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Fuzzy Based Cascaded Multilevel Inverter for Large Scale Solar PV Integration

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Abstract: With increased interest towards the renewable power generation resources due to its profound concerns towards the environmental aspects, the Wind, Photovoltaic (PV), Geo thermal and Tidal based systems are more prominent. The uncertainty nature of power generation is dominating the penetration of these sources into the existing grid. With solar PV, the dependence of irradiance on geography and temperature conditions of the location, the power tracking necessitates certain intelligence-based control techniques for power control. In this regard, this paper proposes a Fuzzy logic-based control system for effective tracking to facilitate the grid integration of installed PV system together with an energy storage system using cascaded multilevel inverters. In order to validate the performance of proposed method, the equivalent models were simulated in MATLAB/Simulink and its performance was tested under various operating conditions as per the IEEE 519 standard.

***Index Terms* – PV. Battery Management System. Fuzzy. Microgrid. MPPT**

I. Introduction

Solar photovoltaic (PV) energy production is getting a larger part of the power market among various distributed energy resources (DER). Many countries intend to expand further in order to achieve a 100 percent renewable grid [1]. These advancements result in the formation of new markets, the installation of additional GW of power plants, and a decrease in the price of PV modules. Global solar photovoltaic (PV) capacity has increased to 627 GW, mainly to growth in residential and commercial installations, as well as utility-scale developments [2]. In areas with limited land space, hybrid solar PV-hydropower systems with floating solar PV modules present new prospects [3].

The centralised PV inverter technologies have been commercially used in the construction of large-scale PV plants [4]. They do, however, suffer from low voltage/power ratings and efficiency loss due to centralised maximum power point tracking (MPPT) control. Adopting a three-phase isolated PV inverter based on cascaded H-bridge (CHB) architecture is one option to implement high-voltage and high-power PV grid-tied power generation [5]. Its modular design allows it to be expanded to a greater voltage and power level using low-voltage devices, and it may be directly connected to a medium voltage power grid without the use of a heavy line-frequency transformer. Furthermore, the multilayer output voltage enables each H-bridge (HB) to operate at a reduced switching frequency, enhancing the inverter's overall efficiency. Grid-connected solar inverters eliminate the need for large battery banks, saving space and money. A traditional two-level (2L) inverter-based solar energy conversion system (SECS) with a modified proportional-resonant (M-PR) controller is described which operates in both stand-alone and grid-connected modes [6]. The main benefits are the simplicity of the circuit and switching.

To correct the voltage imbalance, a power electronic interface between the source and load is proposed, whose goal is to offer output voltage management and increased power quality. The suggested approach is unique in that it employs a multilevel inverter to provide a two-fold advantage [7]. The semiconductor switches commutation aggregates numerous DC sources to produce high output voltage levels. The benefits of multilevel inverters include higher power quality, greater electromagnetic compatibility, decreased switch losses, and increased voltage capabilities.

Beside the huge number of components necessary for a higher number of levels, another issue with cascaded multilevel inverter [CMLI] topologies has been the reduced power ranges caused by the high current rating of some of the switches. Having several DC voltage sources with semiconductor modules can alleviate the problem of lower power ratings. Several CMLI-based topologies with numerous sources have been reported in the literature. CMLI requires the fewest components to accomplish the same amount of voltage levels as other multilevel inverters. One of the major disadvantages of CMLI is that it requires separate DC sources for genuine power conversions. This disadvantage, however, can be mitigated by using solar PV as an input.

The occurrence of conversion loss is one of the most significant challenges in today's power distribution system. The use of DC appliances is becoming increasingly popular. In this environment, there has been a significant increase in the use of DC-powered technology in daily life [8]. Due to the lack of separate DC supply systems at the consumer premises, DC loads are often hooked into the AC terminals. Multiple conversions occur as a result of the AC power being adjusted for diverse DC load requirements utilising converters. Conversion losses and harmonics created by converters are increasing considerably day by day, contaminating the power system network.

