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Enhancement of Power Quality in Grid-Connected PV System Using Fuzzy Logic Controller

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ABSTRACT

The integration of Photovoltaic (PV) systems into the electrical grid has escalated significantly due to the global shift towards renewable energy sources. However, this integration poses challenges related to power quality due to the variable nature of solar energy and the switching operations in power electronic converters. This paper presents a novel approach to enhance the power quality in grid-connected PV systems using a Fuzzy Logic Controller (FLC). The proposed FLC is designed to manage the inverter control strategy effectively, ensuring stable and high-quality power supply to the grid under various operating conditions. The performance of the FLC is compared with traditional control methods under scenarios such as fluctuating solar irradiance and load changes. The system model and control algorithms are developed and simulated in MATLAB/Simulink environment. The results demonstrate that the FLC significantly improves the power quality by reducing Total Harmonic Distortion (THD), maintaining the power factor close to unity, and ensuring voltage and frequency stability of the grid-connected PV system. This study provides a promising solution for addressing the power quality issues associated with the integration of renewable energy sources into the grid, thereby facilitating a smoother transition towards sustainable energy systems..

KEYWORDS: Photovoltaic System, Power Quality, Fuzzy Logic Controller, Grid Integration, MATLAB/Simulink, Total Harmonic Distortion, Renewable Energy.

1. INTRODUCTION

Most of the world's energy needs are now met by burning rapidly depleting fossil fuels including petroleum, coal, and natural gas. In particular, carbon dioxide, a byproduct of burning fossil fuels, is a significant contributor to global warming and a grave threat to all forms of life on Earth [1].

PV array systems are expected to play a substantial part in future energy generation, even more so than other forms of renewable energy. Solar photovoltaic (PV) systems convert light into electricity. Fuel cells, wind generation, and solar systems all provide low voltage output and need large step-up dc/dc converters to meet their various application requirements. With the rising demand for power and the decreasing availability and rising costs of nonrenewable sources, the photovoltaic (PV) energy conversion system has emerged as a viable option since it is abundant, produces no pollution, and is cheap to operate and maintain. Therefore, both independent and grid-connected PV systems should make more use of this energy source. As a renewable energy source, photovoltaic (PV) is subject to fluctuations in supply and demand based on factors such as latitude, longitude, time of day, and weather. Additionally, PV systems have a relatively high upfront cost and maintenance costs. Operating the system close to the maximum power point (MPP) so as to acquire roughly the maximum power of PV array is a crucial factor in improving the efficiency of PV systems. in order to get the most power from a solar array.

When seeking to maximise the output of PV systems, it is common practise to think about installing a high-efficiency power converter designed specifically for this purpose. If you look at the V-I curve, you'll see that there's just one spot—the Maximum Electricity Point (MPP)—where the PV system is functioning at its most efficient and producing the most electricity. The MPP's position may be predicted using search methods or computational models even if its precise location is unknown. Maximum Power Point Tracking (MPPT) methods are used to maintain the PV array's operating position at the optimum point for power production. Various MPPT algorithms have been studied in the literature, including Perturb and Observe (P&O) [2–5], Incremental Conductance (IC) [2–6], Artificial Neural Network (ANN) [7], Fuzzy Logic (FL) [8, etc.]. P&O and IC are the two most typical approaches. This study examines four different MPPT strategies: P&O, the Incremental Conductance (IC) methodology [2-6], the Fuzzy Logic method [8], and the Particle Swarm Optimization strategy [10]. The low price and simple execution of these methods have led to their widespread adoption. Methods like Sliding Mode [9] are beyond the scope of this article due to their intricacy and lack of practical use.

In this study, we will work on a simulation model to determine how to best design and dimension the hybrid system across a wide range of stress and weather circumstances. The efficiency of the suggested system is confirmed by a simulation model run in Matlab and SimPower Systems, with the results reported. In Figure 1 we can see the hybrid energy generating system that is intended to be linked to the grid.

