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Comparative Analysis of Five Level Inverter for Solar PV Application with PI and Fuzzy Controllers

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Abstract

A single phase cascaded five level inverter which consists of two full bridge inverters is designed for Solar PV application. Two controllers namely the PI controller and Fuzzy controller are developed for five level inverter and the results are compared in order to achieve the optimized output from a Solar PV system fed inverter. Designing of Capacitor filter is done to reduce the total harmonic distortion (THD) of the output of five level inverter. The proposed system is simulated using MATLAB/SIMULINK and the results are observed, presented and evaluated to find the system with better performance.

Keywords: Multilevel Inverter(MLI), Capacitor filter, PI controller, Fuzzy controller, Total harmonic distortion

1. INTRODUCTION

Nowadays, a plenty of power scarcity makes us to think about finding an alternative way and providing a feasible solution for balancing the demand of power. Renewable energy conversion system is the only way that is found after a great research. Şaban Yılmaz developed a Mathematical Model Derivation of Solar Cell by Using One Diode. This solar cell using one diode simplifies the design of solar panel which improves the efficiency of power conversion [1]. Invention of new power electronics devices and development of energy conversion schemes are taking us to next level of designing and selecting the multilevel inverters (MLI). One of the focusing area in MLI is the limitation of power electronic switches. Amarjeet.S.Pandey has given a detailed study of MLI in which a three phase flying capacitor type MLI has been developed [2]. There is a problem arising if the power electronic device which can withstand high voltage is used in inverter, then the switching frequency of the power electronic device is getting restricted automatically. A multilevel inverter can reduce the device voltage and the output harmonics by increasing the number of output voltage levels . To increase the number of output voltage levels, number of isolated DC sources has to be increased in the MLI which makes the system as more complex.

To reduce the complexity A.Venkadesan, K.Sedhu Raman have developed a Solar Powered Boost Converter for MLI [3]. Hasaneen, B.M. and Elbaset Mohammed have developed a DC/DC converter which acts as a DC link between MLI and Solar PV system which employs MPPT algorithm to improve the power conversion[4]. Vinayaka B.C, S. Nagendra Prasad proposed “Modeling and Design of Five Level Cascaded H-Bridge Multilevel Inverter with DC/DC Boost Converter” in which a H-bridge MLI has been developed with DC-DC boost converter for solar PV application [5]. To reduce the total harmonic distortion[THD], new pulse width modulation[PWM] techniques are developed. In that case, Divya Subramanian, Rebiya Rasheed proposed “Five Level Cascaded H-Bridge Multilevel Inverter Using Multicarrier Pulse Width Modulation Technique” in which the THD value of output vltage is vry much reduced when compared with conventional PWM techniques[6]. Solar PV system based MLI fed induction motor drive applications are becoming more popular for agriculture based applications. Sandeep Kumar Singh made A Survey and study of different types of PWM techniques used in induction motor drive in order to give the appropriate PWM techniques for MLIs to feed the induction motor drive[7]. Then B. Madhu kiran,B.V Sanker ram proposed “Analysis of cascaded h-bridge multilevel inverter with level shifted PWM on induction motor” in which new PWM technique called level shifted PWM technique has been developed for induction motor drive[8]. Then for the grid connection, Chenlei Bao developed a grid connected inverter in which a step by step controller has been designed for LCL type grid connected inverter with Capacitor–Current-Feedback Active-Damping[9]. M. S. Sivagama sundari and P. Melba Mary developed a Cascaded H-Bridge Five Level Inverter for Grid Connected PV System using PID Controller in which they related the results with other types of controllers[10].

In order to improve the efficiency of power conversion from Solar PV system and to reduce the THD level of output voltage, a new five level inverter which is fed with solar PV system is developed with PI controller and fuzzy controller and the results are compared in order to provide the optimal solution of solar energy conversion using MLI. The proposed system is simulated using MATLAB/SIMULINK.

