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Power Flow Analysis Using Fuzzy for Single Phase Transformer Less PV System Connected with a Nine-Level Converter

Abstract: - Power electronics technology advancements and growing environmental concerns worldwide have made photovoltaic (PV) systems more visible in distributed generation systems. Photovoltaics, or solar PV, is an important component of solar energy for generating electricity. Grid-connected inverters must be able to regulate the amount of power they inject into the grid, track maximum power points, be highly efficient, and inject currents into the grid with minimal harmonic distortion. Two step-down converters were used to construct an inverter without a single-phase transformer. This study investigates two multi-sequence inverter types that use different voltages and are based on single-phase grid-connected photovoltaic (PV) technology. A new nine-level grid-connected transformer-less photovoltaic converter was proposed in this study. MATLAB was used to construct the complicated FFT simulation using fuzzy logic controls. Analyzing efficiency through simulation in order to enhance efficiency. This work aims to replace PI controllers with fuzzy controlled systems so that single-stage operation can be improved with reduced switches in an economic manner. An improvement of 10% over the existing system is achieved by implementing fuzzy computing.

Keywords: Multi-level Inverter,Transformer less , Power quality , THD, Trapezoidal PWM

I. INTRODUCTION

In the last twenty years, global energy demand has been growing at a rapid pace [1]. As the load demand rises, the power quality decreases. Renewable power sources (solar, wind, biomass, fuel cells, etc.) have converter-related power quality issues, but recent innovations in smart and micro grids are pushing customers to use these technologies to generate electricity [2]. The power quality of a distribution system that is connected to the grid improved as the number of levels in a multilayer inverter increased [3]. The multi-level inverter (MLI) makes use of a greater number of switches connected in different modes, including flying capacitors, diode clamps, and cascade H-bridges, to efficiently convert AC into DC. The output voltage of the inverter is a pulse width modulation (PWM) or stepped signal, rather than a pure sinusoidal one. The desired number of voltage levels is obtained by controlling switches coupled in such a way that a sine wave is given to the load [4]. With the use of one-cycle control (OCC), Y. Chen et al. [5] disclosed a reasonably priced single-stage inverter that monitors the peak power point. This control method takes advantage of the ability of OCC to alter the output current. By adjusting the inverter's output current in response to the voltage of the PV array, the power output can be optimized. The task can be accomplished with just one power stage and a straightforward control circuit. Finally, the group headed by Kamran Zeb et al [6]. There are several scientific reasons why photovoltaic (PV) systems have become increasingly important in the past ten years. Integral to the distributed generation system's efficient interface between utility and renewable energy resources (RER) are grid-tied inverters. Joel Anthony [7]. Improvements and new developments in power converter technology for PV systems, which are commonly utilized in residential grid-connected setups, are the main areas of concentration in their study. In jam Harshith et al **[8]** In their study proposes the transformer less photovoltaic (PV) inverter topology to reduce leakage current Multilevel inverters are a source of high power, often used in industrial applications and can use either sine or modified sine waves. The topology has the advantages of simple structure, low weight and provides higher efficiency. Ahmad h. Sabry et al **[9]** multi-level transformer less inverters are widely used in grid-tied PV systems since they characterized by higher efficiency and lower cost. In this context, new topologies, modulation, and control schemes were presented to solve problems of a common-mode voltage and leakage current. Alireza Katouli **[10]** to investigate the effect of mismatched condition on voltage balance of PV arrays, which leads to the increment of common-mode current. A new circuit structure is presented for compensating for voltage drop caused by partial shading and ambient temperature and removing the effect on the common-mode current.

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A. Background of work enhancement

A 5 level transformer-less inverter with PI controller has been proposed by Felipe Bovolini & Grigoletto [14]. Their findings indicate that low-cost multilevel inverters can be developed with PWM to give better performance including leakage currents and load losses. The author proposes a transformer-less inverter with multilevel common ground which does not use switched capacitors. Compared to full-bridge configuration, this one utilizes fewer switches but has a greater input voltage need. It is common for transformer inverters to have quoted efficiencies of more than 95%. However, keep in consideration that various experimental setups described in the literature use different switching frequencies and semiconductor technologies. These inequalities make it possible to compare

In addition, PWM modulators can be easily used to modulate the voltage over the capacitors in order to maintain a balanced voltage. By operating at five levels, the inverter achieves a superior harmonic distortion reduction compared to inverters that have fewer levels. By considering the above reference strategies the work enhanced for nine levels with flying capacitors in the present work with new fuzzy controller.

II. SCOPE FOR PROPOSED CONCEPT

Many traditional control methods, including as PI, PID, and PD, have been developed for MLIs [11]. Overshoot and settling time are two issues that can arise with these approaches. When it comes to intelligent control approaches, the most user-friendly tool for converters to achieve the desired mode of operation of MLI is fuzzy control. Rahim et al. [12] in their research the method of capacitor balancing addition is missing, despite the fact that seven output levels were produced by connecting three DC-bus capacitors in series with an H-bridge, a diode bridge, and a unidirectional switch. To enable grid-connected operation of this basic topology with no galvanic isolation, a different PWM strategy has been developed. A low ground leakage current cannot be maintained solely by a PWM strategy. Other components are necessary. The most common models of control systems today are mathematical models derived from mathematical logic, stochastic models, or models that follow the laws of physics. When it comes to creating a suitable mathematical model for a certain situation, there is a common issue with such a built model. By tolerating a certain level of imprecision, haziness, and uncertainty in modelling these complicated systems, it is feasible to streamline systems. So, while it may be impossible to construct a perfect system, it can typically find an adequate solution.

III. Existing Zone system for approach

Table 1: Theoretical switching zones

Zone	Output Voltage	On Devices	Off Devices	Switching Devices
Zone 3B	$-V_{DC} - V_{fc} \leftrightarrow -V_{DC}$	$T2, T3, T7$	$T1, T4, T8$	$T5, T6$
Zone 3A	$-V_{DC} \leftrightarrow -V_{DC} + V_{fc}$	$T2, T3, T8$	$T1, T4, T7$	$T5, T6$
Zone 2A	$-V_{DC} + V_{fc} \leftrightarrow 0$	$T3, T7$	$T4, T8$	$T1, T2, T5, T6$
Zone 2B	$-V_{DC} \leftrightarrow -V_{fc}$	$T3, T7$	$T4, T8$	$T1, T2, T5, T6$
Zone 1B	$-V_{fc} \leftrightarrow 0$	$T1, T3, T7$	$T2, T4, T8$	$T5, T6$
Zone 1A	$0 \leftrightarrow V_{fc}$	$T2, T4, T8$	$T1, T3, T7$	$T5, T6$
Zone 2A	$V_{fc} \leftrightarrow V_{DC}$	$T4, T8$	$T3, T7$	$T1, T2, T5, T6$
Zone 2B	$0 \leftrightarrow V_{DC} - V_{fc}$	$T4, T7$	$T3, T8$	$T1, T2, T5, T6$
Zone 3B	$V_{DC} - V_{fc} \leftrightarrow V_{DC}$	$T1, T4, T7$	$T2, T3, T8$	$T5, T6$
Zone 3A	$V_{DC} \leftrightarrow V_{DC} + V_{fc}$	$T1, T4, T8$	$T2, T3, T7$	$T5, T6$