The battery storage systems (BSS) are an essential component of any microgrid because they help to preserve grid network stability by establishing and maintaining a balance between the fluctuating power provided by the Renewable Energy (RE) system and the load demand that uses the electricity [9 - 10]. The grid operator benefits from BSS by assisting in grid network activities such as peak saving, load shifting, load levelling, frequency regulation, and voltage stability control. The goal of this project is to provide an algorithm for controlling battery storage and demand-side power management in microgrids, hence reducing electricity costs [11-14]. This control method is created by adding fuzzy logic to the battery management system [BMS], allowing for more cost-effective operation. This paper proposes a Fuzzy logic-based control algorithm using cascaded multilevel inverters which is able to track maximum power effectively and facilitate the grid integration of installed PV system.

II. Fuzzy Logic controller-based MPPT algorithm for PV System

Due to limited reserve capacity, shoot up of generation prices, and environmental concerns, interest in renewable energy is growing as an alternative energy source to traditional fossil fuels. The global research community is investigating all options for efficient energy conversion from freely available renewable energy sources. This paper presents a direct maximum power point tracking (MPPT) method, based on an easy and robust way of identifying the maximum power point of a photovoltaic source that needs the measurement of the PV generator voltage only. The algorithm accurately detects the Maximum Power Point and can rapidly track it in the presence of irradiance variations, with no erratic behaviour. This work presents the maximum power point tracking technique based on fuzzy logic control.

The MPPT controller is used for integration and control to generate maximum power from renewable energy sources under different weather conditions. The Fuzzy based MPPT controller model simulated in MATLAB environment is depicted in Figure 1. The necessary inputs for the controller are shown in Figure 2. The PV voltage and current are represented in Figure 3 and Figure 4 respectively. The duty cycle is obtained as the output of the fuzzy controller. The trapezoidal and triangular fuzzification methods are used for modelling the input and output membership functions. In continuation to that defuzzification is performed using the centroid method. The output membership function of the duty cycle designed is as shown in Figure 5. The fuzzy IF-THEN rules are represented in Figure 6.

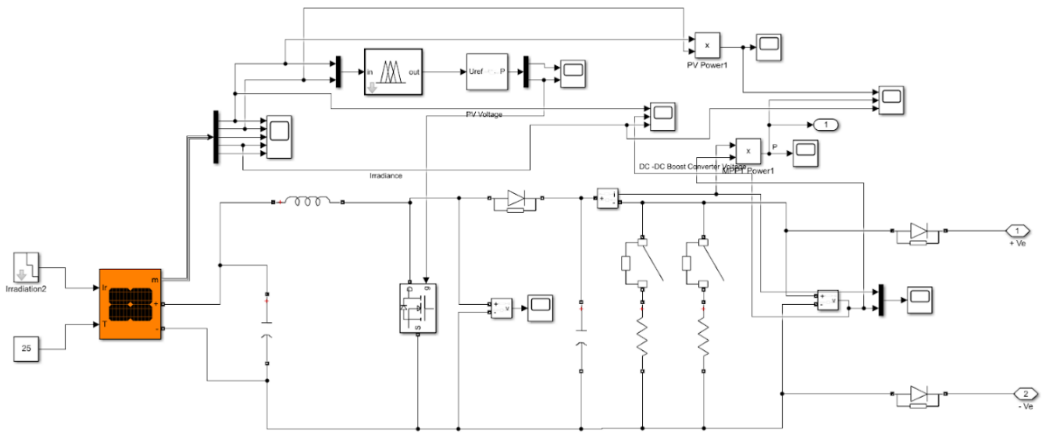


Figure 1. Simulation model of Fuzzy MPPT Controller for Photovoltaic system

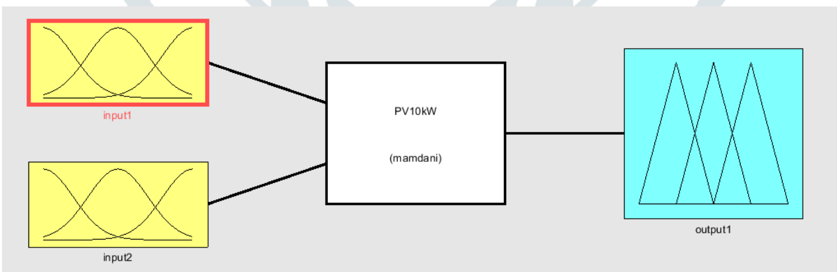


Figure 2. Fuzzy logic controller model for PV MPPT system (11 kW)