2. PROPOSED CASCADED H-BRIDGE MLI WITH PI CONTROLLER AND FUZZY CONTROLLER

Conventional cascaded multilevel inverters are one of the most important topologies in the family of multilevel and multi-pulse inverters. The cascade topology allows the use of several levels of DC voltages to synthesize a desired AC voltage. The DC levels are considered to be identical since all of them are fuel cells or photo voltaic, batteries, etc. Since this topology [11] consists of series power conversion cells, the voltage and power level may be easily scaled.
The concept of this inverter is based on connecting H-bridge inverters in series to get a sinusoidal voltage output. Figure 1 shows the proposed H-bridge cascaded MLI. The output voltage is the sum of the voltage that is generated by each cell.
The number of output voltage levels (n) is

$$n = (2C + 1) \quad (1)$$

where C is the number of cells. The switching angles can be chosen in such a way that the total harmonic distortion is minimized.

A 'n' level cascaded H-bridge multilevel inverter needs m number of switching devices which is given by

$$m = 2(n - 1) \quad (2)$$

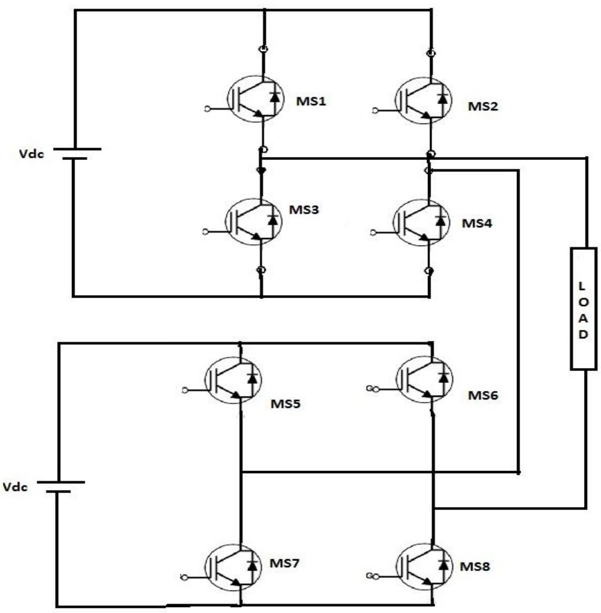

Figure.1 Proposed H-bridge cascaded MLI

There are five level of output voltage (i.e) 2V, V, 0, -V, -2V.The main advantages of cascaded H-bridge inverter is that It requires least number of components compared to diode-clamped and flying capacitors type multilevel inverters and no specially designed transformer is needed as compared to multi pulse inverter. But the main disadvantage is that when the voltage level increases, the number of switches increases and also the sources, this in effect increases the cost and weight.

The cascaded H-bridge multilevel inverters have been applied where high power and power quality are essential, for example, static synchronous compensators, active filter and reactive power compensation applications, photo voltaic power conversion, uninterruptible power supplies, and magnetic resonance imaging. Furthermore, one of the growing applications for multilevel motor drive is electric and hybrid power trains.

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3.4 Pulse Width Modulation Technique

A various types of Pulse Width Modulation(PWM) techniques are being used in MLI for renewable energy conversion. The PWM techniques used are

a. Sinusoidal and Modified Sinusoidal PWM technique
b. Space Vector PWM technique
c. Multi Carrier PWM technique(MC-PWM)

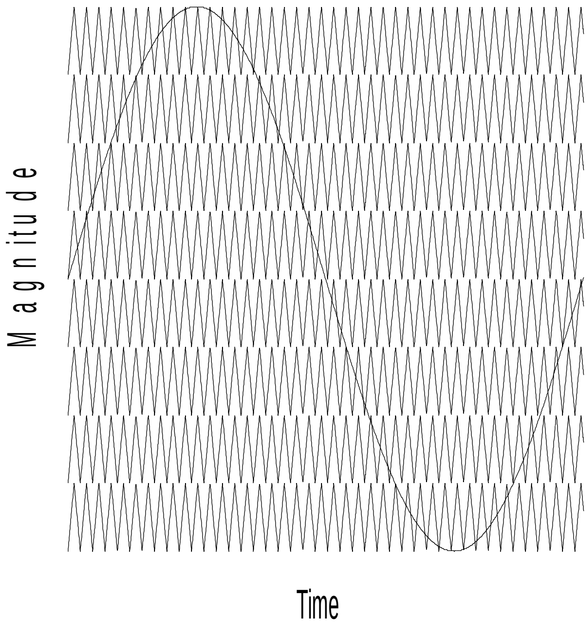


Figure.2 Multi Carrier-PWM technique

Among these techniques, MC-PWM is used in this cascaded MLI in order to produce five level output voltage level with low THD value. Figure 2 shows the MC-PWM technique in which 8 triangular carrier signals with 2KHz frequency is compared with a single sinusoidal reference signal with 50Hz frequency. In the MC-PWM, positive ongoing sinusoidal signal is compared with four carrier signals to generate switching pulses for upper leg switching devices and negative ongoing sinusoidal signal is compared with four carrier signals to generate switching pulses for lower leg switching devices.