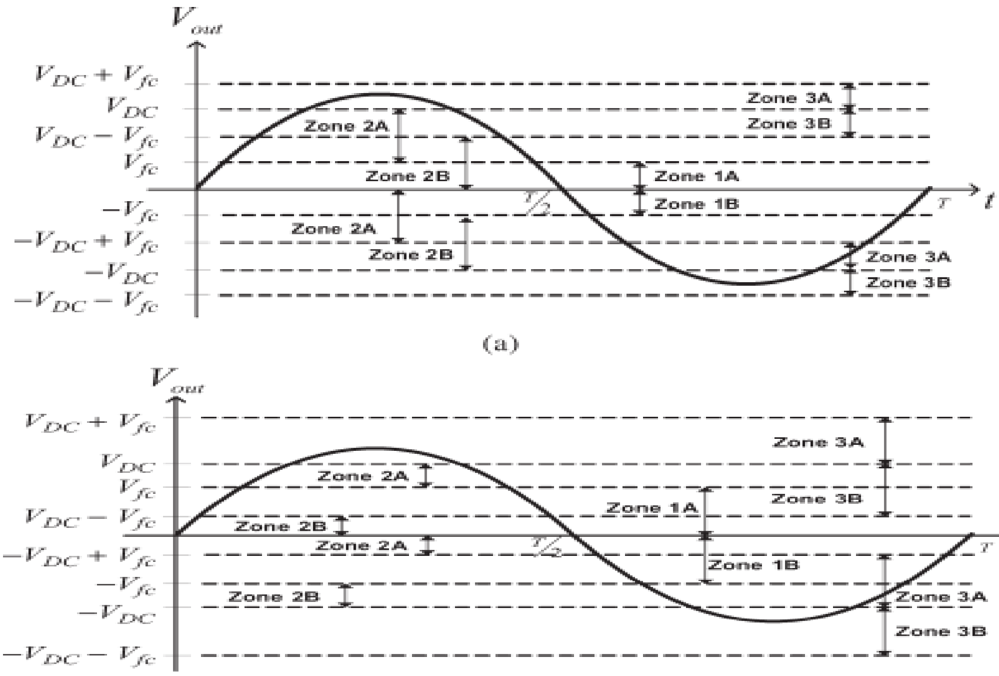


Figure: 1 operating zones with different Vfc ranges

The mode of switching operations has been shown in figure 2 with transition time of on/ off operations to find $V_{out.}$ The multilevel operations can be proved with different modes of time transition can calculated from T_0 to $T_{n.}$ V_{grid} voltages can be calculated with the mode of setting switches regulation with respect to time.

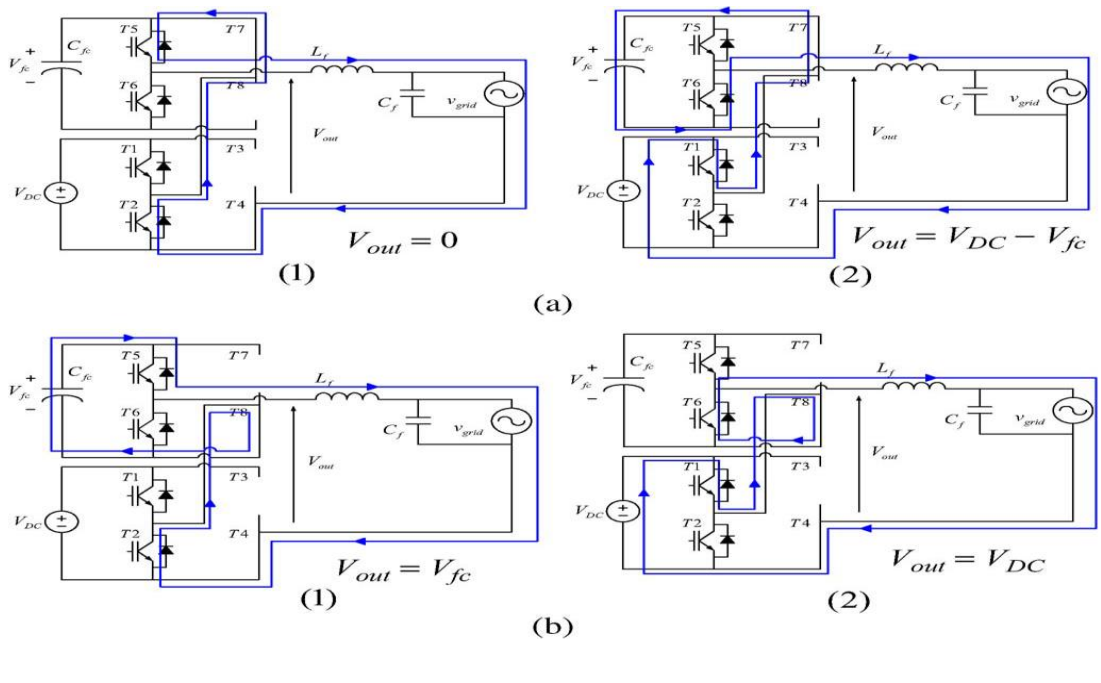


Figure2: Configurations of converters for controlling the flying capacitor. (a) Flying-capacitor charge. (b) Flying-capacitor discharge [13].

Transition switching values of voltage input to V_{out} can be determined with the existing theoretical zones referred by PI.

A. Proposed Fuzzy Logic System

Fuzzy logic plays a crucial role in the single-phase transformer-less PV system by enabling intelligent control and decision-making. It allows the system to adapt to varying environmental conditions, such as fluctuations in solar irradiation and temperature, ensuring optimal power generation and efficient utilization of the photovoltaic panels. Fuzzy logic also enhances the system's fault detection and protection capabilities, improving its overall reliability and performance. Using Fuzzy logic, a single phase inverter system with 9 levels has been developed with fewer switches to improve the system's performance. This paper compares PI with Fuzzy to control power transmission disturbances.

