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DESIGN OF FUZZY CONTROLLER FOR GRID CONNECTED PHOTOVOLTAIC POWER GENERATION

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ABSTRACT

Multilevel inverter technology has emerged recently as an important alternative in the area of high-power medium-voltage energy control. In this paper, a multilevel inverter topology is developed and applied for injecting the real power of renewable power into the grid to reduce the switching losses, total harmonic distortions and electromagnetic interference caused by switching operation of power electronic devices. The grid connected photovoltaic system consists of a solar cell array, dc-dc boost converter, a multi-level inverter are coupled to the load system. This multi-level inverter consists of two capacitors, a dual-buck converter, a full-bridge inverter and a filter. In photovoltaic grid connected systems, power electronic converters are used to convert the power, which is generated from PV panel and transfer to grid. So, the dc-dc converter, dc-ac inverters and their controllers are playing an important role in grid connected PV systems. The output power of solar cell array is dc power. So, the inverter is necessarily to convert the dc power to ac power and inject that power into grid. In this paper, five-level inverter with dual-buck converter is used. The dual-buck converter converts the dc voltage from PV panel into three level voltages. Further, the three level voltages is converted into five-level with the help of full-bridge inverter. The dc-dc converter and dc-ac inverter are controlled by developing fuzzy logic controller. The performance of the developed renewable power generation system is compared for Proportional-Integral controlled system and Fuzzy logic controlled system. However the Efficiency of using fuzzy controller to the system is increased.

KEYWORDS: Grid connected photovoltaic power generation system, Multi-level inverters, Proportional-Integral controlled system and fuzzy logic controlled system.

I. INTRODUCTION

The world is concerned with fossil fuel exhaustion and environmental problems caused by conventional power generation, renewable energy sources, particularly solar and wind energy have become very popular and demanding. Now-a-days solar energy is becoming more important due to reduction in supplies of non-conventional energy sources. Along with less pollution, cost of solar array is also decreasing day by day. Photovoltaic systems are used in different applications such as traffic signaling, electric power plant, satellite power systems, battery charging and water pumping. Solar energy is always better in residential applications in near future. Solar cell generates dc power which should be converted into ac power before feeding it to utility grid. Photovoltaic systems require interfacing power converters between the PV array and the grid. These power converters are used for two major tasks. First is to inject a sinusoidal current into the grid. And second is to reduce the harmonics content in the grid injected voltage and current. The dc-dc power converter that is used to operate the PV arrays at maximum power point and boost the solar output voltage. The inverter is necessary in the power conversion interface to convert dc power to an ac power.

Generally the conventional single-phase inverter topologies for grid connection include half-bridge and full-bridge [1-4]. The half-bridge inverter consists of one capacitor and one power electronic switch. The dc bus voltage of half-bridge inverter must e higher than double of the peak voltage of the output ac voltage. The output ac voltage of half-bridge inverter is two levels. The voltage jump of each switching is the dc bus voltage of the inverter. The full-bridge inverter is configured by two power electronic arms. The popular modulation strategies for the full-bridge inverter are bipolar modulation and uni-polar modulation [5-7]. All the power electronic switches operate in high switching frequency in both half-bridge and full-bridge inverters. The active and passive devices in inverter lead to conduction loss and switching loss. The conduction loss depends on the

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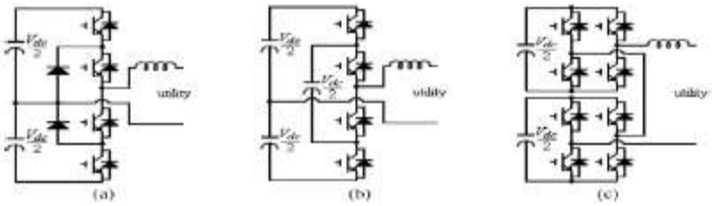
handling power of power electronic switch. The switching loss is proportional to switching frequency, voltage jump of each switching, and the current of the switch. The power efficiency can be advanced if the switching loss in reduced. Multi level inverter technology should be designed with higher voltage levels in order to improve the conversion efficiency, reduce switching harmonic content, smaller filter inductor and electromagnetic interference compared with the conventional half-bridge and full-bridge inverters. Thus, both performance and complexity should be considered in designing the multi-level inverter [8-9].