4. PI CONTROLLER AND FUZZY CONTROLLER

PI Controller

PI and Fuzzy controllers are employed in the proposed MLI which is fed with solar PV system to achieve the nominal operating point in the presence of lot of disturbances and noise and the results of both the controller employed MLI are compared to justify the best controller for renewable energy conversion systems. Singh, S.,Pandey, A.K., Dipraj has designed a PI controller for DC servo motor to reduce the speed error and to obtain the optimal speed within a short range of period without over fluctuation [12]. In this proposed system, PI controller is designed with K_p=1 and K_i=0.003 by using Ziegler-Nichols tuning technique. Simulink diagram of PI controller is shown in Figure 3. The output from PI controller is used to control the magnitude of reference sinusoidal signal thereby the modulation index is varied in order to change the width of the switching pulses to get variation in the output voltage.

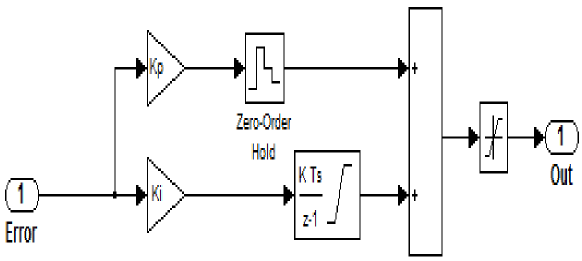


Figure.3 Simulink diagram of PI controller

Fuzzy Controller

Feng proposed hybrid energy storage with multimode fuzzy power allocator for PV systems in which he developed a fuzzy controller hybrid energy storage and Solar energy conversion system[13]. The structure of fuzzy knowledge based controller (FKBC) includes fuzzification module, knowledge base and defuzzification module. There are two blocks in fuzzification module. They are normalization block and fuzzification block. Normalization block performs the scale transformation (i.e. an input normalization) which maps the physical values to the current process state variables into normalized universe of discourse (normalized domain). Fuzzification block performs fuzzification which converts acrisp value, current value of a process state variable into a fuzzy set, in order tomake it compatible with the fuzzy set representation of the process state variable in the rule antecedent. The knowledge base of a FKBC consists of a database and a rule base. The basic function of the database is to provide the necessary information for the proper functioning of the fuzzification module, the rule base and the defuzzufication module. The design parameters of data base includes,

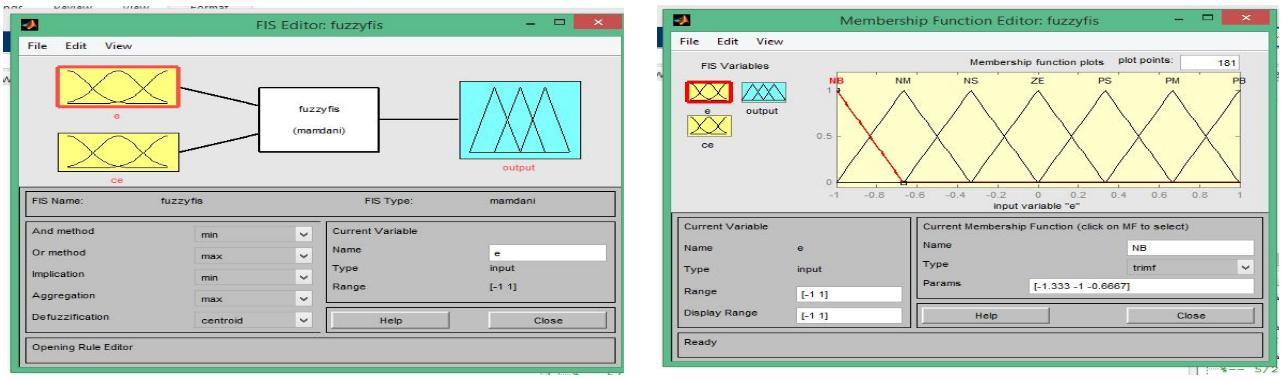
- Choice of membership functions
- Choice of scaling factors