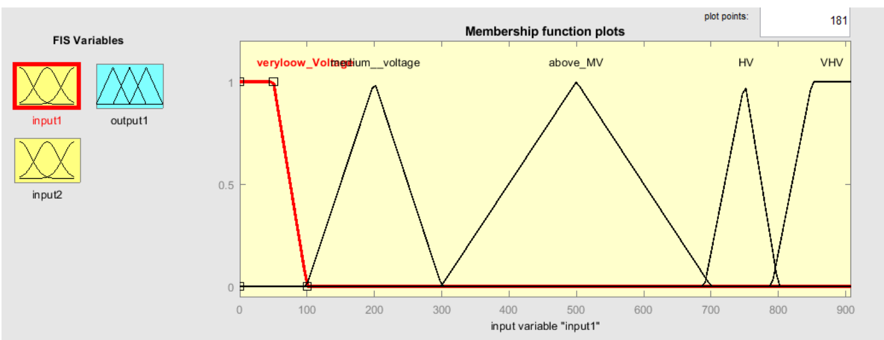


Figure 3. Fuzzy input membership function (PV Voltage - 11 kW)

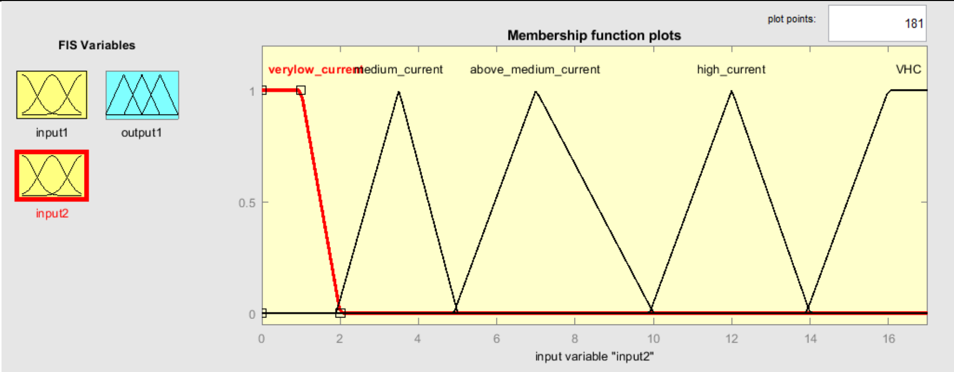


Figure 4. Fuzzy input membership function (PV Current - 11 kW)

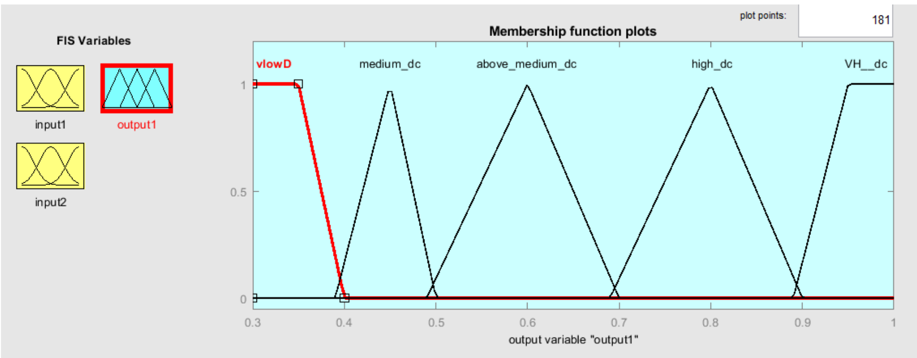


Figure 5. Fuzzy output membership function (Duty Cycle - 11 kW)