Figure: 1



(a.)Diode clamped (b). Flying capacitor (c).H-bridge inverter

The single-phase multilevel inverter topologies are classified into diode clamped, flying capacitor and H-bridge types [10-12] shown in Fig 1. (a), (b), (c) . In this paper, multi-level inverter with fuzzy controller is developed and applied for injecting the real power of renewable power into the utility. This five level inverter is designed with two dc capacitors, a dual-buck converter, a full-bridge inverter and a filter. The dual-buck converter power electronic switches are switched in high frequency to generate a three-level voltage and balance the two input dc voltages. The power electronic switches of full-bridge inverter are switched in low frequency synchronous with the utility to convert the output voltage of the dual-buck converter to five-level ac voltage.

II. CIRCUIT CONFIGURATION

The proposed photovoltaic power generation system is developed with Fuzzy controller, to convert the dc power, which is generated from PV cell array into ac power and that power injects into grid with series connection of power electronic devices like DC-DC boost converter, two dc capacitors, dual-buck converter, full-bridge inverter, filter and switches [13]. The PV arrays are connected to the inverter through a DC-DC converter which performs the function of maximum power point tracking (MPPT) and boosting the output voltage of the PV cell array because of power generation, which is less. The inverter capability is used to generate five level voltages from the three level input voltages.

The circuit configuration of the five-level inverter applied to a photovoltaic power generation system shows in Fig.2. The PV cell array inputs are irradiance and temperature. The power of PV system is in DC form. The output of the solar cell array is connected to the input port of the dc-dc boost converter. The two dc capacitors perform as energy buffers between the dc-dc converter and five-level inverter. The dual-buck converter is designed by two buck converters through which the dc-dc the voltage balancing between the two dc capacitors is done and converts into three level DC output voltage i.e., Vdc/2, Vdc, 0. The output of the dual –buck converter is connected to the full-bridge inverter to convert the three level dc voltage to five level ac voltages. The output current of the five-level inverter is controlled to generate a sinusoidal current in phase with the grid voltage to inject into the grid. An inductor is placed at the output of the full-bridge inverter to perform as a filter inductor for filtering out the high frequency switching harmonics. Switches sw1 and sw2 are placed between the five-level inverter and the utility. And they are used to disconnect the photovoltaic power system from utility when fault condition occurs.

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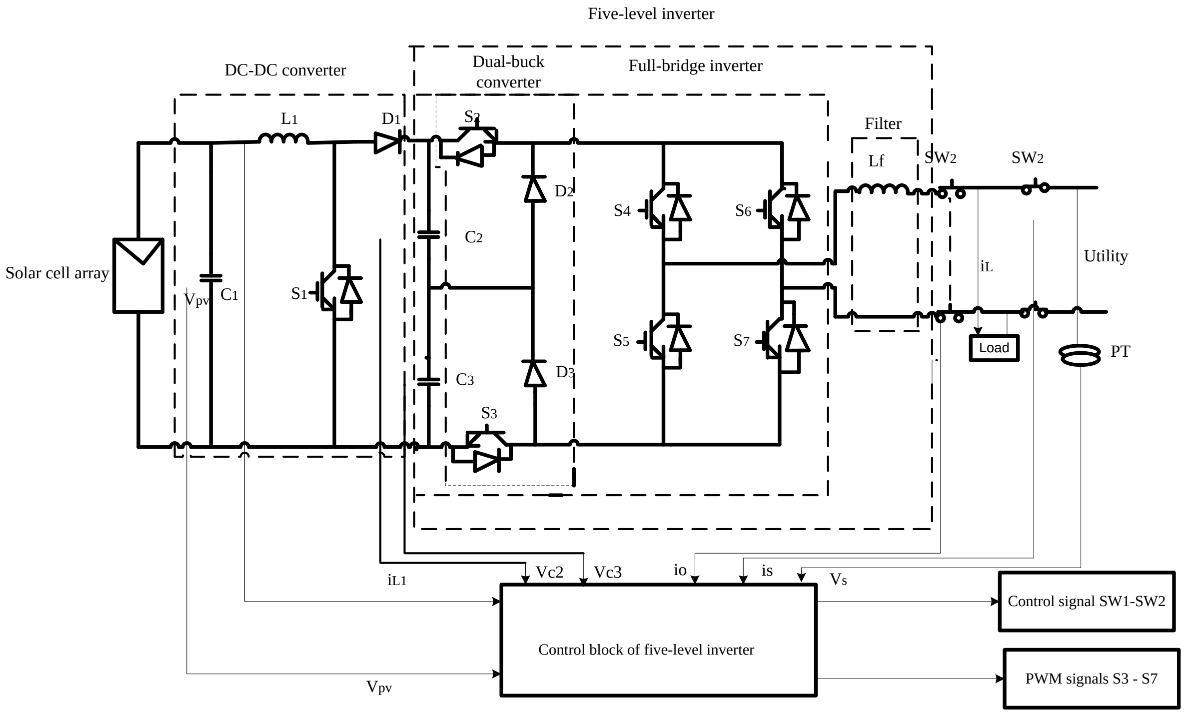
Figure.2:



Circuit configuration of grid connected photo voltaic power generation system of five-level inverter

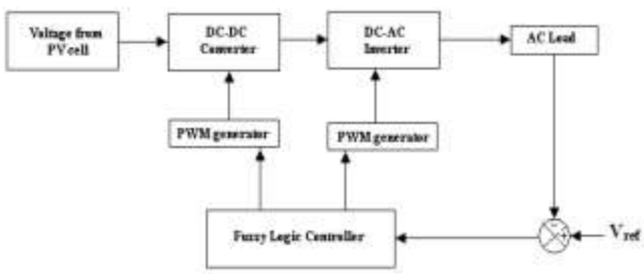
III. CONTROLLER

In grid connected photovoltaic systems power electronic devices are used to transfer the dc power from PV panel to grid. The dc-dc converter and dc-ac inverter and their controllers are very important in photovoltaic systems. The photovoltaic system is controlled by Fuzzy controller.

Fuzzy Logic Controller

The FLC is range-to-range controller. Fuzzy logic controller is useful for non linear systems and it is used of linguistic variables rather than numerical variables. It has four sections which are fuzzifier, inference engine, rule base and defuzzifier. The block diagram of fuzzy logic controller for grid connected PV system is shown in Fig.3.

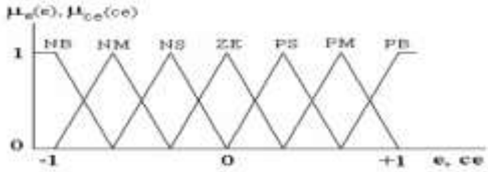
Figure.3:



Block diagram of fuzzy control for grid connected PV system.

FLC is developed for converter and inverter to obtained desired output voltage and output current. For dc-dc converter the inputs to the FLC are the present error pe = Vref-Vo and change in error ce = pe-e-1 where e-1 is the previous error. For dc-ac inverter, the inputs to the FLC are the present error e = Iref-Ig and change in error ce = pe-e-1. All input variables have membership functions and each membership functions have membership grade as shown in fig.4. Input and output variables have seven triangular membership functions. Membership functions are denoted with linguistic variable using seven fuzzy subsets: negative big, negative medium, negative small, zero, positive small, positive medium, positive big. The range of this membership functions are between-1 to+1.

Figure.4:



Membership functions of e and ce

The behavior of a FLC depends on the shape of membership functions of the rule base. The control rules are defined by fuzzy inference MIN/MAX method.