The most popular choices for the shape of the membership function include triangular, trapezoidal and bell membership functions. The basic function of the rule base is to represent in a structured way, the control policy of an experienced process operator and / or control engineer in the form of a set of production rules. The process state variable representing the contents of the rule antecedents selected as error, denoted by (e) and change in error(ce).

$$e = V_{ref} - V_o \qquad (3)$$

$$ce = e_n - e_{n-1} \qquad (4)$$

where V_{ref}=desired output voltage of MLI, V_o=actual output voltage of MLI and subscript n represents the number of sampling instances.
The control output variable representing the contents of the rule-consequent are selected as control output, denoted by δm_n (change of modulation index). The error and change in error is given to fuzzifier there are two basic types of approaches employed in the design of inference engine of the FKBC. They are Mamdani based inference and Sugeno based inference. Rule base consist the rules and decision making based on rules and given to defuzzifier. The defuzzification module has the following blocks in it; they are defuzzification block and denormalisation block. Defuzzification block performs defuzzification which converts the set of modified control output values into a single point wise value. Fig. 4(a) and 4(b) shows the Simulink diagram of fuzzy controller design in which it clearly gives the details about the membership function plot creation for e and ce and for δm_n.



(a) (b)

Figure.4 Membership function plot: (a) creation of input signals and (b) creation of membership function plots

The fuzzy rules are as follows. R_i: if e is X_i and ce is Y_i, then δm_n is Z_i, where X_i, Y_i, Z_i are fuzzy subsets in the universe of discourse. Each universe of discourse is divided into seven fuzzy subsets namely NB (Negative Big), NM (Negative Medium), NS (Negative Small), PB (Positive Big), PM (Positive Medium), PS (Positive Small), as shown in the Fig. 4(a) and 4(b) and table 1.
Table 1 gives the rule base of membership function plots.

Table 1: Rule base of membership function plots

e/ce	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

5. SIMULATION REULTS

Figure 5 shows the Simulink diagram of design of solar PV cell whose input parameters are given. The input voltage (mag=20.4), insulation (1000w/m^2),and temperature($25^0 C$)

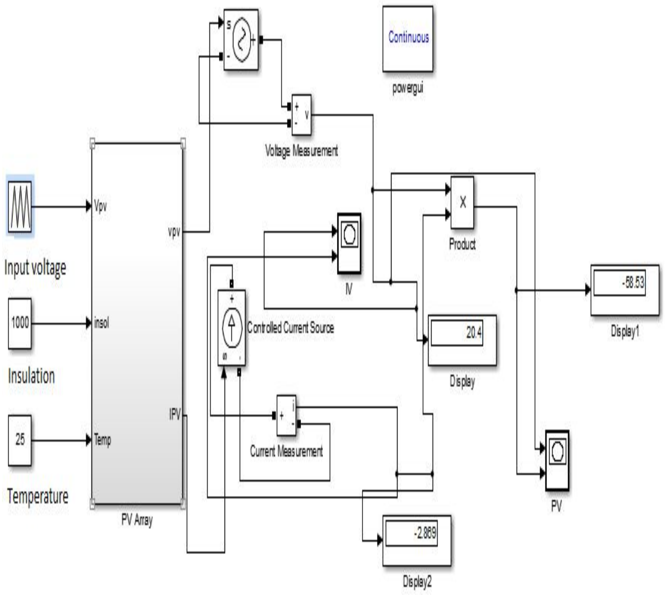


Figure.5 Simulink diagram of Solar PV cell

Figure 6 shows the Simulink model of proposed five level MLI.