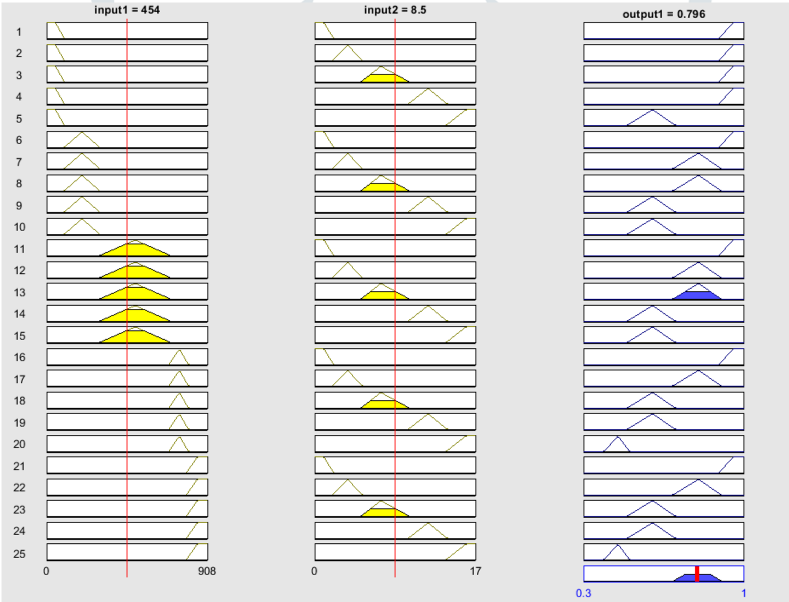


Figure 6. Fuzzy Rule-based system for PV MPPT algorithm (11 kW)

III. MULTILEVEL INVERTER FOR PV SYSTEM

The cascaded multilevel inverter is well known for grid integration of renewable energy sources to improve system power quality and reliability. The proposed cascaded multilevel inverter was designed using a small number of power electronic switches to reduce THD for both the current and voltage waveforms. Six MOSFET-based power electronic switches are employed, with three PV sources coupled in each power electronic switch as shown in Figure 8. The suggested multilevel inverter uses the staircase modulation technique to generate pulses and is designed in two stages, DC-DC and DC-AC, utilizing an H-bridge. The three-phase output voltage waveform is shown in Figure 9.

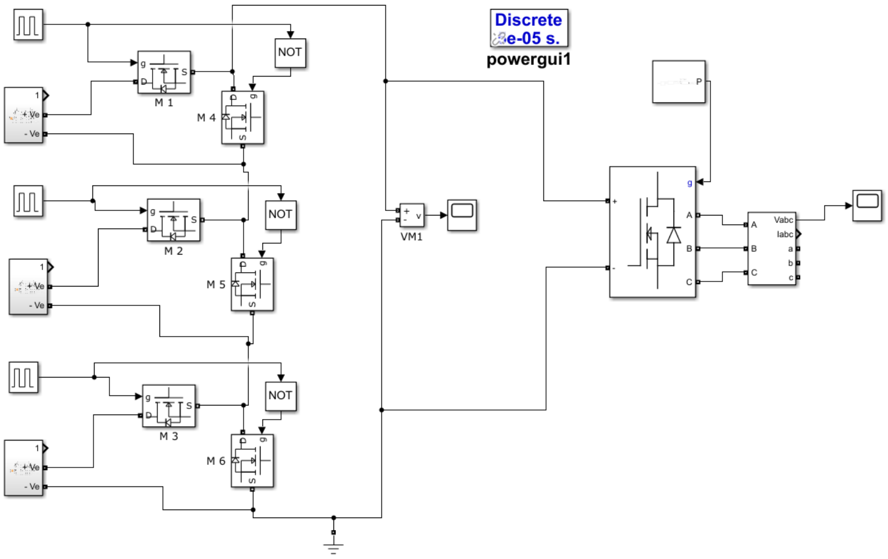


Figure 8. Simulation model of Seven level cascade multilevel H -Bridge inverter for PV system