Table.1 Rule base of fuzzy logic control

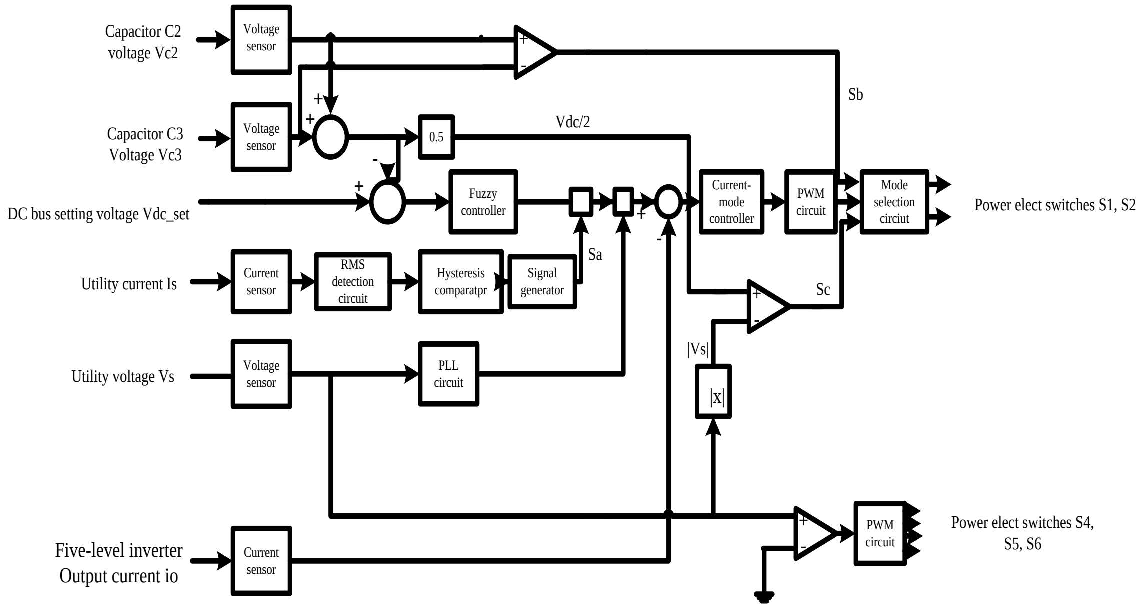
		Error (e)						
		NL	NM	NS	Z	PS	PM	PL
Change in error (ce)	NL	NL	NL	NL	NL	NM	NS	Z
	NM	NL	NL	NL	NM	NS	Z	PS
	NS	NL	NL	NM	Z	Z	PS	PM
	Z	NL	NM	NS	PS	PS	PM	PL
	PS	NM	ZS	Z	PM	PM	PL	PL
	PM	NS	Z	PS	PL	PL	PL	PL
	PL	Z	PS	PM	PL	PL	PL	PL

The Defuzzification method converts the fuzzy values into accurate values. This means that the defuzzification block converts inferred control action back to a continuous signal which is applied to power electronic switches of converter and inverter.

Controlling Methodology

The power from photovoltaic cell is given to the dc-dc boost converter where the input voltage is boosted up to the required dc voltage, and then given to the dc-ac converter and later this arrangement is controlled through a controller. The actual parameter, which has to be controlled, is compared with the reference parameter and this error is fed as an input to the controller. The controller takes the error as input and generates a corresponding control signal to operate dc-dc converter switches and dc-ac inverter power electronic switches. The developed photovoltaic power generation system consists of controllers of a dc-dc converter and five-level inverter. Fig. 5 shows the control block diagram of five-level inverter.

The five-level inverter must generate a sinusoidal current in phase with the utility voltage to be injected into the utility. This control must generate PWM signals to operate the power electronic switches of dual-buck converter and full-bridge inverter. The dc bus voltage must be larger than the peak voltage of the utility. The dc capacitor voltages of C2 and C3 must be controlled to be equal *i.e.*, 85V respectively. The voltages of dc capacitors C2 and C3 are detected and then added to obtain a dc bus voltage is 170V.



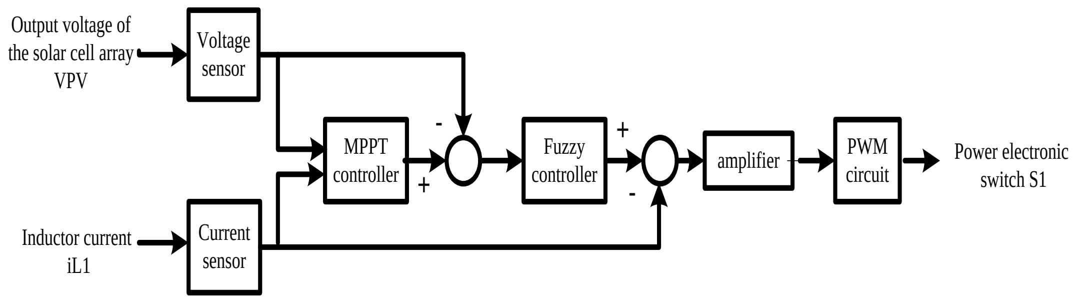
Control block diagram of five-level inverter