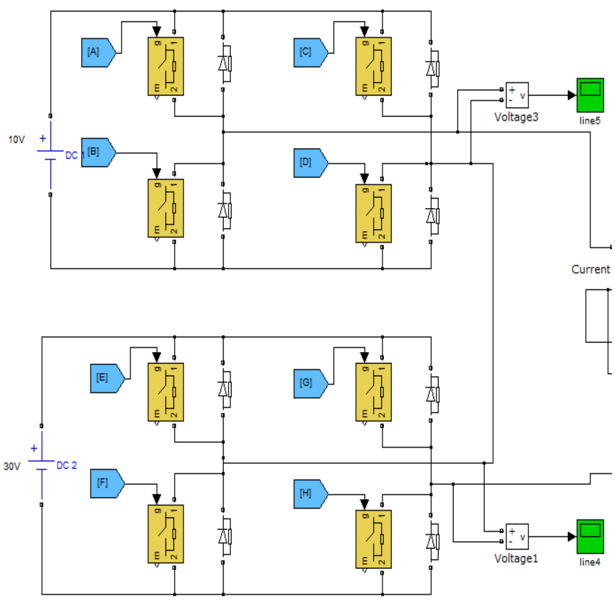


Figure.6 Simulink diagram of proposed five level MLI

Figure 7 shows the Simulink model of Multi-carrier PWM generation for proposed MLI.

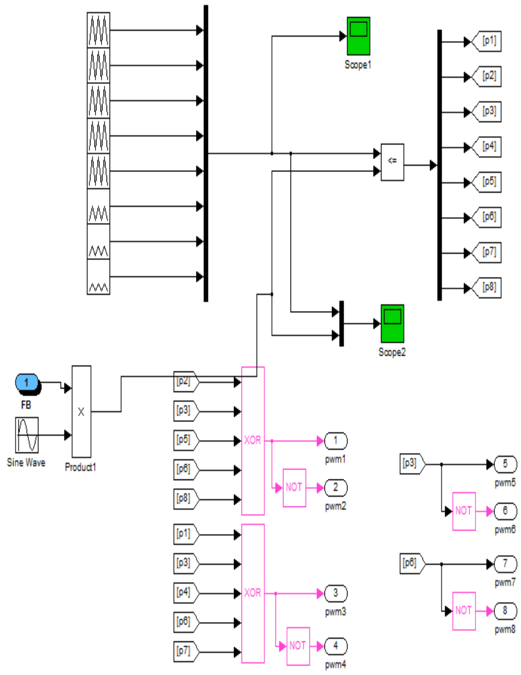


Figure.7 Simulink diagram of MC-PWM generation for proposed MLI

Figure 8 shows the open loop Simulink model of proposed five level MLI in which the boost converter is used with the L and C values of 150uH and 220uF respectively and 66.6% of duty cycle with 100kHz frequency in order to boost up the input voltage of 12V to output voltage range of 30V and L and C values of 65uH and 130uF respectively to boost up the input voltage of 12V to output voltage range of 15V.

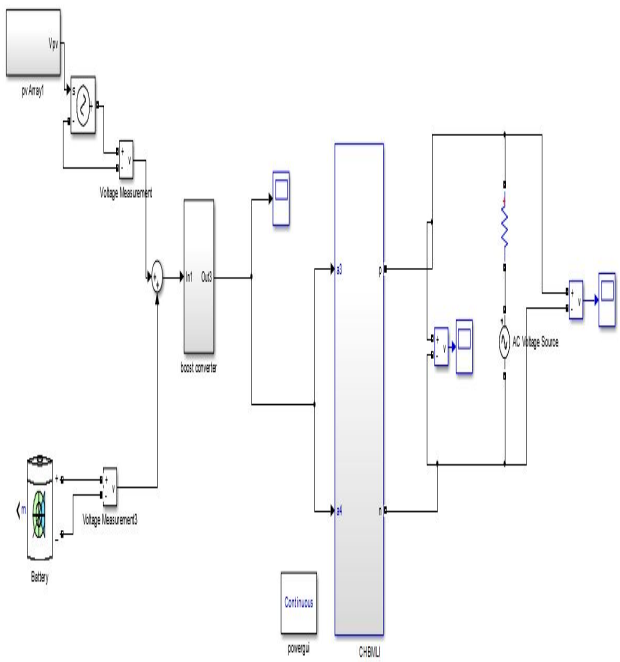


Figure.8 Simulink diagram of open loop model of proposed five level MLI

Figure 9 shows the output voltage waveform and THD value which is done by using FFT analysis in MATLAB/SIMULINK for open loop model of proposed five level MLI.