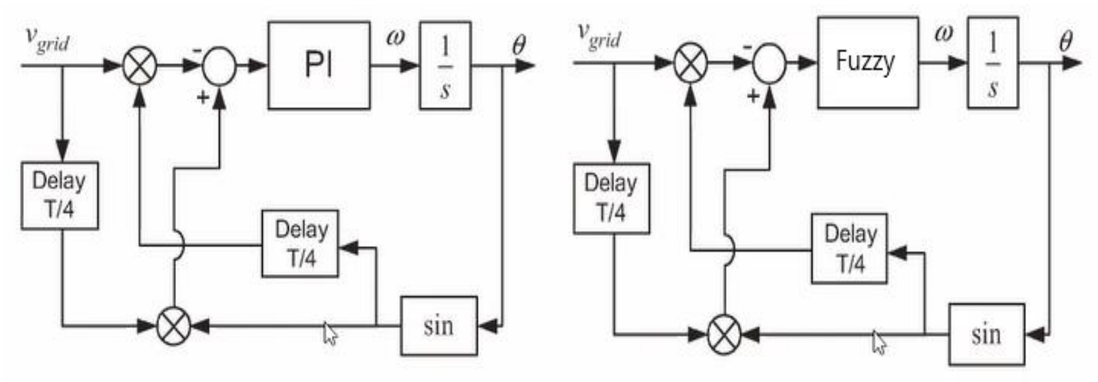


Figure 3: a) Existing PI controller b) Proposed Fuzzy controller

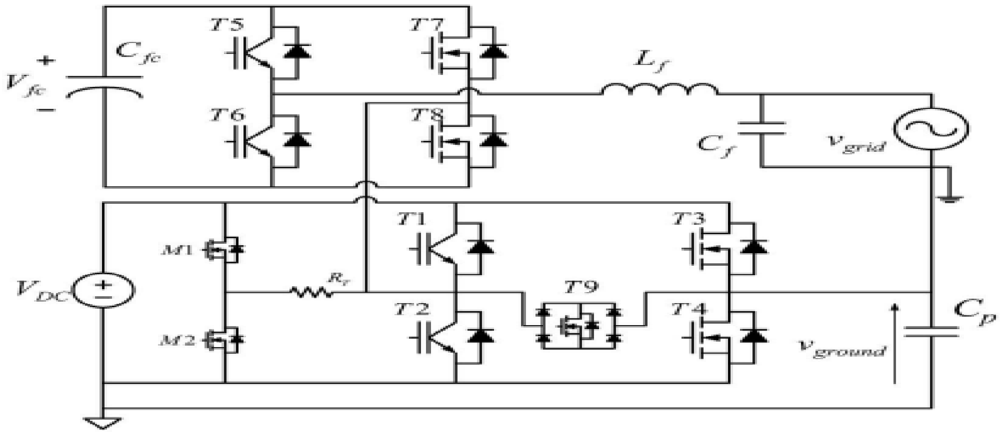


Figure 4: Switch controllers design in circuit

This study introduces a thorough FL-based CHB-MLI that may be implemented in PV systems that are connected to the grid as well as those that are off-grid. An H-bridge's efficiency is improved with the help of a power-sharing algorithm, and the simulation is carried out using a mixed-mode (analogue and digital) FPGA. The system also uses a fully FLC, which eliminates the need for an ideal PWM switching-angle generator and a fuzzy controller. To resolve errors in the existing system, we used the data derived from the existing PI controller-based experiments. Two MOFSET's linked to T9 to neutralize power.

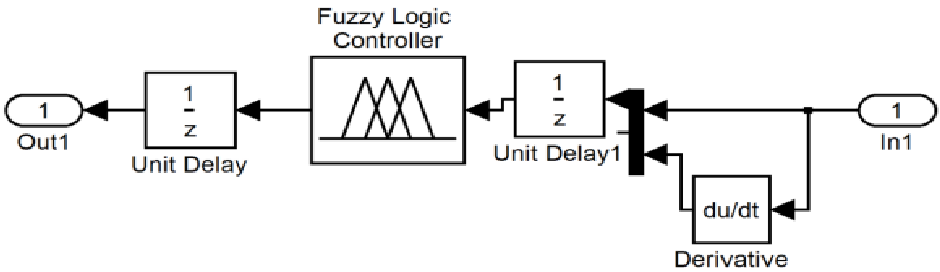


Figure 5: Fuzzy control

Proposed fuzzy control is an integration with two feed-back systems one with grid and another with solar to check the error compensation from solar DC to grid until V_{in} to V_{out} until the requirement of V_{grid} is satisfactory.

