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Power Quality Improvement in Solar Fed Cascaded Multilevel Inverter Using Fuzzy Logic Controller

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ABSTRACT
Providing electrical energy access to rural zones is a fundamental requirement as a means of improving sustainable living standards topping the agenda in many developing countries. However, there are many challenges in the solar energy system in the form of mismatch of the generated power from the PV and the demand, which leads to the numerous other challenges. The presence of harmonics in solar Photo Voltaic (PV) energy conversion system results in deterioration of power quality. To address such issue, this project aims to investigate the elimination of harmonics in a solar fed cascaded Multilevel inverter with aid of Fuzzy Logic Controller (FLC). Unlike other techniques such as Artificial Neural Network (ANN), the proposed FLC based approach helps in obtaining reduced harmonic distortions that intend to an enhancement in power quality, and to provide constant output voltage in terms of maintaining of voltage and frequency at the inverter output end. The simulations will be performed in the MATLAB / Simulink environment for solar fed cascaded Multilevel inverter incorporating with Fuzzy Logic Controller (FLC).

Keywords: Multi level inverter, photo voltaic solar energy conversion system, harmonics, power quality.

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I. INTRODUCTION

Minimum cost and quality of energy to the loads is the important aspect of power generation. Energy efficiency, electricity supply and sustainability are the most important research topics in society. The energy that is sustainable, renewable, cost-effective, reliable and secure is the fundamental requirement for economic growth, human and industrial development ofa country. [1] Renewable energy can be termed as liveliness from unlimited natural resources. There are many sources of renewable energy resource like sunlight, water, air, biomass, and geothermal heat. Over a specified geographical area, the scope and opportunities for [7-9] renewable energy resources are vast in contrast to other forms of energy like fossil fuels that are limited and concentrated to specific localities. With the rapid deployment of renewable energy, efficiency, economic benefits are immense and would result in significant energy security, while reducing the environmental effects. This includes positive developments in improved healthcare and reduction in infant mortality rates due to reduced pollution effect and countries would save millions on healthcare. Solar energy is harnessed from the sun using PV technologies, solar heating, concentrated solar power, concentrated photovoltaics and are generally characterized based on the way the energy is captured, converted and distributed. They are either classified as active or passive. A PV system converts light into electrical energy taking advantage of the photoelectric effect. The PV system involves an array of silicon semiconductors that collect the photons and changes over to electrons. The generated DC is then converted to AC using converters. Therefore, it is essential to utilize specific MPPT system to maximize the energy captured from the sun. This is generally achieved by using sun-tracking PV's. The sun-tracking PV's achieve this goal by adjusting itself to the global solar insolation shifts and amplifies the captured sunlight radiation to generate maximum power at a steady voltage. Efficiency in the solar array is estimated by the capacity to change over daylight into energy and is an exceptionally unique factor in picking the right panel for the PV system. As a reliable RE source, solar PV's can be successfully integrated into the mainstream power supply. However, there are many challenges in the solar energy system in the form of mismatch of the generated power from the PV and the demand. This is primarily due to the stochastic generation in PV. It leads to numerous other challenges, and one such problem is voltage imbalance. To alleviate the voltage imbalance, a power electronic interface is suggested between the source and load whose function is to provide output voltage regulation and also improving power quality. The novelty of the proposed work is to make use of multilevel (15 levels) inverter for providing the dual advantage. The term multilevel comes from the three level converters. The commutation of the semiconductor switches aggregates the multiple DC sources to achieve high output voltage levels.