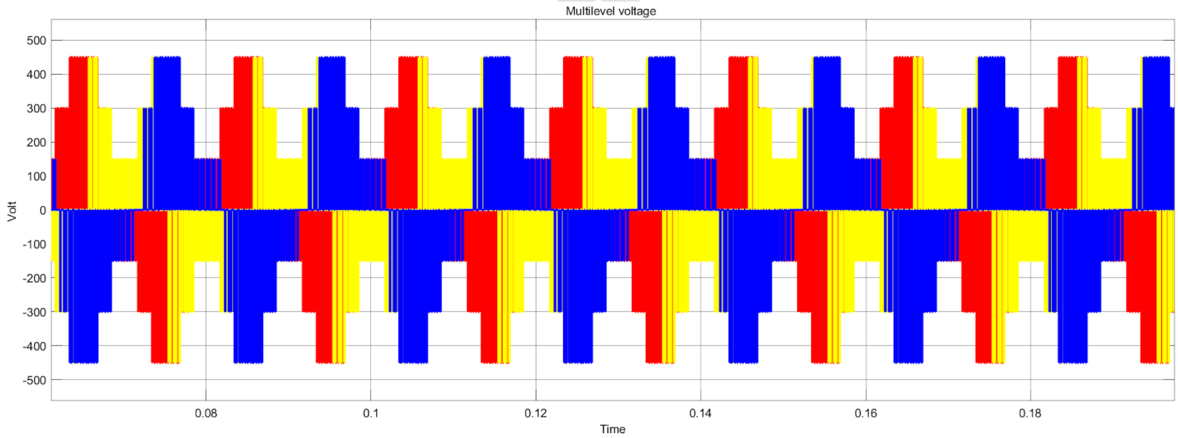


Figure 9. Seven Level output voltage waveform

IV. Microgrid Integration of PV System and Energy Storage Devices

The proposed grid integration of a 50 kW PV system has been developed in a MATLAB environment as shown in Figure 10. In this simulation model, 50 kW PV system is integrated with power grid through seven-level cascaded multilevel H bridge inverter. The cascaded multilevel inverter has been operated and controlled by a voltage source controller. The control algorithm of voltage source inverter is shown in Figure 11, which consists of phase lock loop [PLL], voltage regulator, and current regulator. The current regulator has been controlled by a fuzzy logic controller and the proposed PV system is connected to the inverter for synchronising into the power grid. The fuzzy logic controller was created for a VSC current regulator. The fuzzy controller has two input signals and two output signals, two input & output are direct axis (I_d) and quadrature axis current (I_q).

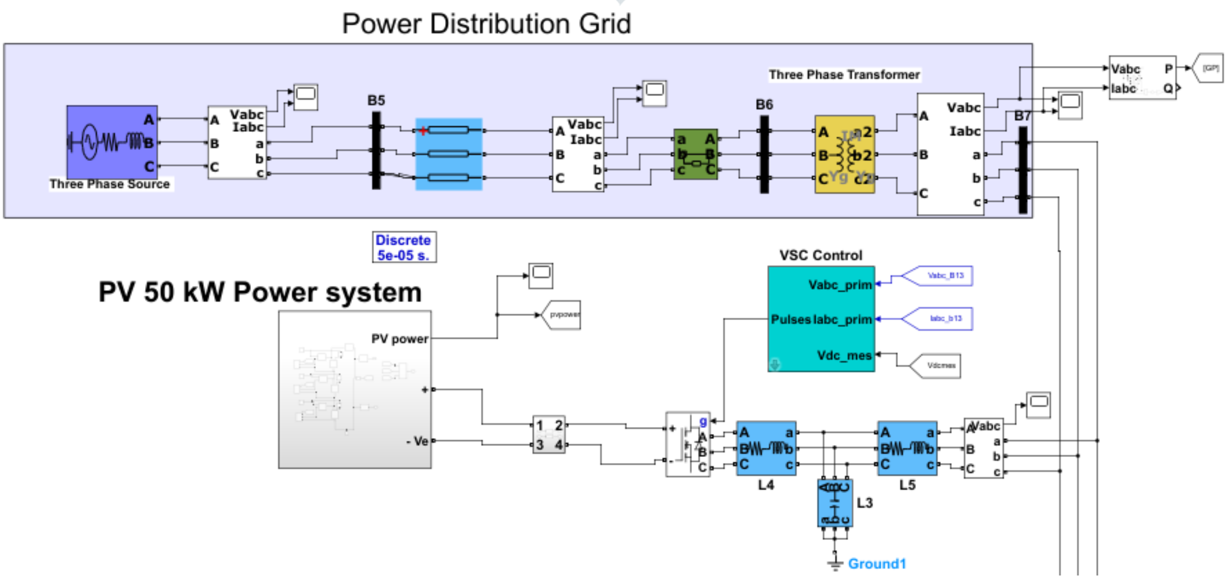


Figure 10. Grid integration of proposed multilevel inverter-based PV system

When the Id current is positive, the inverter generates active power, and when Iq is positive, the inverter observes reactive power. The fuzzy membership functions were created using the triangle method for fuzzification and the centroid method for defuzzification as presented in Figure 12 and Figure 13 respectively. The fuzzy output membership function has been developed as shown in figures 14 & 15. Figure 16 represents the fuzzy rules system for the current regulator. The direct axis current value is positive, and the converter delivers active power to the microgrid, while the quadrature axis current value is positive, and the converter observes reactive power from the microgrid. PV with Microgrid and its voltage source converter has been used with the proposed fuzzy control. The LCL filter has been used to reduce the THD value and smoothen the waveform.