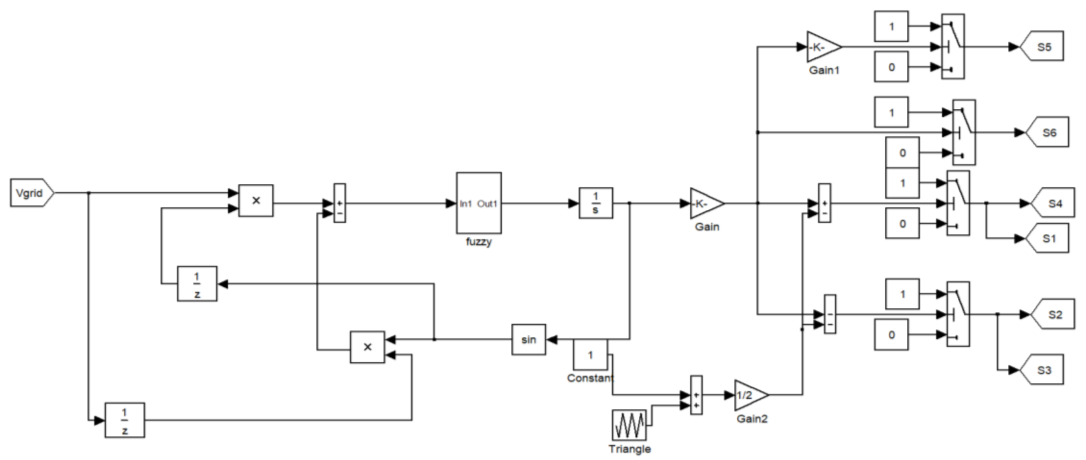


Figure: 6 Fuzzy control block diagram

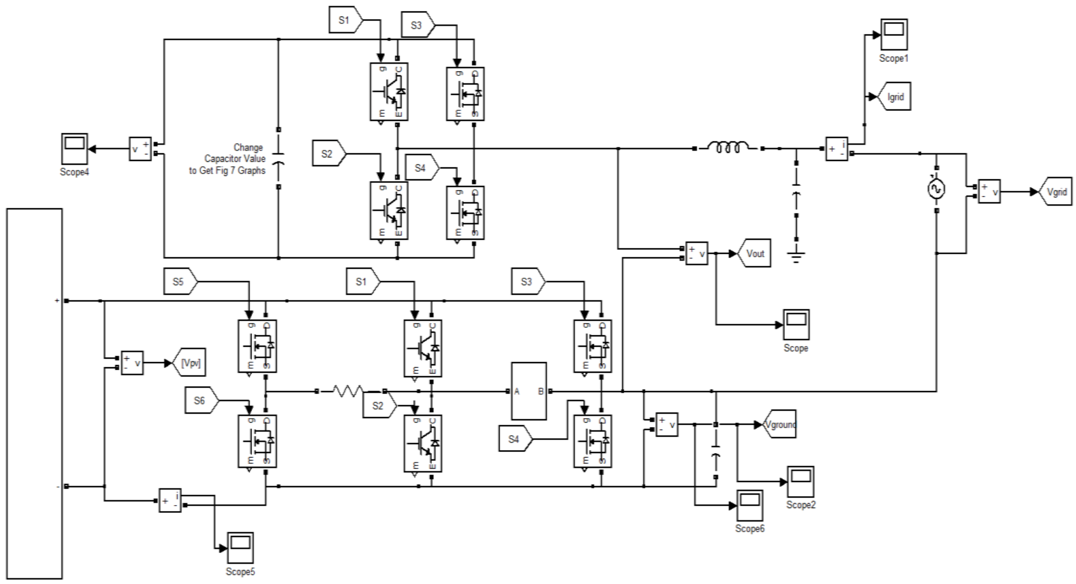
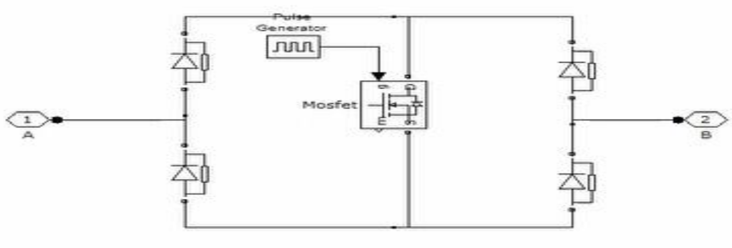


Figure: 7 Mat lab PV block diagram for H-based 9 level inverter

A solar input DC voltage of 330V has been taken as a test of the compensation from the converter when the grid is set to AC. The present design uses a single-stage multilevel converter with fewer switches in order to reduce costs. Fuzzy control block diagram and PV resource diagram has been shown in figure 6 and 7.



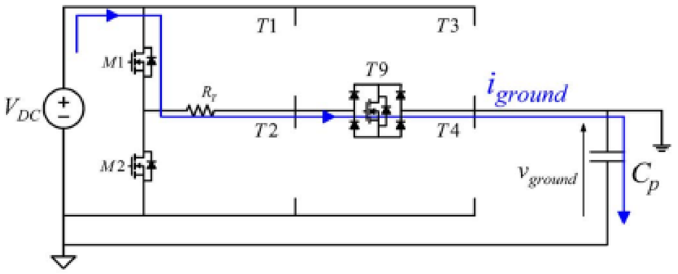


Figure: 8 9th switch for controlling rest of switches

Consider the available PV fields and design concerns when choosing the number of k-bridges. The sinusoidal waveform is more aesthetically pleasing when there is a wide range of levels. When compared to two-level converters, systems with more levels are more complicated and expensive. Energy savings are achieved at lower maximum voltages due to the reduced conduction resistance of insulated-gate bipolar transistors (IGBTs) and MOSFETs, even if switching losses rise with increasing device number in series. Therefore, multilevel converters can reduce total losses compared to two-level converters. Compared to high-power transistors low-voltage transistors (usually MOSFETs) possess a significantly higher switching frequency.

B. Proposed multi-level inverter system

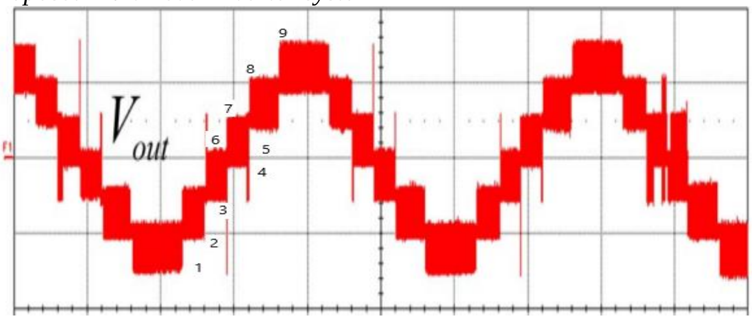


Figure: 9 Experimental multi-level system (Existing system for proposed work)

Table: 2 Switch controllers for combinations

Level	Assignment	S1	S2	S3	S4	S5	S6	S7	S8	S9
1	V dc	off	off	off	off	on	off	on	off	on
2	2Vdc	off	on	off	on	off	off	on	off	off
3	3Vdc	on	off	on	off	off	on	off	off	off
4	4V dc	off	on	off	on	off	off	off	off	off
5	0	off	off	off	off	off	on	off	on	on
6	-V dc	on	off	off	on	on	off	on	off	off
7	2Vdc	off	on	off	on	off	on	off	on	off
8	3Vdc	on	off	on	off	off	on	off	on	off
9	4V dc	off	off	off	off	off	on	off	on	off

The nine level strategies from experimentation are shown in figure 9, according to Giampaolo Buticchi et al. The level 0 was divided into 3 levels with a negative half and a positive half to check the harmonics between level 0 to +Vdc and -Vdc. Likely strategies developed in fuzzy design to control the leveling disturbances in grid power.

Table: 3 the proposed inverter's switching states and voltage outputs

Level	S1	S2	S3	S4	S5	S6	S7	S8	S9	O/P voltage
1	0	0	0	0	1	0	1	0	1	V dc
2	0	1	0	1	1	0	1	0	0	2Vdc
3	1	0	1	0	0	1	0	0	0	3Vdc
4	0	1	0	1	0	0	0	0	0	4V dc
5	0	0	0	0	0	1	0	1	1	0
6	1	0	0	1	1	0	1	0	0	-V dc
7	0	1	0	1	0	1	0	1	0	-2Vdc