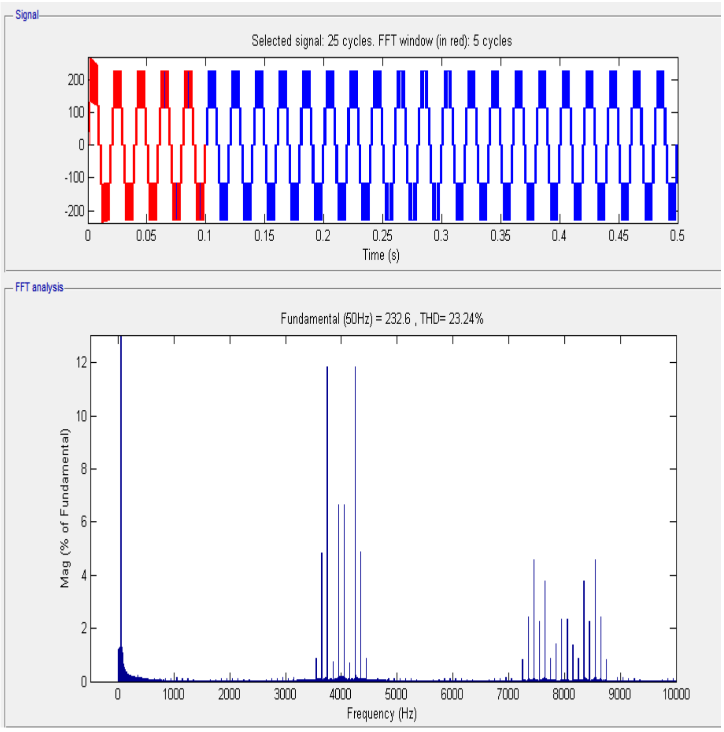


Figure.9 Output voltage and THD value of open loop model of proposed five level MLI

Figure 10 shows the output voltage waveform and THD value which is done by using FFT analysis in MATLAB/SIMULINK for open loop model of proposed five level MLI with capactor filter of C=10mF.

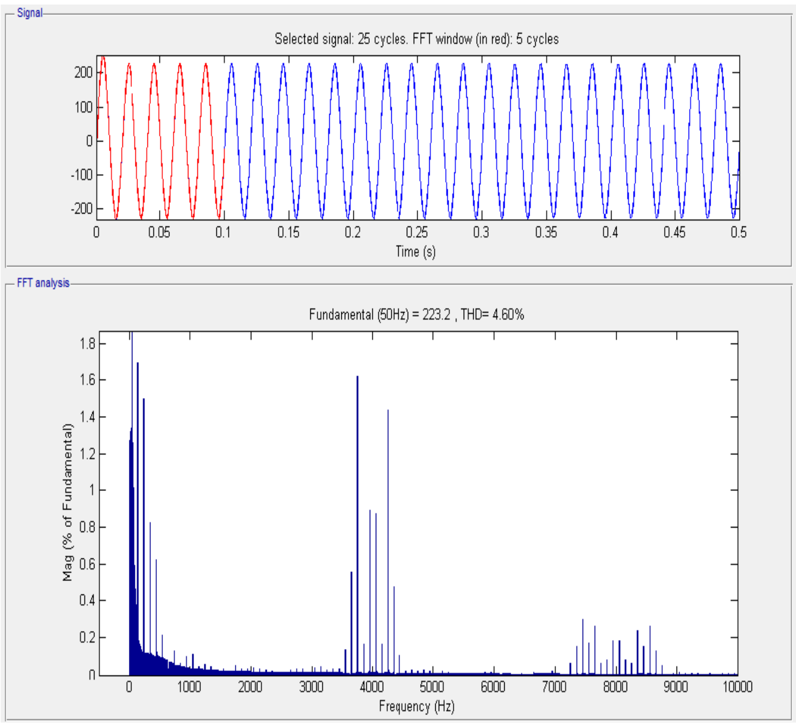


Figure.10 Output voltage and THD value of open loop model of proposed five level MLI with capacitor filter

Figure 11 shows the closed loop Simulink model of proposed five level MLI with PI controller.