The added result is subtracted from a dc bus setting voltage V_{dc} set. The dc bus setting voltage is larger than the peak voltage of the utility 110V. The actual value and measured value are compared to form error signal. The error signal is given to the fuzzy controller to generate control signals.

The utility current is sent to a root mean square (RMS) detection circuit. The output of the RMS detection circuit is sent to a hysteresis comparator. It contains a low threshold value and a high threshold value. If the RMS value of the utility current is smaller than the low threshold value, the output voltage hysteresis comparator is high, the condition of islanding operation or power balance occurs. On other hand, the utility is normal. The output of the hysteresis comparator is sent to a signal generator. The outputs of the fuzzy controller and signal generator are sent to a multiplier. The utility voltage is detected and then sent to a phase-look loop (PLL) circuit to generate sinusoidal signal is in phase with the utility voltage. The outputs of the multiplier and PLL circuit are sent to the other multiplier. The product of this multiplier is the reference signal of the output current. The output of the current-mode controller is sent to PWM circuit to generate a PWM signal. DC bus voltage is also sent to an amplifier with a gain of 0.5 to obtain voltage signal $V_{dc}/2$. The detected utility voltage is sent to obtain voltage signal Vs. Voltage signals $V_{dc}/2$ and Vs are compared to obtain signal Sc. The output signal of the PWM circuit and signals Sb and Sc are sent to the mode selection circuit. The output of the mode selection circuit will generate the control signals of the power switches S2 and S3.

Control Of DC-DC Converter

Control block of the dc-dc converter shows in Fig.6. Output voltage of solar cell array contains a ripple voltage. Therefore, the ripple voltage superimposed by the dc–dc boost converter for improving the function of MPPT. The perturbation and observation method is adopted to obtain the function of MPPT. MPPT is interconnection between the PV array and grid.



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Control block of DC-DC Boost converter

The output voltage of the solar cell array and the inductor current are detected and sent to a MPPT controller to obtain the desired output voltage of the solar cell array. The actual output voltage of solar cell array and desired output voltage are sent to a sub tractor, and this result is sent to fuzzy controller. The output of the fuzzy controller is the reference signal. The reference signal and the inductor current are sent to a sub tractor, and the subtracted result is sent to an amplifier. The output of the amplifier is sent to the PWM circuit. The output signal of the PWM circuit is the driving signal for the power electronic switch of the DC–DC Boost converter.

The conventional PI controller is a fixed-gain feedback controller. Therefore it cannot compensate the parameter variations in the process and cannot adapt changes in the environment. PI controlled system is less responsive to real and relatively fast alterations in state and so the system will be slower to reach the set point.

Table.2 simulation parameters

SOLOR MODULE	
Rate of Maximum Power	75 W
Open Voltage	21.7 V
Short Current	5.0 A
DC-DC Converter	
Capacitor (C1)	470 μF
Inductor(L1)	2 mH
Switch Frequency	20 KHz
Five-Level Inverter	
DC Bus Capacitor (C2,C1)	2,200 μF
Filter Inductor (Lf)	1.4 mH
DC Bus Setting Voltage	170 V
Switch Frequency (PWM)	20 KHz
Utility Voltage	110 V
Utility Frequency	60 HZ