8	1	0	1	0	0	1	0	1	0	-3Vdc
9	0	0	0	0	0	1	0	1	0	-4V dc

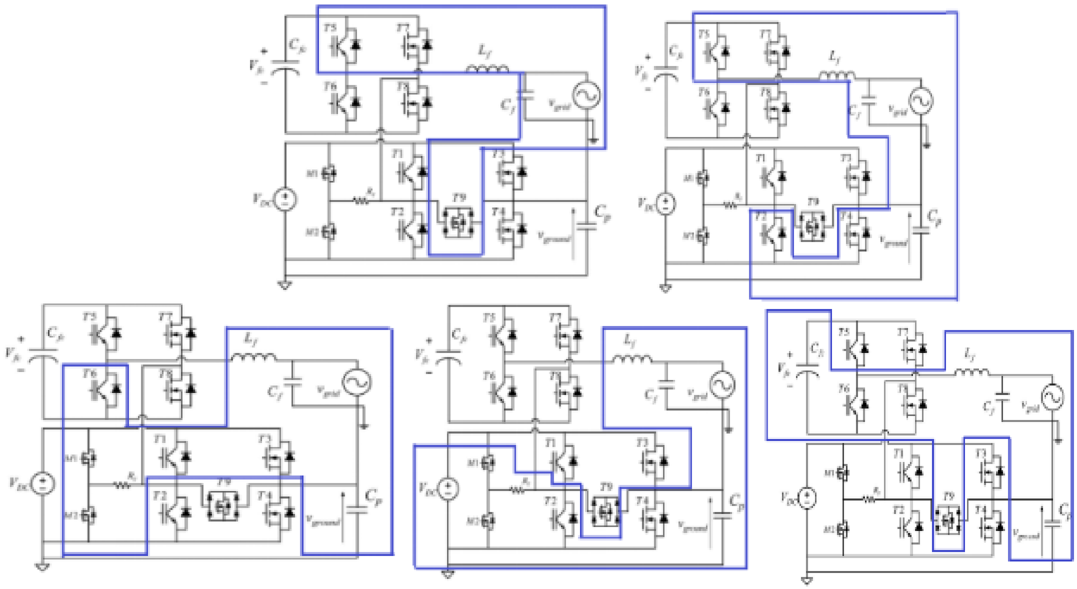
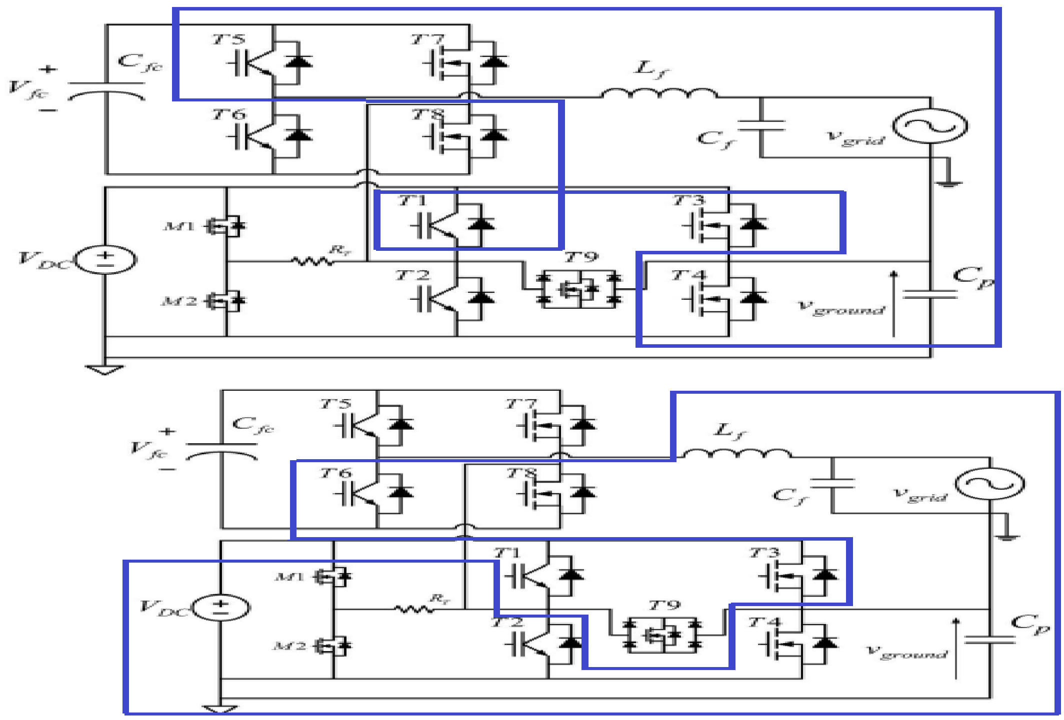


Figure 10: Positive sequences for the synthesis of voltages producing nine levels of output. a) 1 volt direct current; (b) 2 volt direct current; (c) 3 volt direct current; and (d) 4 volt direct current are the possible output voltages. e) Nothing.

Table 3 presents the nine states that can be produced by each of the positive-signal operational modes in figure 10a-d, and to generate the exact same nine states, the negative-signal modes are illustrated in Figure 11a–d. Based on these operating sequences, the suggested design creates DC voltage sources in an easy way, lowering the stress voltage across the active switch and generating enough voltage without complex regulation of switch pulses.



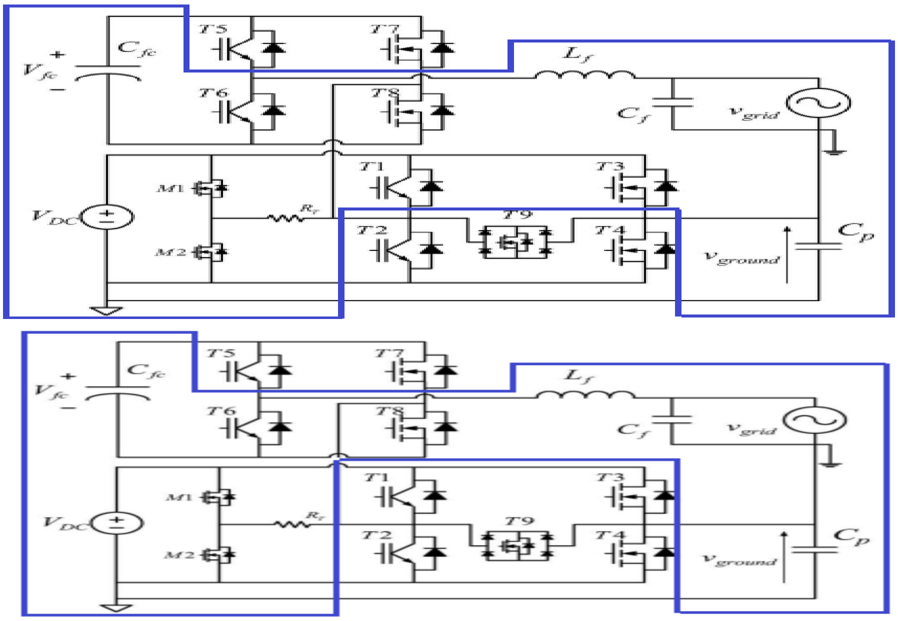


Figure 11: Negative steps for creating voltages with nine levels of output. (a) -2 Vdc is the output voltage; (b) -3 Vdc is the output voltage; and (d) -4 Vdc is the output voltage.