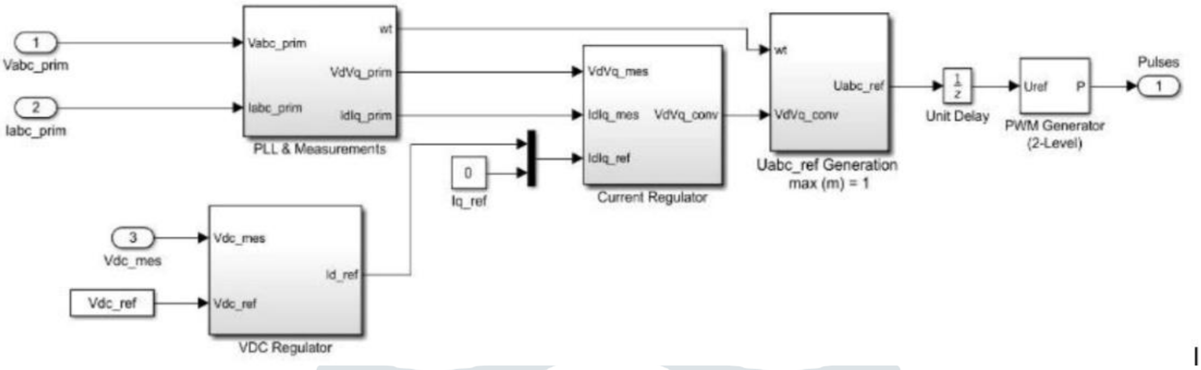


Figure 11. Control Algorithm of VSC

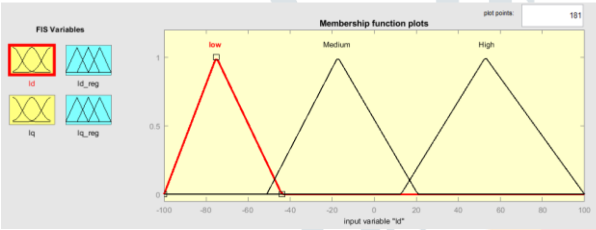


Figure 12. Fuzzy input membership for current regulator (Id)

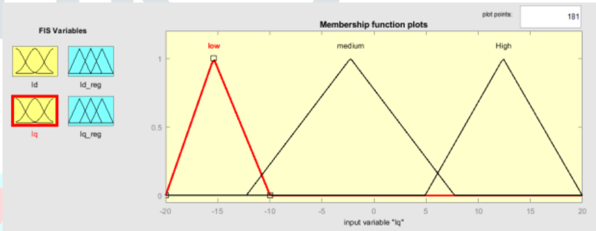


Figure 13. Fuzzy input membership for the current regulator (Iq)

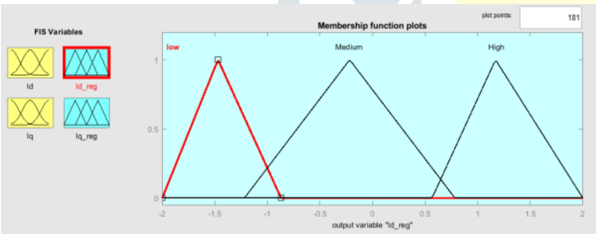


Figure 14. Fuzzy output membership for current regulator (Id)

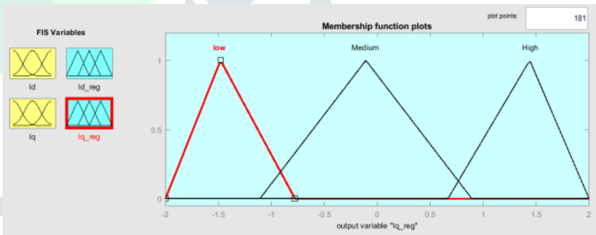


Figure 15. Fuzzy output membership for the current regulator (Iq)