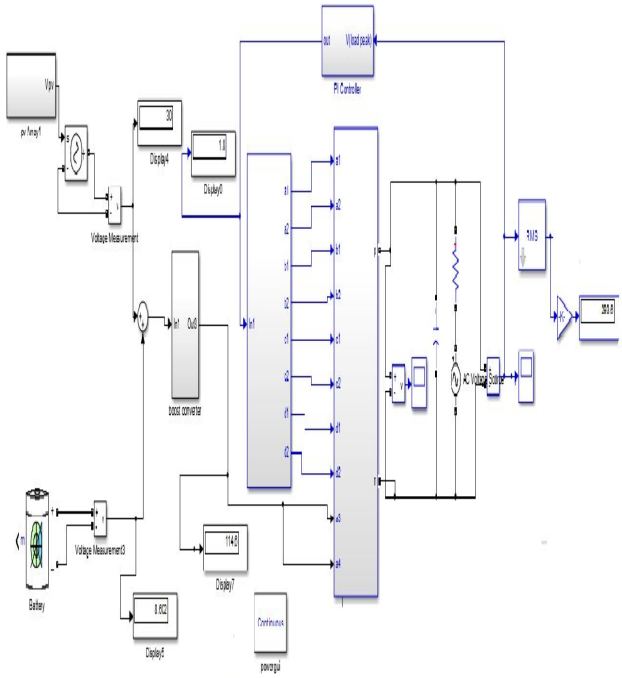


Figure.11 Simulink diagram of closed loop model of proposed five level MLI with PI controller

Figure 12 shows the output voltage waveform and THD value which is done by using FFT analysis in MATLAB/SIMULINK for closed loop model of proposed five level MLI with PI controller and capactor filter of C=10mF.

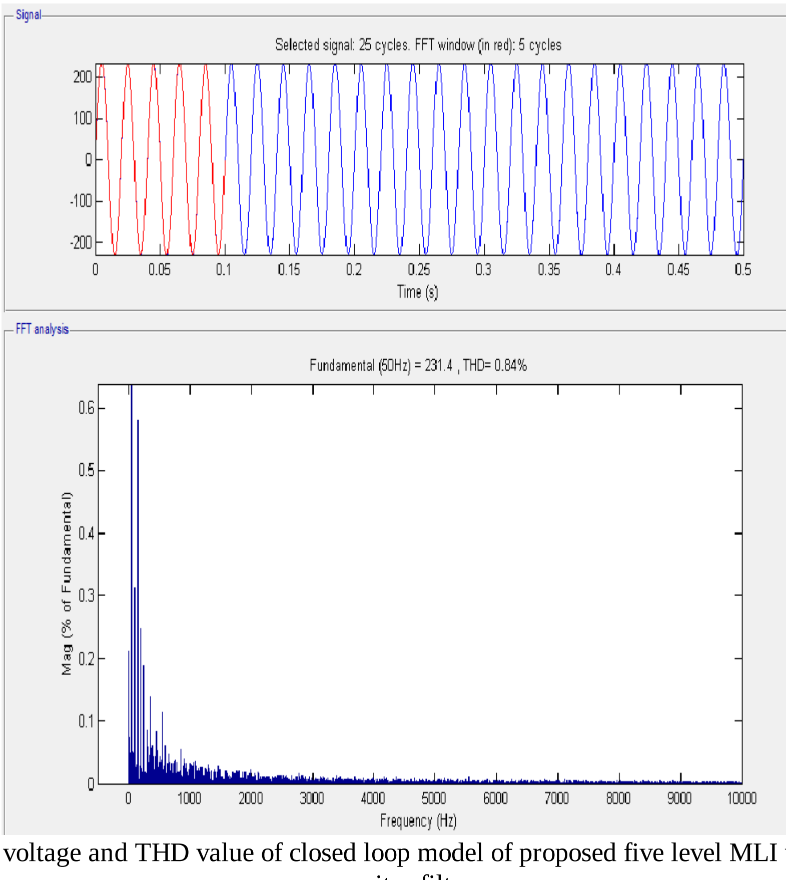


Figure.12 Output voltage and THD value of closed loop model of proposed five level MLI with PI controller and capacitor filter

Figure 13 shows the closed loop Simulink model of proposed five level MLI with Fuzzy controller.