IV. RESULTS

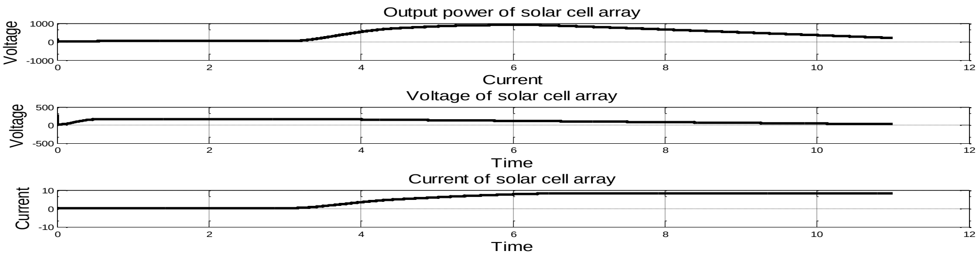

Figure.7. The power, voltage and current characteristics of solar cell array

The simulation results of grid connected photovoltaic system with fuzzy controller are shown in figures. The characteristics of the solar cell array are shown in fig.7. The environmental temperature and radiation levels are 30.7 ◦C and 922 W/m2, respectively. The temperature of the solar module is 52.3 ◦C. The maximum output power of the solar cell array is about 830W.

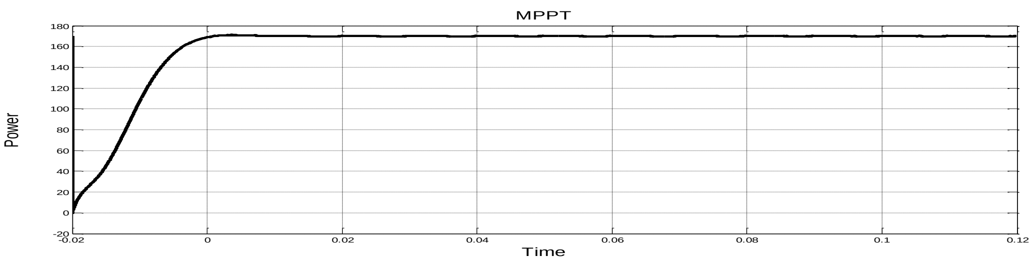

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Figure.8. MPPT performance the grid connected photovoltaic system

Figure.8 shows the simulation results of MPPT performance of grid connected photovoltaic system with fuzzy controller. The developed photovoltaic power generation system. The MPPT controller was agitated every 1.45 s. The output power of the solar cell array in the developed photovoltaic power generation system is about 830 W. Therefore, the developed photovoltaic power generation system can track the maximum power point of the solar cell array effectively.

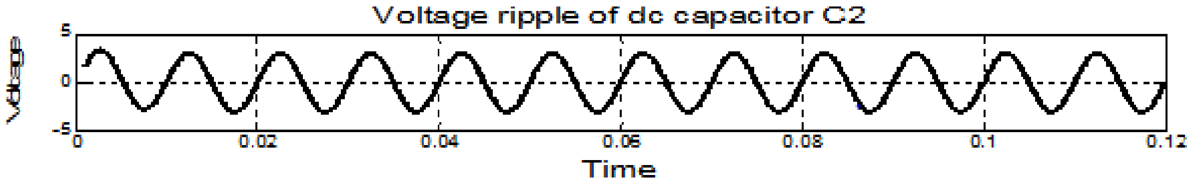

Figure.9. Voltage ripple of dc capacitor Vc2

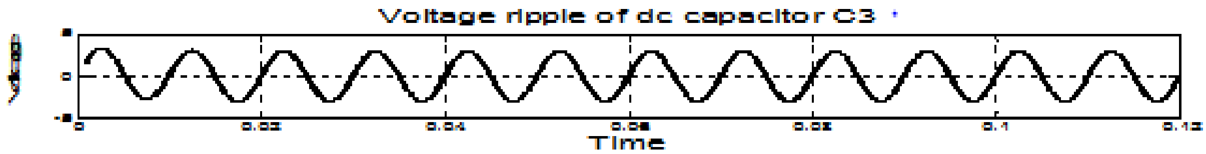

Figure.10. Voltage ripple of dc capacitor Vc3

Fig.9 and Fig.10 shows the voltage ripple of dc capacitor C2 and voltage ripple of dc capacitor C3. The peak-to-peak value of the voltage ripple at dc capacitors *C*2 and *C*3 is about 5 V.