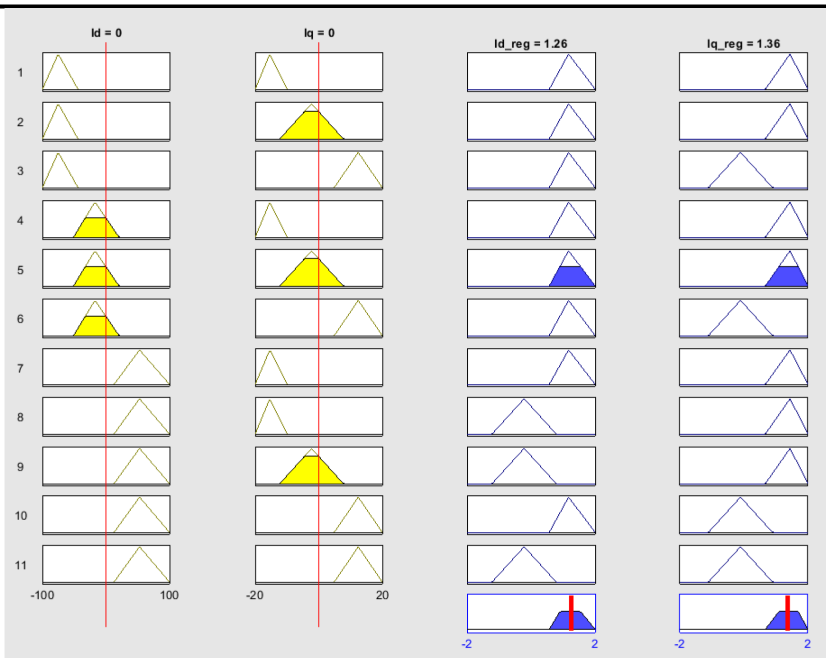


Figure 16. Fuzzy rule-based system for current regulator

V Results and discussion

The overall system performance was tested using MATLAB Simulink software for different load conditions. Three phase voltage and current waveform at the load side is depicted in Figure 18. The harmonic analysis with R, R-L and R-L-C load have been shown in Figure 19. Total harmonic distortion for voltage and current are tabulated in table 1.

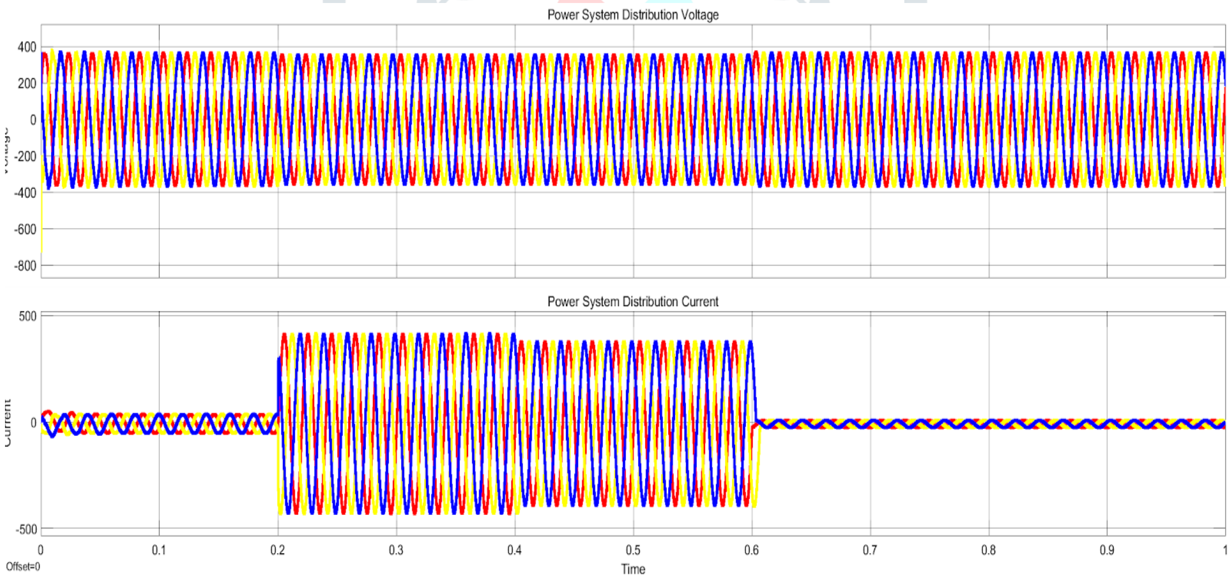
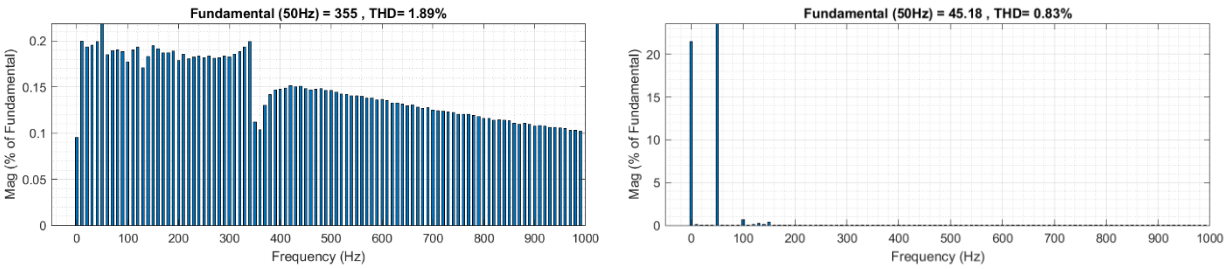
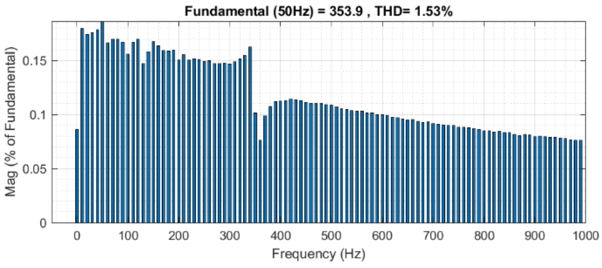