Number of membership functions = 7 and array 7^7= 49	Strategical inputs
MF1='LN' MF2='MN' MF3='SN' MF4='ZE' MF5='SP' MF6='MP' MF7='LP'	Version=2.0 Numb Inputs=2 Numb Outputs=1 Numb Rules=49 And Method='min' Or Method='max' Imp Method='min' Agg Method='max' Defuzz Method='centroid'

Table: 4 Fuzzy rule consideration for present work

e/de	LN	MN	SN	ZE	SP	MP	LP
LN	LN	LN	LN	LN	NM	NS	ZE
MN	LN	LN	LN	MN	SN	ZE	SP
SN	LN	LN	NM	NS	ZE	PS	PM
ZE	LN	MN	SN	ZE	SP	MP	LP
SP	NM	SN	ZE	SP	MP	LP	LP
MP	NS	ZE	SP	MP	LP	LP	LP
LP	ZE	SP	MP	LP	LP	LP	LP

The simulations utilized a DC-link voltage of VDC = 300 V. The output filter of the grid had two capacitors and one inductor for an amplitude of 50 Hz and a voltage of 230 V. With an amplitude of 50 Hz and a voltage source of 230 V, a sinusoidal voltage was used to mimic the grid. This total distributed grid inductance was represented by an extra inductor Lgrid = 40 µH. The flying capacitor has a capacitance of 500 µF as measured with a PWM frequency of fs = 20 kHz. A limit of 1.5 kΩ was set for surges when RT was chosen. The grid was supplied with 8.5 A rms of current through a proportional-integral regulator with feed forward [13]. The MOSFETs M1 and M2 are low-power MOSFETs, the bidirectional switch T9 is a resistor, and the MOSFET M3 is a high-power MOSFET. A converter entering operating zone 1 results in zero HVFB output voltage when T1 and T3 are turned on or T2 and T4 are turned on. When zone 1 is entered, TC turns on T9, but disables T1, T2, T3, and T4. The other zone strategies are likewise as shown in table 2.

IV. RESULTS AND DISCUSSIONS

Performance was independent of the power factor due to the perfect switches and instantaneous commutations, even if the injection of reactive and active power was simulated. Consequently, the outcomes of the unity power factor simulation are the only ones that are shared. Since data on the grid voltage angle was already accessible, no PLL was included in the simulations. A floating capacitor provides one of the two full bridges in its controlled feedback topology.

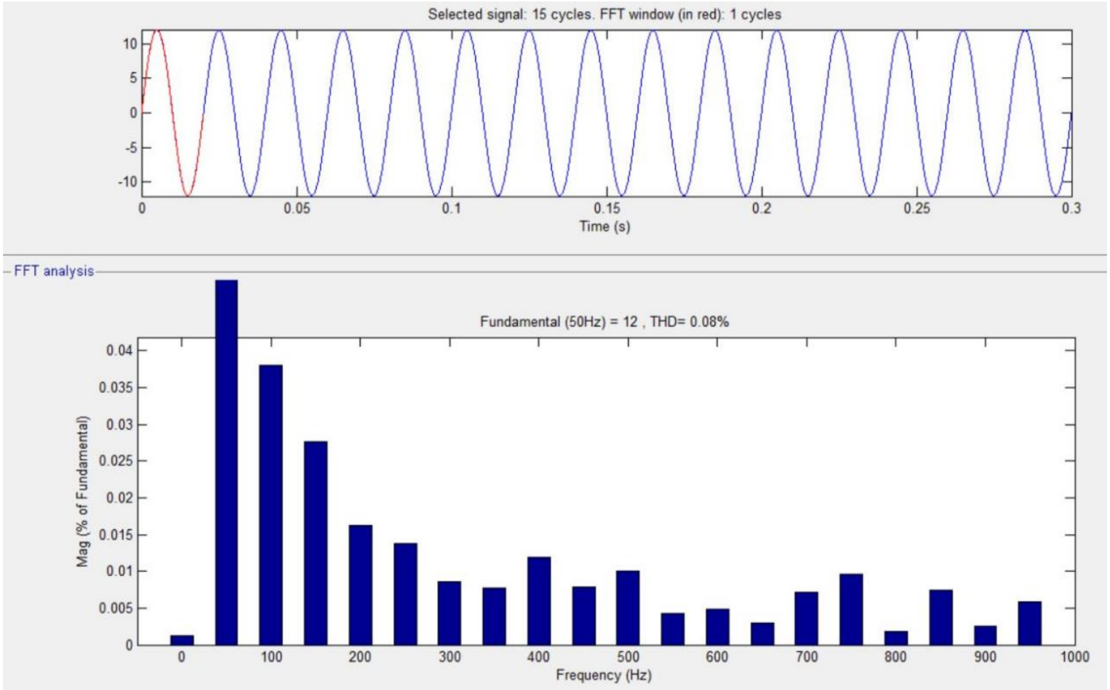


Figure 12: Total harmonic distortion (THD)

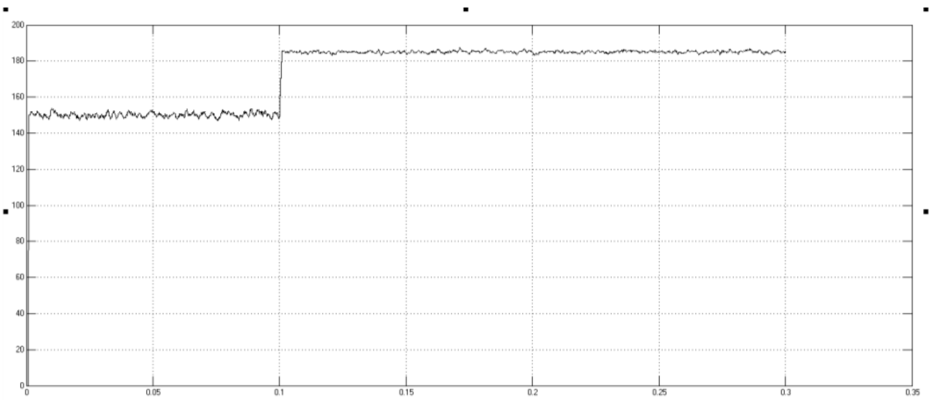


Figure 13: Measured efficiency of proposed inverter

Also, the high-power rating's simulation results were confirmed. The calculated total harmonic distortion (THD), the actual current flowing via the resultant the terminals, and the hypothetical inverter voltage across the same terminals are shown in Figures 12, 13, and 14, correspondingly. We take the 360 V DC input voltage and use it to determine the AC output voltage. As it was, the current THD was a miniscule 0.08%.

