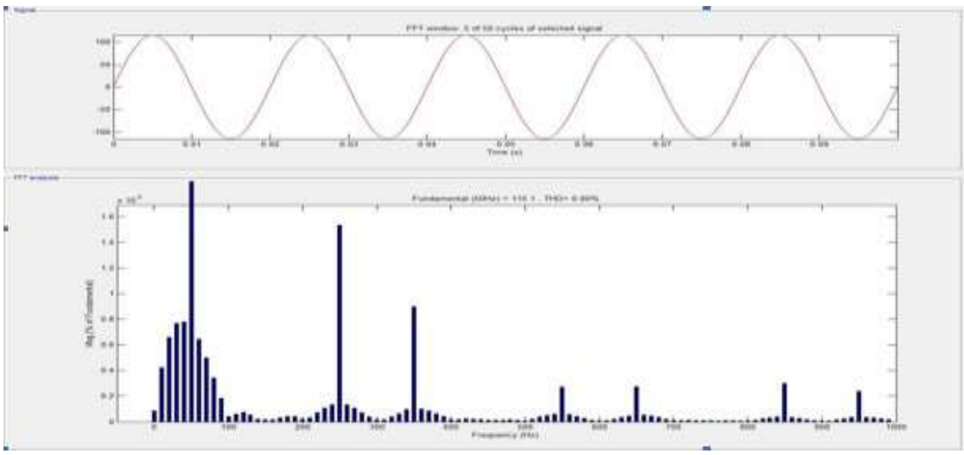

Fig-9 FFT Analysis of a source voltage

4.2 Analysis of Current Distortion

THD for current (THDi) of Photovoltaic-grid integration performed through the simulation is revealed as FFT analysis in figure 10 and 11.

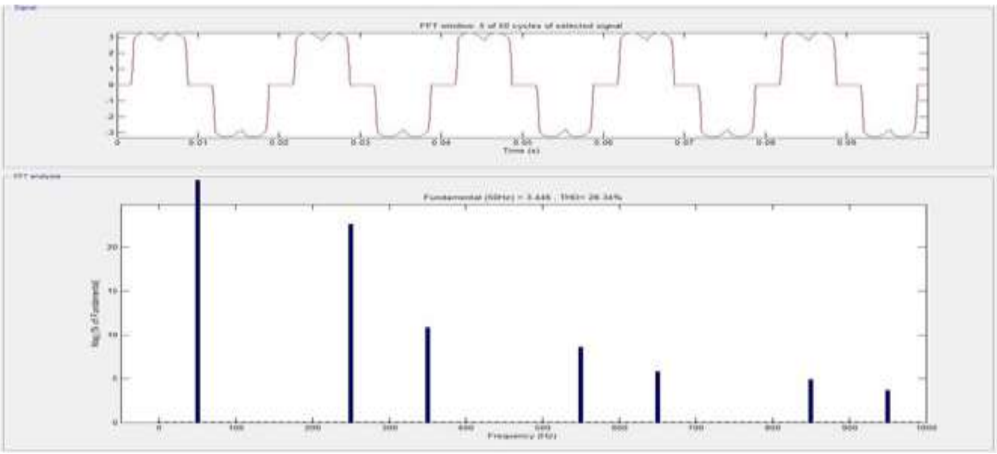

Fig-10 FFT Analysis of load current

Figure 10 demonstrates the current harmonics occurred at the PCC near the load. Figure 8 shows the THDi generated at the 3 phase source end. This phenomenon of THDi has occurred due to the integration of the photovoltaic system in the grid. As seen through the figures, THDi at the PCC is analyzed to be 28.34% and at the source end, it comes to be very less. A large amount of distortion may harm the equipment at load end as well as the power distribution network.

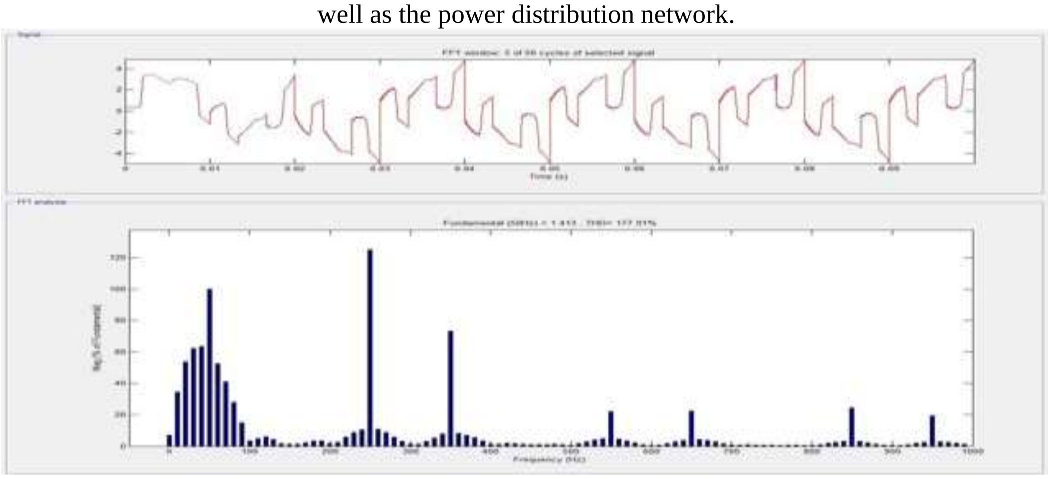

Fig-11. FFT Analysis of compensating current

5. CONCLUSION

The result of this study shows that the THD comes to be 2.65% at the source end. This distortion is within the specified limits of 3-5% as set by the IEEE Standard. THDi comes to be 28.34% at PCC. These values are much above the specified limits of 5% as set by the standard of IEEE. The current harmonics were caused by the non-linear loads and the power electronics devices used for the Photovoltaic plant. The power quality problem of harmonics shown above can badly impact PV plant economics. The results of the report show that several challenges related to harmonics and power quality occurs while integrating PV with a grid. It is required to bring current harmonics within the defined limit of 5%.To do so; smart control solutions need to be adopted.

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