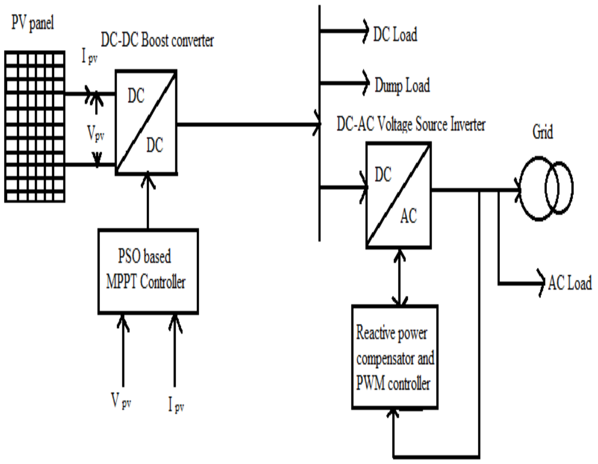

Figure 1: Configuration of proposed grid connected hybrid system

2. LITERATURE SURVEY:

Control solutions for a single-stage photovoltaic (PV) inverter were studied by Ciobotaru et al. [15]. We have constructed two distinct current controllers and compared their performance experimentally. Moreover, the single-phase PV system's whole control architecture is detailed. In order to keep active and reactive power in balance during isolated microgrid operation, Mahmud et al. [16] suggested a resilient nonlinear distributed controller architecture. Microgrids are defined in this research as inverter-dominated networks that include renewable energy sources (RESs) and battery energy storage systems (BESSs), with solar photovoltaic generators playing the role of RESs and plug-in hybrid electric cars filling the role of BESSs. The implementation and enhancement of the performance of the electrical power system rely heavily on power electronics converters. Increased use of distributed energy resources (DERs) is correlating with the need for both new power sources and improved power supply quality. A model predictive controller's goal is to reduce common mode voltages and voltage discrepancies between capacitors and their nominal values. By providing a simulation flowchart, settings, and results using the PLECS programme, Bo and Yang [17] prove the efficacy of their suggested control mechanism and the value of multilevel inverters.

3. SOLAR SYSTEM

To put it simply, solar cells are the workhorse of any photovoltaic (PV) system. A PV array is simply a group of solar cells wired in series or parallel to produce the desired current, voltage, and high power. Each solar cell can be thought of as an individual diode with a semiconductor p-n junction [5]. When light is shone onto the junction, the photovoltaic effect causes currents to flow. The power output characteristics of the PV array at an insulation level are shown in Figure 3. Each output power characteristic curve displays a maximum power point. In Figure 3, we can see the (I-V) and (P-V) characteristics of the PV array at varying solar intensities. Solar cells have an equivalent circuit made up of a forward-biased diode connected in series with the current source. The terminals at the end of the output are used to link up the load. The solar cell's current equation is as follows:

$$I = I_{ph} - I_D - I_{sh}$$

$$I = I_{ph} - I_o [\exp(q V_D / nKT)] - (V_D / R_S)$$

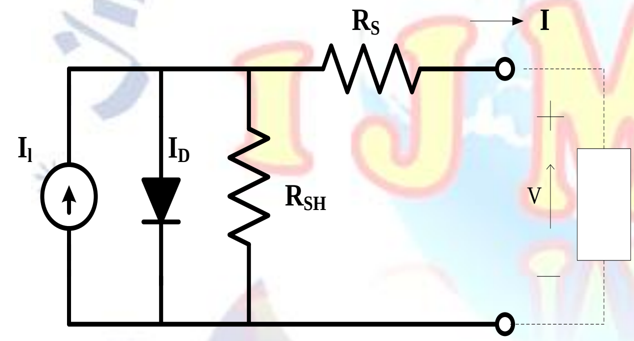

Figure 2: Equivalent circuit of PV Module

Power output of solar cell is P = V * I

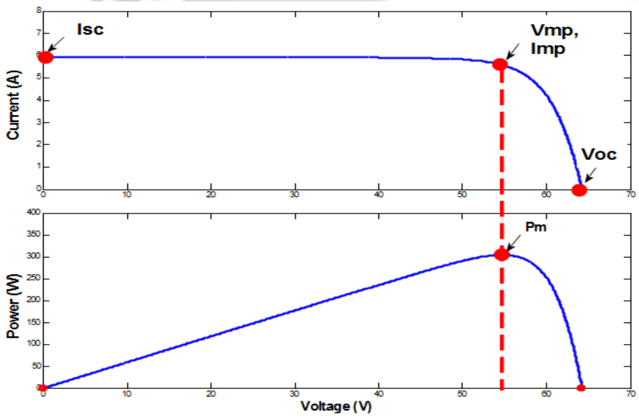

Figure 3: Output characteristics of PV Array

4. MAXIMUM POWER POINT TRACKING METHOD:

When it comes to the output power characteristics of a PV system, the irradiance and temperature curves play the most important roles. For the time being, solar radiation and temperature keep these two constant. Figure 1 depicts the dramatic fluctuations in solar radiation levels that have been described. Only around 30% to 40% of the solar irradiance that hits a typical solar panel is converted into usable electricity. The thevenin impedance (source impedance) of a circuit must coincide with the thevenin impedance (load impedance) of the circuit for maximum power transfer to occur. Therefore, it is essential to employ the Maximum power point tracking approach to maximise solar panel performance.

In response to rising input voltage or current, a PWM generator can increase the frequency of its switching to boost the solar array's output current. While doing this, more voltage is given to the inductor, which increases the charge current. Where sensor readings of current and voltage are used to determine a starting voltage and power output [9]. After determining the true power output, the Vref reference voltage is adjusted by comparing the current measurement to the previous one.

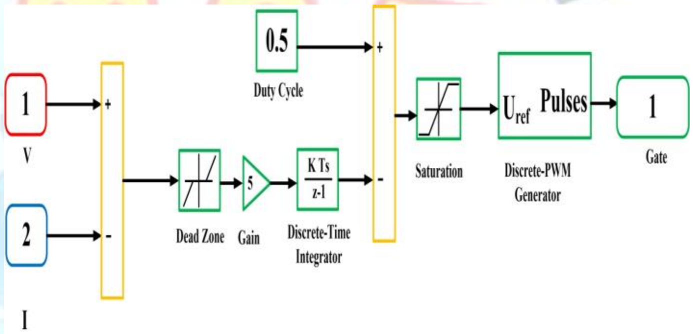

Figure 4: DC-DC converter MPPT Controller

5. PROPOSED SYSTEM

The amount of solar insolation affects the amount of active power that can be pumped into the grid by a solar inverter that is connected to the grid. The amount of active power pumped into the grid will be less than the solar inverter's rated capacity if the sun's rays are less intense than expected. A consequence of this is that the inverter is underutilised. When the solar resource is not at full capacity, the inverter can still function at its rated capacity if it is programmed to provide reactive power in addition to active power (based on the availability of solar irradiance). Controlling network voltages by injecting and absorbing reactive power is an intriguing method, and reactive power compensation using a solar inverter is one promising approach.