The advantages of multilevel inverters include improved quality of power, better electromagnetic compatibility, reduced losses in switches and enhanced voltage capability. The three structures of MLI are Neutral Point Clamped or Diode Clamped Multi Level Inverter, Flying Capacitor Multilevel Inverter and Cascaded Multilevel Inverter. In this paper, Cascaded Multilevel Inverter (CMLI) of 15 level is utilized. The primary role of CMLI is to synthesize a preferred voltage from separate DC sources (SDCs) which may be obtained from batteries or solar cells. As solar PV voltages are variable with respect to environmental factors, asymmetrical inverters are highly recommended. Asymmetrical inverters have unlike values of DC link voltages. Compared with other multilevel inverters, CMLI requires the least number of components to achieve the same number of voltage levels. The only disadvantage of the CMLI is that it needs separate DC sources for real power conversions. However, this disadvantage can be compensated by utilizing solar PV at its input. Against this backdrop, the paper provides an elucidation to alleviate the voltage imbalance control and improve power quality in a solar power circuit by reducing the harmonics. Section two reviews about proposed method techniques used in voltage control. Section three discusses about the simulation analysis for the proposed system, and lastly section concludes the research.

II. LITERATURE SURVEY

A. Literature Review on Power Quality Issues

In [1], The power quality issues for distributed generation systems based on renewable energy resources such as solar. A throughout discussion about power quality issues, their sources, and parameters have been presented here. In this research, transient has been found out to be the most severe power quality issue, Voltage and frequency fluctuations are mainly caused by two reasons:

I) Non controllable variability of renewable energy resources.

II) Power grid-side disturbances.

However, Harmonics are produced by power electronic converters which are used in renewable energy generation. As defined by the IEEE Standard 929-2000 there are four major parameters to evaluate the power quality in PV systems such as voltage, voltage flicker, frequency, and distortion. Deviation from these parameters creates power quality problems. These discoveries help the people in today's environment.

In [2], The Renewable energy sources like wind, sun, and hydro are seen as a reliable alternative to the traditional energy sources such as oil, natural gas, or coal. Distributed power generation systems (DPGSs) based on renewable energy sources experience a large development worldwide, with Germany, Denmark, Japan, and USA as leaders in the development in this field. Due to the increasing number of DPGSs connected to the utility network, new and stricter standards in respect to power quality, safe running, and islanding protection are issued. As a consequence, the control of distributed generation systems should be improved to meet the requirements for grid interconnection. This paper gives an overview of the structures for the DPGS based on fuel cell, photovoltaic, and wind turbines. In addition, control structures of the grid-side converter are presented, and the possibility of compensation for low-order harmonics is also discussed. Moreover, control strategies when running on grid faults are treated. This paper ends up with an overview of synchronization methods and a discussion about their importance in the control.

B. Literature Review on Multilevel inverters

In [3], Three phase multilevel inverter with reduced number of components count is proposed in this paper. This inverter is designed using a single DC source per phase to generate multiple level output voltage which makes it suitable for low and medium voltage applications, including ac- coupled renewables or energy storages. The most common and classic MLI topologies include neutral point clamped (NPC), flying capacitor (FC) and cascaded H-bridge (CHB) which have been established extensively in numerous applications in energy storage and electrical conversion systems. NPC and FC inverters introduce balanced charging problem of DC link capacitors.

In [4], DC-AC power conversion has now become a key technology in the areas of generation, transmission, distribution and utilization of electric energy. To serve this purpose it is discussed that modern setup, DC-AC converters ('inverters') are playing an important role in various key areas such as HVDC power transmission, static VAR compensators, electric drives,Flexible AC Transmission Systems (FACTS), renewable energy integration (such as solar PV, DFIG and variable speed wind turbine system, fuel cells) and electric vehicle/hybrid electric vehicles. Based on the nature of output waveform, inverters are classified as: two level or square wave inverters, quasisquare wave inverters, two-level PWM inverters and multilevel inverters (MLIs).