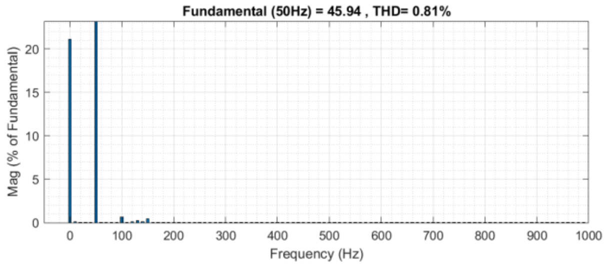
Figure 18. Three-phase voltage and Current waveform at the load side



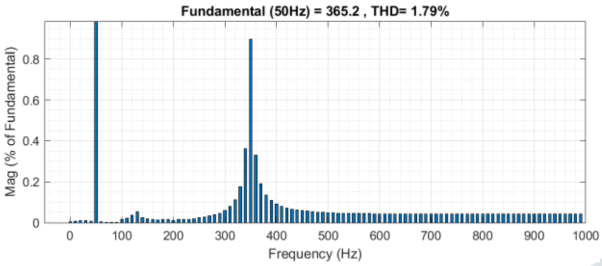
(a) (b)



(c)



(d)



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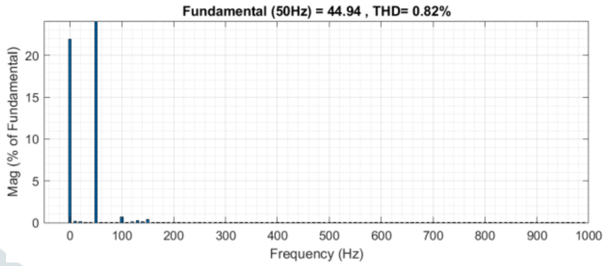

(f)

Figure 19. Total Harmonics Distortion a) For voltage with R load, b) for current with R load c) For voltage with R-L load, d) for current with R-L load e) For voltage with R-L-C load, f) for current with R-L-C load

Table 1. THD values under various load

Load	Voltage - THD	Current - THD
R	1.89%	0.83%
RL	1.53 %	0.81 %
RLC	1.79 %	0.82 %

V. CONCLUSION

A Cascaded Multilevel Inverter is designed using a fuzzy logic controller for a Large Scale Solar PV Integration system. The system is able to track the maximum power point of the solar PV effectively. The cascaded multilevel inverter helps in efficient conversion with reduced total harmonic distortion. Also, as the number of switches are reduced, that helps in reducing the complexity of pulse generation. Analysis is carried out with different types of loads to indicate the applicability with various loads. THD values under various load conditions within prescribed range as per IEEE-519.

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