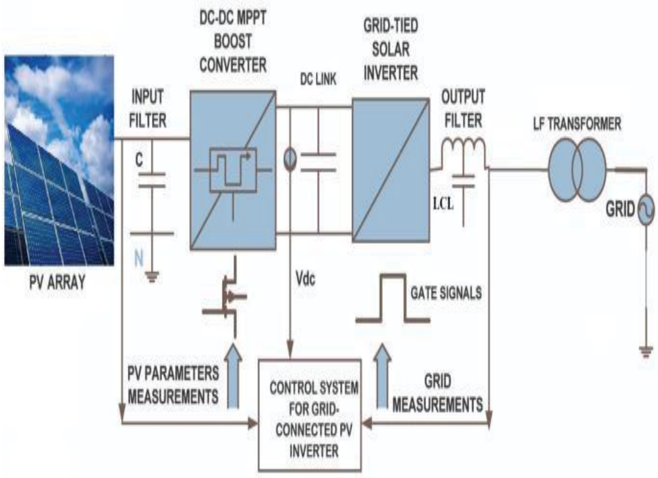

Figure 5: Structure of Grid Connected PV system for Reactive Power Control

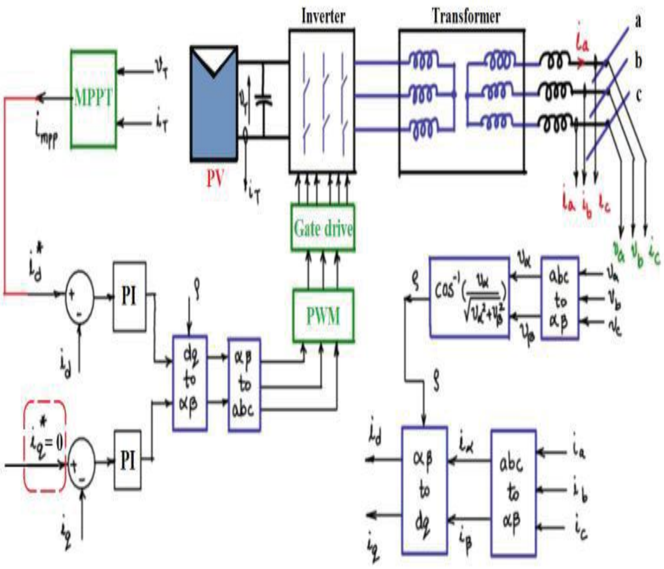

Figure 6: Control of VSI

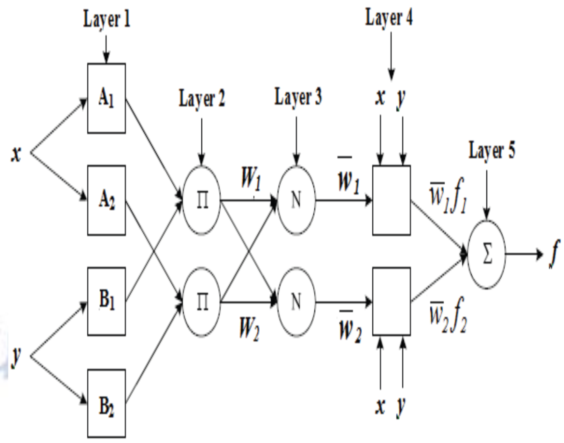

Figure 7: A two-input multi-layer ANN structure

Artificial Neural Network:

Figure 7 depicts the fundamental structure of an artificial neural network, with a circle representing a hidden layer and a square representing an adaptable node. Nodes serving as membership functions are provided between the input and output levels of this architecture, and the rules established by if-then statements are obliterated. We assume the analysed ANN [14] has two inputs and a single output to keep things simple. Each neuron in this network is linked to each component of the input vector p through a weight matrix W.

6. RESULTS AND DISCUSSION:

Modeling the intended control situation was done in MATLAB/Simulink. The suggested system is tested under a variety of scenarios, including steady state, dynamic load, load removal, grid voltage imbalance, varying solar irradiance, and distorted grid voltage.

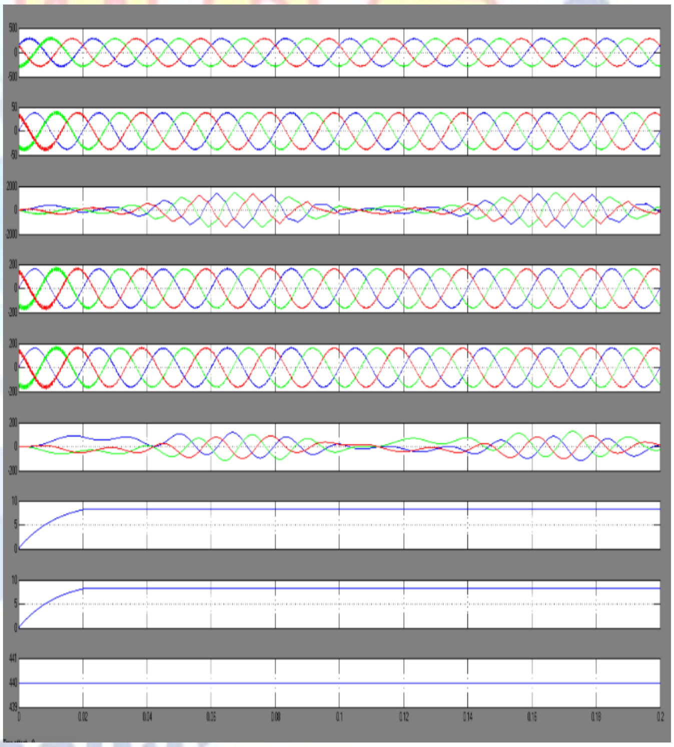

Fig: Without Filter (a) Grid Voltage, (b)Grid Current, (c)Load Current, (d) Voltage at the LCL filter, (e) Voltage at PCC (f) Current at LCL filter (g) DC Voltage