In [5], This paper explains about multilevel inverters that exhibit various advantages such as decreased blocking voltage of power semiconductor switch, lower total harmonic distortion (THD), and easy maintenance. Therefore, multilevel inverters are used as an alternative to the two-level inverters in medium-voltage and high-power applications such as direct current (DC) distributions, photovoltaic generation, and solid-state transformers. The CHMI exhibits a multilevel inverter topology, and it consists of many cells that correspond to a full-bridge inverter. Multilevel inverters require a lot of power semiconductor switches when compared to a two-level inverter. However, itis reported that power semiconductor switch is one of the most prone to failures components in power electronics systems. The reliability of a power semiconductor switch is an extremely important issue for improvement reliability in a multilevel inverter.

In [6], Multilevel inverters emerged as the solution for overcoming the limitations of two- level inverters, such as total harmonic distortion, high magnetic interference, and high dv/dt in high power voltage applications. The ability to generate sinusoidal output voltage is another specialty of multilevel inverters. The wide range of applications in fields such as power grids, motor drives, and Volt-Ampere Reactive compensation enhances the visibility of multilevel inverters. This paper identifies the conventional multilevel inverter topologies such as diode clamped multilevel inverters, flying capacitor multilevel inverters, and cascaded H bridges and presents a literature review on the topologies considering the facts of structural and functional diversities over the ages which have been adapted right from the beginning of its emergence. It also details the various optimization technologies that are used in multilevel inverters to obtain the optimal switching angle for harmonic elimination. This paper also explains the modulation techniques that are in effect for a specific purpose in different applications to get the best possible result.

III. PRAPOSED SYSTEM

CONTROLLER MODELLING

Most renewable energy resources, such as solar PV, are connected to a DS (Distribution System and its operations are identical and analogous to those of a generator or a synchronous machine connected to the grid. Because the power output by a PV change owing to irradiation absorption on the panel, the rated voltage can fluctuate between -20% and +20% throughout the day. It is feasible to ensure a stable DC voltage in the PV by using power electronic circuits. Because grid electricity is transmitted in AC, the stabilized DC voltage is inverted to AC. In accordance with this, the suggested experiment employs a suitable inverter with a maximum fluctuation of 1% to ensure accuracy for a 48V, 7A solar panel with a maximum variation of 1%.

A. FUZZY LOGIC CONTROLLER

Lofti A. Zadeh proposed fuzzy logic, which is not the same as Boolean algebra. fuzzy logic differs from Boolean logic dur to its ability to accept two are more values between True and False. Fuzzy logic aids in the development of fixed conclusions from confusing, hazy, and imprecise data.

The block diagram in Fig.1 shows the fuzzy logic system which contains all the modules required for obtaining a control of a particular system. The FLC is made up of five major block sets, they are the fuzzifier, the defuzzifier, the inference system, the rule base, and the database. The inputs and the outputs of the system are always crisp inputs, but for processing inside the fuzzy inference engine the values are converted into the fuzzy inputs using fuzzification interface and defuzzification blocks.

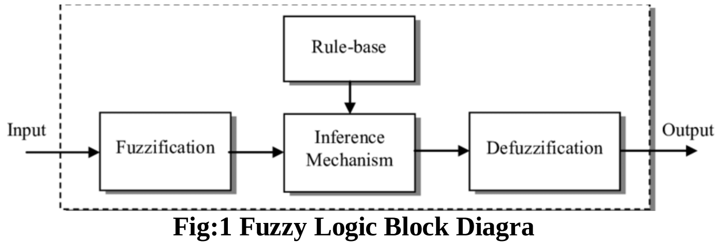


Fig:1 Fuzzy Logic Block Diagra

Figure 2 shows the structure of the Fuzzy Logic Controller (FLC) for a solar PV-fed cascaded H bridge multilevel inverter. The output voltage (Vo) from a fifteen-level inverter is compared to the reference voltage (Vref), in this case which is the inverter's preferred voltage to reach in compliance with grid standards.

The FLC uses the subsequent error, e = Vref- Vo, and the rate of error change, de/dt, as input attributes. The FLC's commanding signal (or control signal) Cs is then compared to Vef to form the modulating signal Ms required for PWM (pulse width modulation) generation, providing adequate gating signals to the inverter power circuit's semiconductor switches.