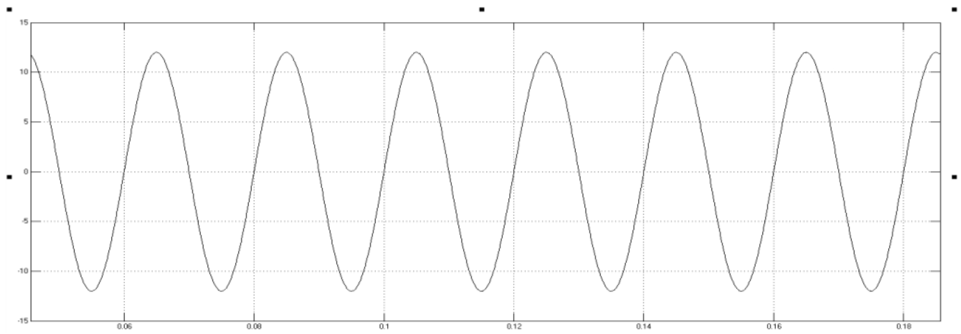


Figure 14: Output current

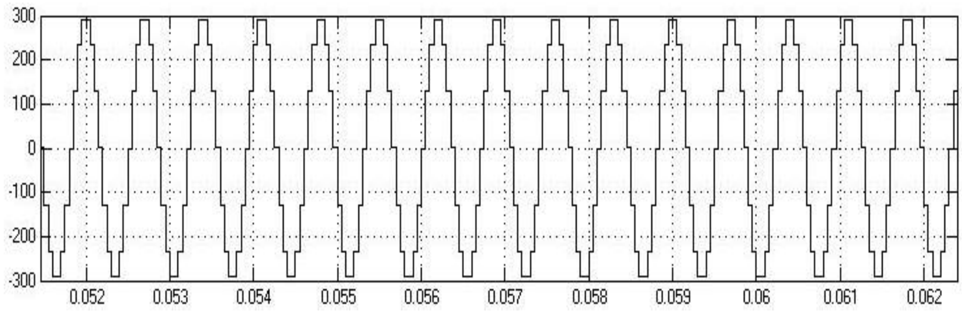


Figure 15: Multi-level voltages (Capacitor voltage levels)

The output voltage of a nine-level inverter with a single stage of source. An almost sinusoidal form characterizes the inverter's output current. All signs point to a low Total Harmonic Distortion (THD) for the nine-level single-source arrangement. A power factor of nearly one means improved operation when used in grid-connected applications.