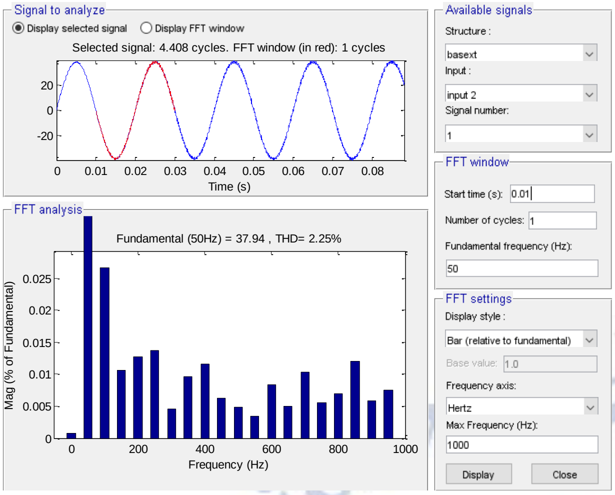

Fig: THD of the grid current without filter

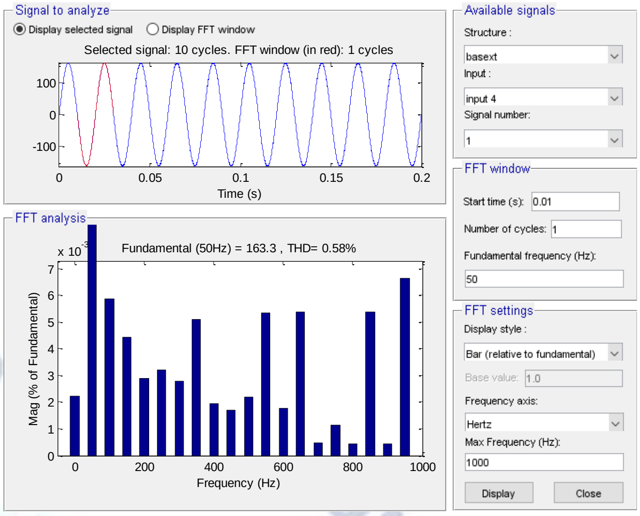

Fig: THD of the grid current when the LCL Filter are connected

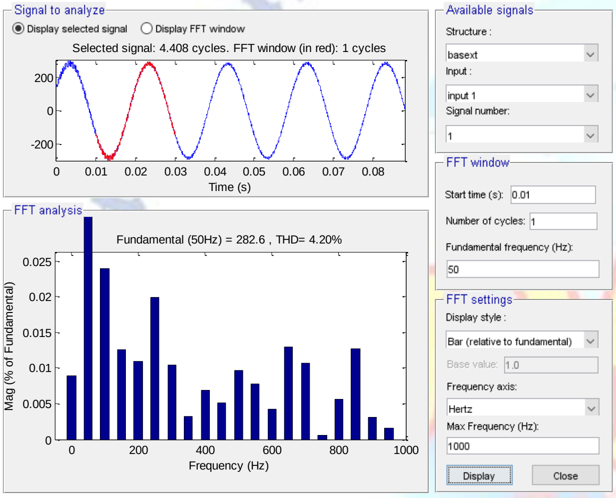

Fig: THD of the grid voltage without filter

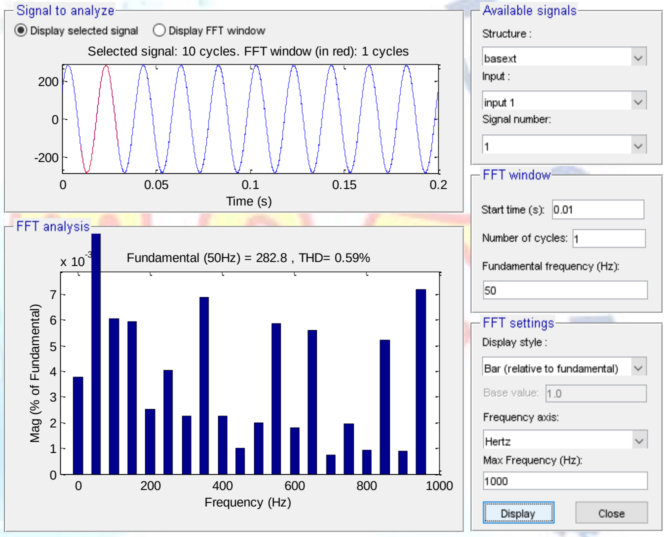

Fig: THD of the grid voltage when the LCL Filter are connected

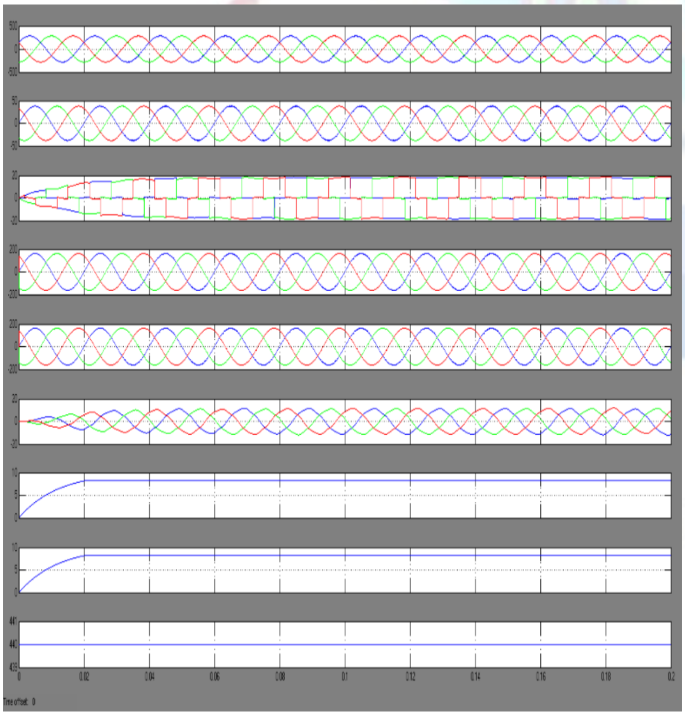

Fig: With Filter (a) Grid Voltage, (b)Grid Current, (c)Load Current, (d) Voltage at the LCL filter, (e) Voltage at PCC (f) Current at LCL filter (g) DC Voltage

Comparision Table

	THD % without LCL filter	THD % with LCL filter
Grid Voltage	4.50	0.59
Grid current	2.25	0.58

7. CONCLUSION

Your data outlines the impact of using an LCL filter in a grid-connected solar photovoltaic system on the power quality, specifically in terms of reducing the Total Harmonic Distortion (THD) of both the grid voltage and grid current. Here's a more detailed look at the results:

THD in Grid Voltage:

Without LCL Filter: The THD is 4.50%, indicating a moderate level of harmonic distortion relative to the fundamental frequency. This level of distortion can affect sensitive equipment and is higher than what is typically desired for grid-connected systems.

With LCL Filter: The THD significantly drops to 0.59%. This is a substantial improvement in power quality, reducing the harmonic distortion to a much more acceptable level that is likely compliant with most grid codes and standards for interconnection.

THD in Grid Current:

Without LCL Filter: The THD is 2.25%, which, while lower than the voltage THD, still indicates the presence of undesirable harmonics in the current waveform.

With LCL Filter: The THD is reduced to 0.58%, showing a similar significant improvement as seen with the grid voltage. This reduction is crucial for preventing issues related to overheating, inefficiency, and the potential for erroneous operation of protective devices.

The use of an LCL filter in a grid-connected solar photovoltaic system clearly demonstrates its effectiveness in enhancing power quality by significantly reducing the THD levels in both grid voltage and grid current. This not only helps in complying with strict grid codes but also improves the efficiency and reliability of the solar photovoltaic system and the grid to which it is connected. Lower THD levels contribute to a more stable and efficient power system, reducing losses and the potential for interference with other equipment connected to the grid.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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