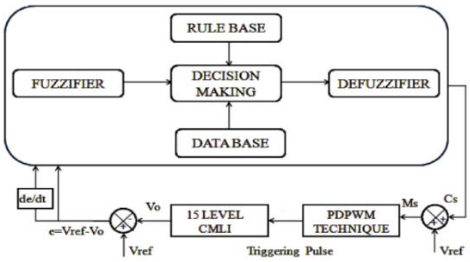


Fig:2 Fuzzy Logic Control Structure

B. Membership Functions

Membership functions are the values which gives the values of the degrees of the truthfulness to the universe of discourse of the input. The input range which is normally represented on the x axis is defined a relationship between the truth and false value by using a membership function. The choice, shape and number of membership functions are usually a choice of a fuzzy logic designer.

There are various shapes of the membership functions available for the use such as singleton, Gaussian, Gbell, Gaussian2f etc. The curve which represents the membership functions are denoted by the Greek letter μ. The different membership functions require different parameter to be defined.

An error and its derivative MF (membership function) are used to formulate the problem. In Figure 3, the MF for the erroneous (error) signal is shown. In which N represents for Negative, P for Positive, and Z for Zero in this graph. Similarly, B denotes large, M denotes medium, S denotes tiny, and E denotes an error. Figure 4 shows the derivative of the error signal for the fuzzy logic controller.

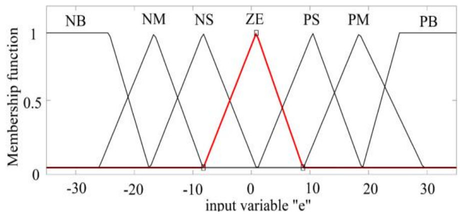


Fig:3 Membership Function for Error Signal

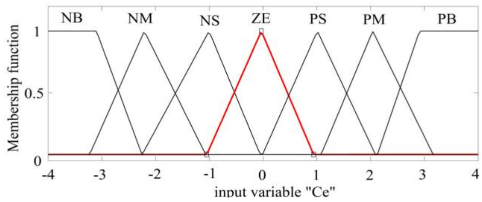


Fig:4 MF for Change in an Error Signal

C. Evaluation of Rules

Fuzzy logic operations are carried out based on the rules that define the inputs. The fuzzy set rules are compliment to the normal crisp operation rules. The normal crisp rules are AND, OR and NOT functions. Hence there should be a fuzzy equivalent of the said functions which operate on the degree of the truthfulness. The equivalent rules for AND, OR and NOT functions are min, max or Big, Medium, Small, and compliment functions. These are represented in the form of a rule matrix shown in, Table I. with two inputs (error and its derivative signal) and one output.

Ce \ e	NB	NS	NM	ZE	PB	PS	PM
NB	PB	PB	PB	PB	ZE	PM	PS
NS	PB	PM	PB	PS	NM	ZE	NS
NM	PB	PB	PB	PM	NS	PS	ZE
ZE	PB	PS	PM	ZE	NB	NS	NM
PB	ZE	NM	NS	NB	NB	NB	NB
PS	PM	ZE	PS	NS	NB	NM	NB
PM	PS	NS	ZE	NM	NB	NB	NB

Table I: FLC Rule Matrix

D. Design of Fuzzy Logic Controller

This part of the section discusses the design of a fuzzy logic system as a controller module for the CMLI (Cascaded Multi Level Inverter). This module will accept the inputs such as error and derivative of errors generated during solar power generation throughout the day.

Figure 5 represents the controller block used to design the fuzzy logic controller.