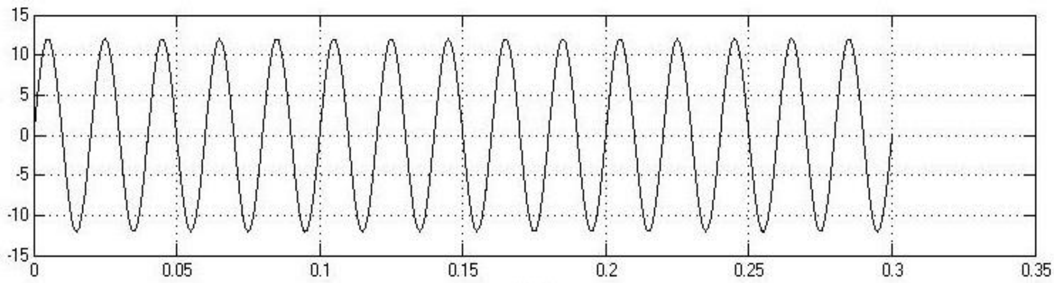


Figure 16: single phase Grid voltage

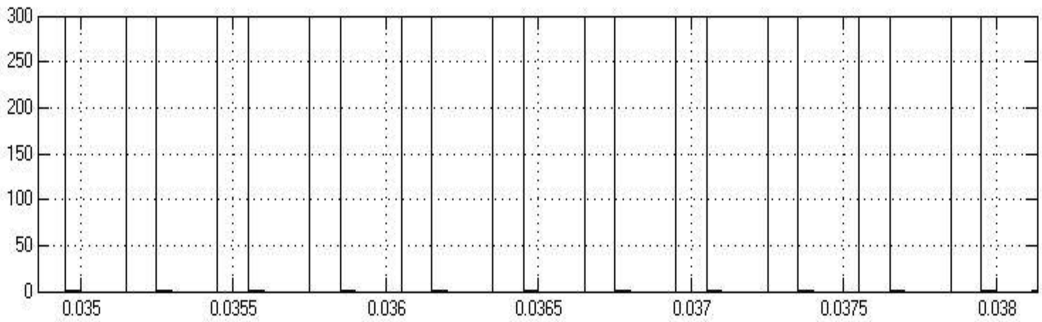


Figure 17: Transient modulation index showing output current and PWM voltage

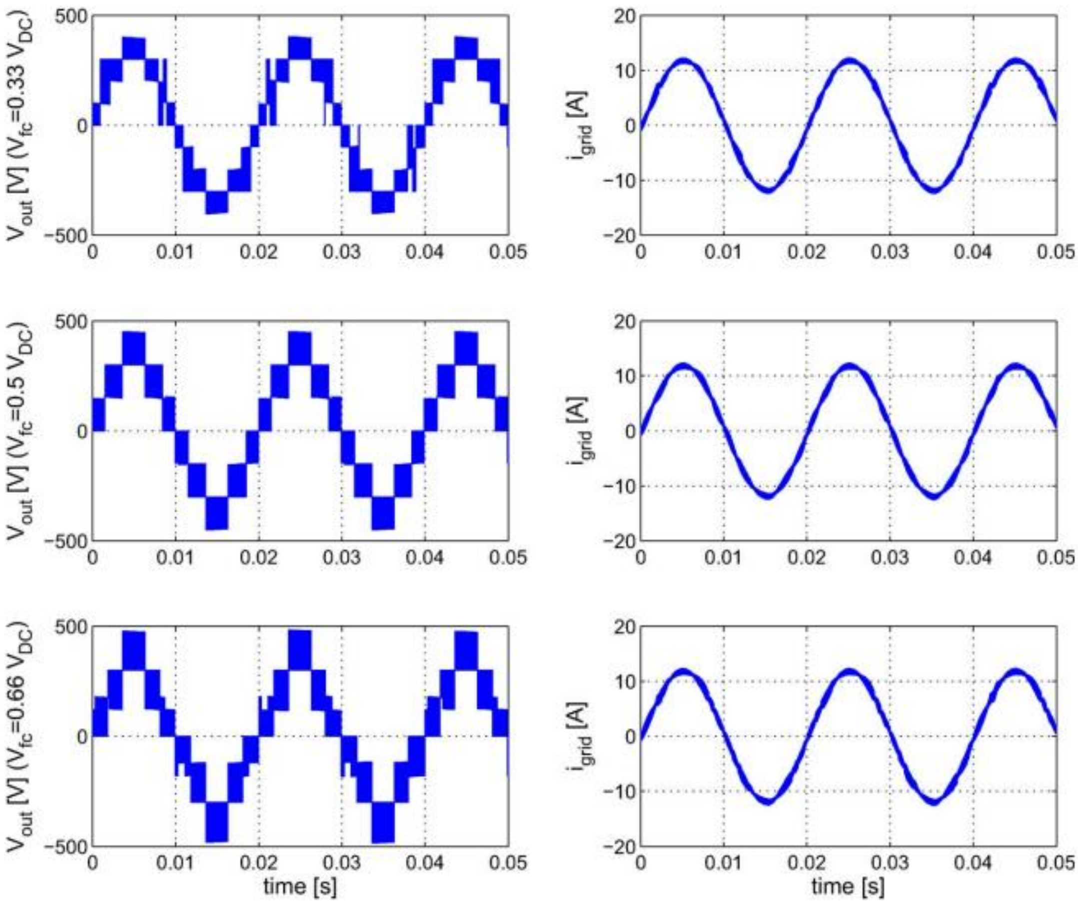
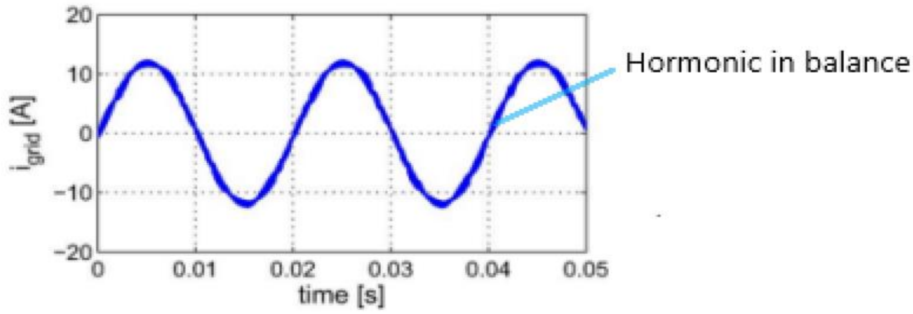
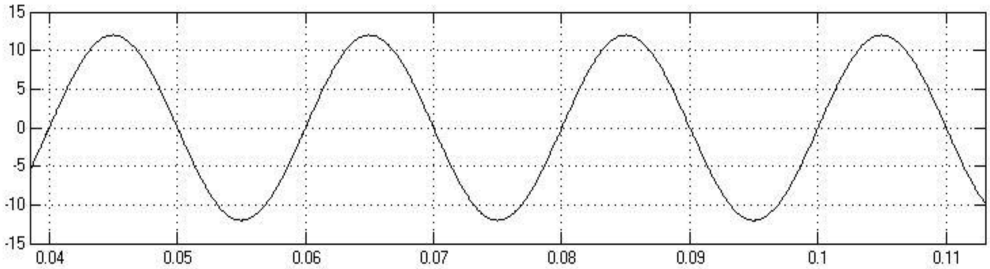


Figure 18: Results of existing PI controller for comparison [13]



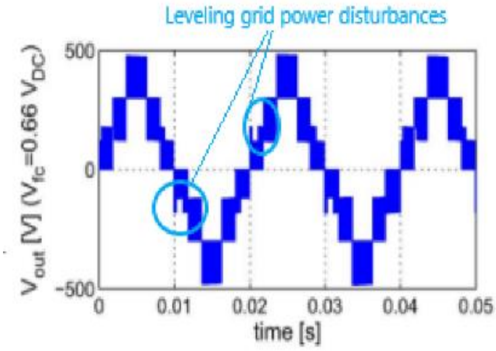
(a) Existing PI controller



(b) Proposed Fuzzy

Figure 19: (a), (b) Results of existing PI controller to Fuzzy comparison

Harmonic disturbances controlled by using fuzzy controller as shown in figure 12 when compared with existing PI controller [13] an approximate difference of 12 % in the proposed work. Leveling distortion on grid current also solved as shown in figure 13 using fuzzy controller.



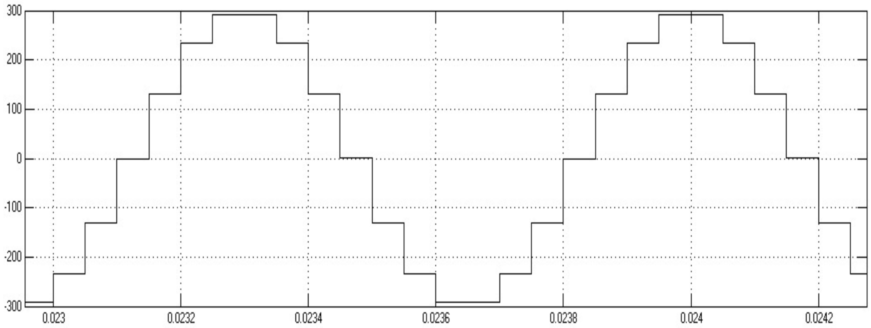


Figure 20: Leveling comparison between PI controller to Fuzzy

Figures 14, 15, 16, and 17 show the results of a MATLAB Fourier transform (FFT) analysis showing the harmonic spectrum of the current and voltage waveforms produced by the filter circuit.

V. Conclusion

This study proposed a nine-level Fuzzy controller that uses PWM techniques to prevent power losses in PV systems with a nine-level grid. An improvement to the simulation that uses Fuzzy instead of PI. Based on the current state of the art, simulations were conducted using five-level and nine-level transformer-less PV circuits as references. We have resolved the power leakages in our existing work in line with the PI controller. The suggested PWM method is able to control the voltage of flying capacitors. A multilevel inverter offers better output wave forms with lower THD in this paper. The SPWM approach is utilized to operate the IGBT Nine-Level inverter, which in turn generates the PWM switching signals presented in this work. PWM switching signals are created using the reference signal and the triangle carrier signal. The behavior of multilevel inverters was determined via a detailed analysis. Results from comparing Nine-level inverters to PI and fuzzy controllers in terms of THD show that these inverters provide a promising alternative for PV-connected inverters. There is no specific funding to support this research

Acknowledgment

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