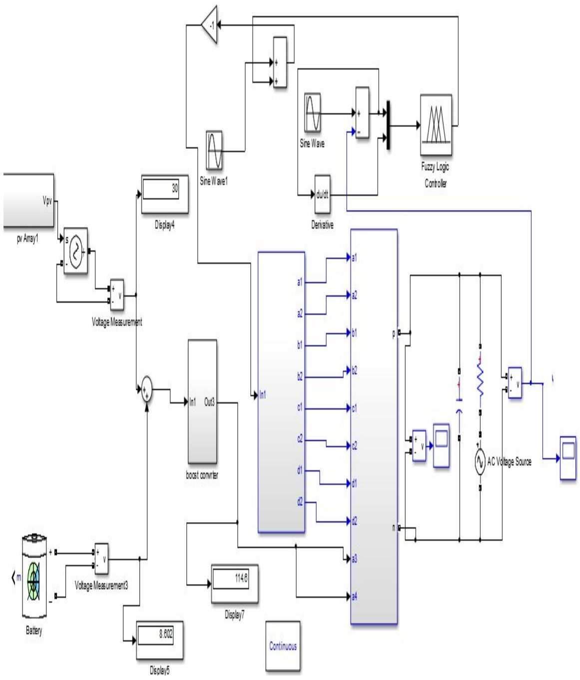


Figure.13 Simulink diagram of closed loop model of proposed five level MLI with fuzzy controller

Figure 14 shows the output voltage waveform and THD value which is done by using FFT analysis in MATLAB/SIMULINK for closed loop model of proposed five level MLI with fuzzy controller and capactor filter of C=10mF

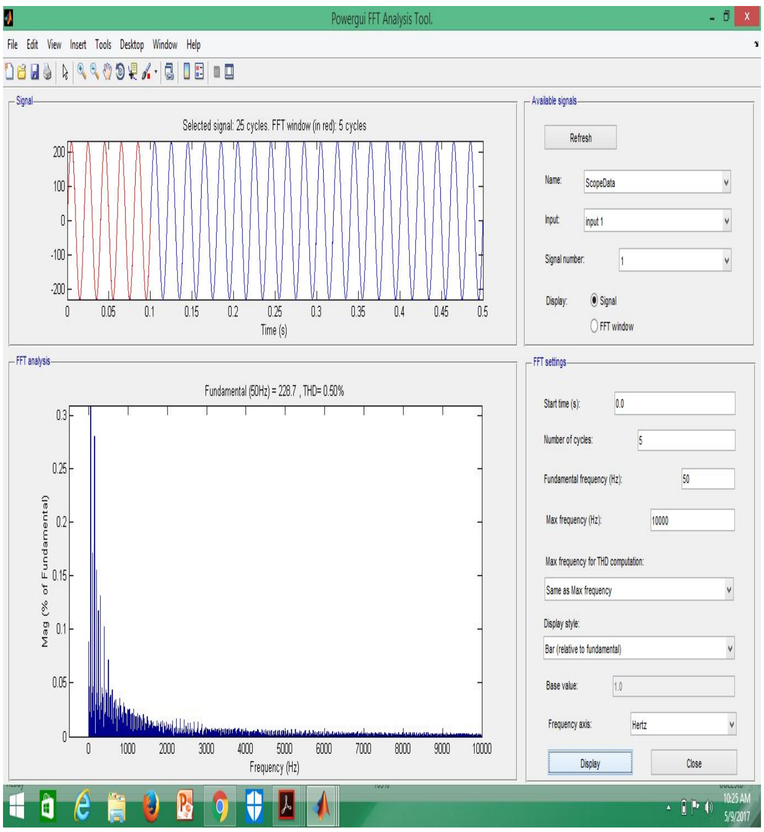


Figure.14 Output voltage and THD value of closed loop model of proposed five level MLI with fuzzy controller and capacitor filter

Table 2 shows the comparison of THD values for open and closed loop of proposed five level inverter with PI controller and fuzzy controller

Table 2 : Comparison of THD values for open and closed loop five level inverter with PI controller and fuzzy controller

S.No.	Topology	Capacitor filter value	THD value(%)
1	Open loop five level inverter without filter	---	23.24
2	Open loop five level inverter with filter	10mF	4.60
3	Closed loop five level inverter with PI controller and filter	10mF	0.84
4	Closed loop five level inverter with fuzzy controller and filter	10mF	0.50

6. CONCLUSION

The 5 level cascaded h-bridg inverter is proposed for solar PV application for which a new multi-carrier PWM modulation is developed and it is checked for different systems like open loop and closed loop 5 level cascaded h-bridg inverter with and without filter. The closed loop system of 5 level cascaded h-bridg inverter is designed with PI controller and fuzzy controller and it is simulated using MALTAB/SIMULINK and the THD value of output voltages of these systems are calculated and compared in order to analyse the closed loop system for solar PV application.

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