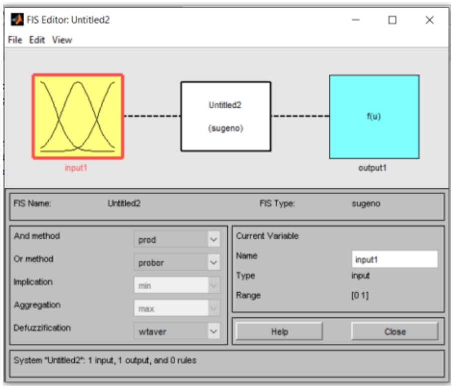


Fig:4 fuzzy logic editor

Two different inputs are considered for the purpose of comparison of the generated output voltage from CMLI and reference voltage represented in figure 5.

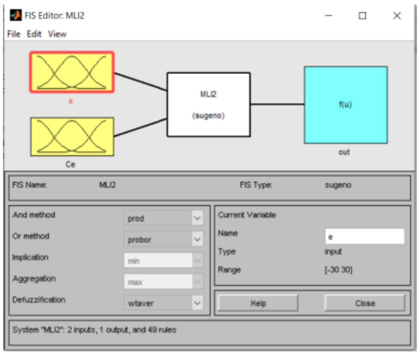


Fig:5 Fuzzy Logic Controller with two inputs.

In input data set of error signal, time is divided into seven membership functions naming them as negative small, negative medium, negative big, zero error, positive big, positive medium, positive small.

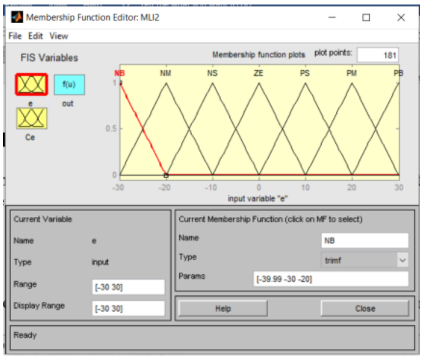


Fig: 6 Membership Functions for error signal (e).

In the next input data set is change in error (Ce), in which the time is also divided into seven membership functions.

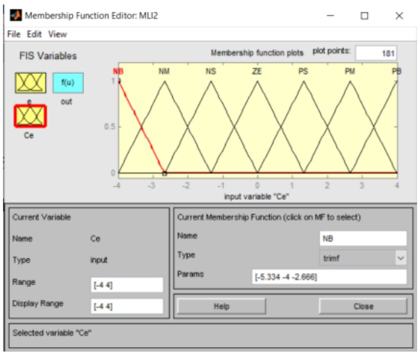


Fig:7 Membership Function for change in error (Ce).

In the next step the controller is designed based on the rules given from the rule matrix.

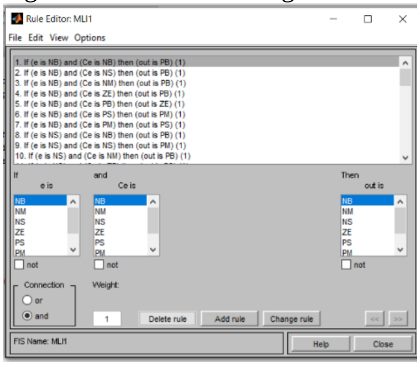


Fig:8 sugeno controller designing with the rules.

The output data set which needs to be obtained from the combination of the input data sets is as also in the similar range as of the inputs, and is also divided into seven membership function.

IV. SIMULATION AND ANALYSIS

Multilevel converters include many DC lines to allow for independent control of possible voltage and MPP tracking at each string. A solar-fed 15-level inverter is an open-loop system. Panels with varying levels of irradiance are created and connected to the various stages of the CMLI. Seven cascaded Hbridges are connected in series for the fifteen levels, each bridge is connected with four semiconductor switches such as IGBT which has high speed switching performance as shown in the figure 11. A reference and carrier signal are compared for pulse production. In order to generate a pulse signal, the reference is sinusoidal signal and triangular is a carrier signal are compared.

The bipolar PWM technique is used to generate the pulses. For the pulse sequence, triangle wave and positive sinusoidal signal are compared for one leg, and triangular wave and negative sinusoidal signal for the other leg. Figure 7 depicts the modelling of a PV panel with varying irradiance levels to represent the change in inverter output voltage. Figure 8 shows the output voltage waveform derived from solar PV modules with varying irradiance and partially shadowed situations. This leads in an unequal distribution of output voltage, resulting in a voltage imbalance. These unbalanced shifts can be adjusted by using fuzzy logic controller technique.

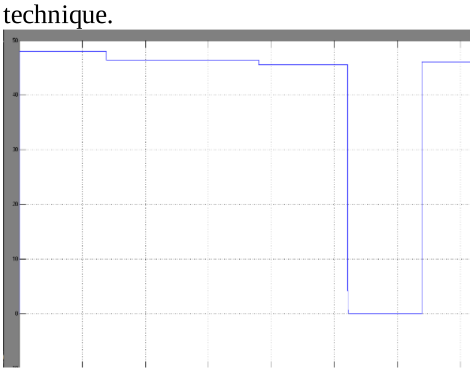


Fig:9. Variation of output voltage with respect of irradiance.

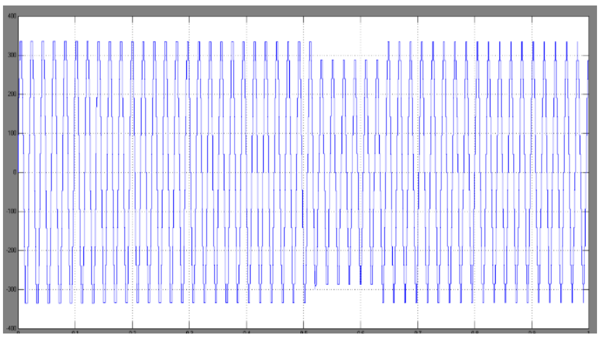


Fig:10. Fifteen level output voltage with variable irradiance.

A. FIFTEEN LEVEL INVERTER WITH FUZZY LOGIC CONTROLLER

Fuzzy inference is used to make decisions and create patterns. The two input signals are the error and derivate error signals, which are framed as a membership function.

The controller employs a triangular membership function. The PWM generator receives a modulating output signal from the membership function. Each membership function in the error and derivative error has seven members. For better voltage regulation, over 49 guidelines have been devised and implemented. Figure 12 shows the regulated output voltage, whereas Figure 13 shows the related FFT analysis.

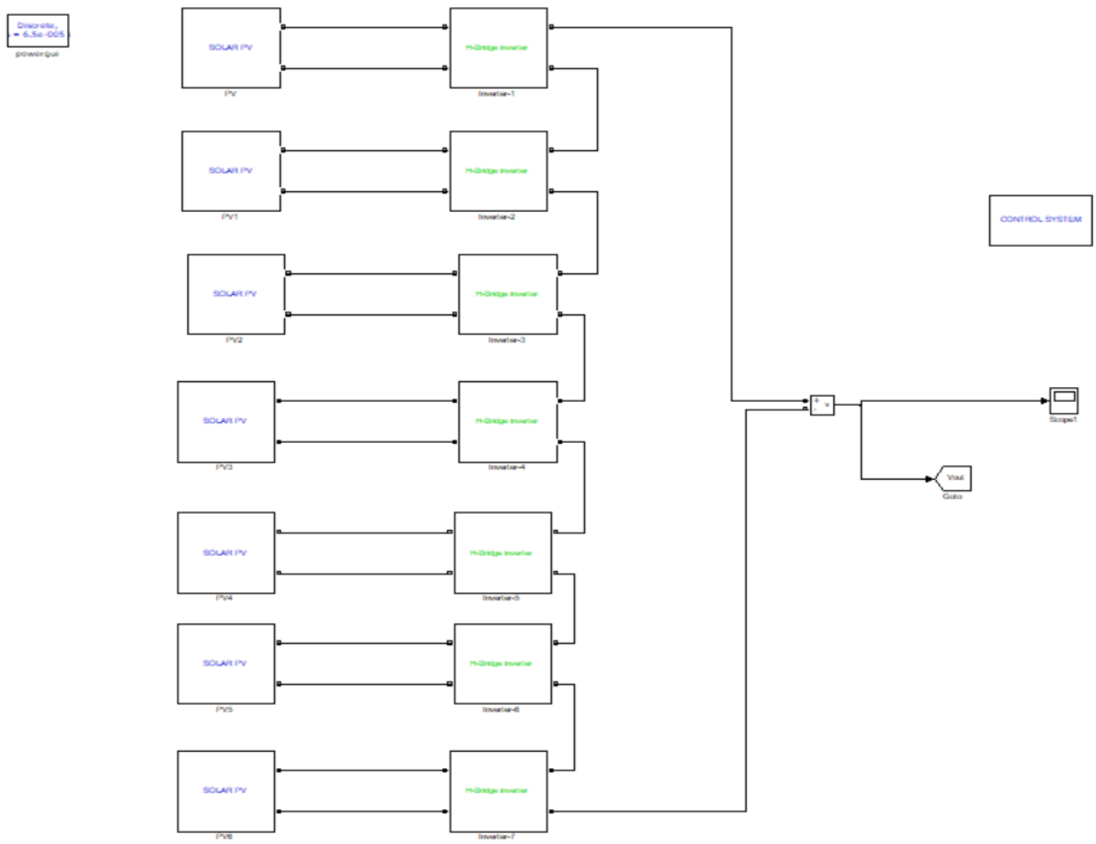
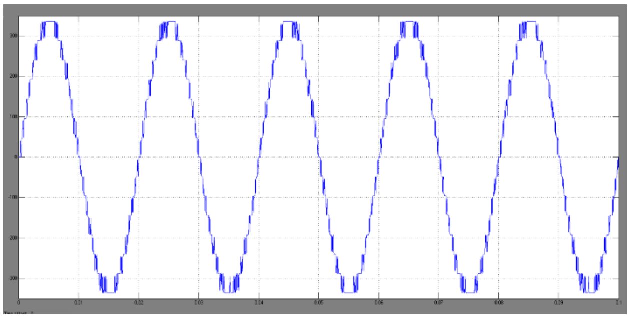


Fig:11 Simulink model of solar fed 15 level CMLI with fuzzy logic controller

B. Simulation results and comparison



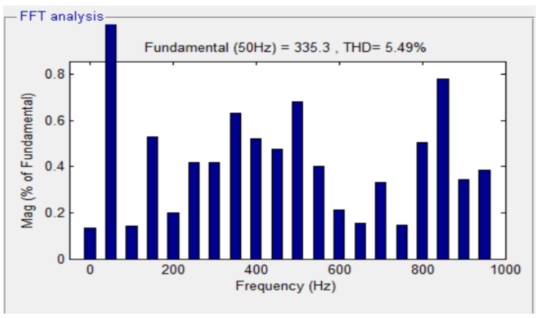


Fig:12 Regulated fifteen level output voltage with FLC. Fig:13 FFT analysis for FLC based voltage regulation

C. Comparison Of Results

Table 2

S.NO	Method	Level	THD
1	ANN	15	7.94%
2	FLC	15	5.49%

V. CONCLUSION

The power quality improvement with reduced THD (Total Harmonic Distortion) is considered and implemented in MATLAB Simulink simulation software for a solar fed 15 level CMLI inverter. While considering the results, it is found that FLC presents better results in control of variations at the input solar PV. Despite this, FLC is considered for reduction in THD values. Utilization of CMLI is done for generating constant output voltage, and the simulation results prove the effectiveness of the proposed system. The method is applicable for the users require grid interaction along with the power quality improvement.

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