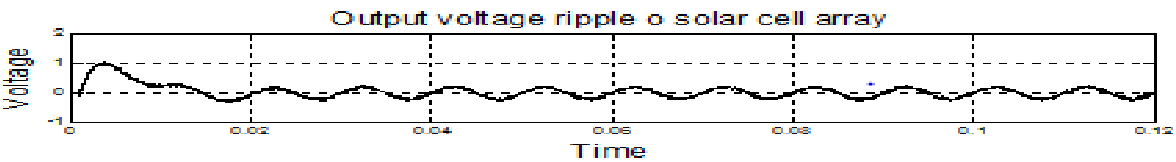

Figure.11. Voltage ripples of solar cell.

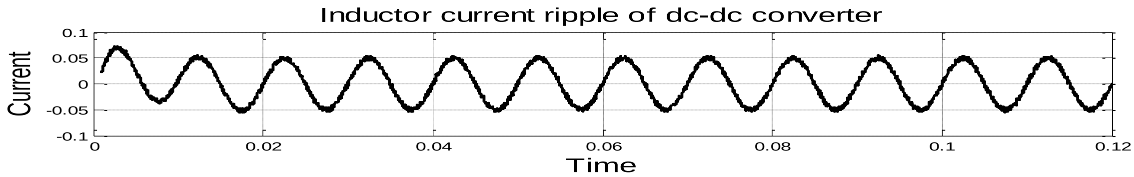

Figure.12. Current ripple of DC-DC converter

Figure.11 and Figure.12 shows the simulation results of ripple voltage of solar cell array and current ripple of dc-dc converter. The peak-to-peak value of the voltage ripple at the solar cell array is only about 1.6 V. The ripple of the inductor current is very small due to the use of the current mode control.

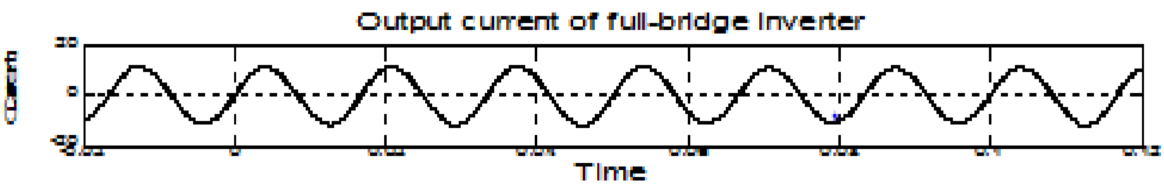

Figure.13. Output current of the full-bridge inverter

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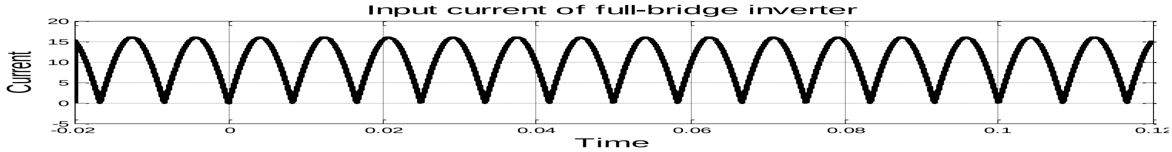

Figure.14. Input current of the full-bridge inverter

Figure.13 and Figure.14 shows the Simulation results of output current of the full-bridge inverter and input current of the full-bridge inverter of the five-level inverter. Switch frequency of the power electronic switches *S*4 and *S*5 is 60 Hz. This verifies the power electronic switches of the full-bridge inverter are switched in low frequency, and the full-bridge inverter can convert the dc power into ac power.

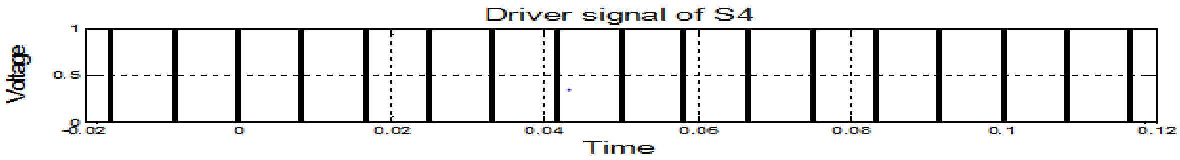

Figure.15. Driver signal of S4

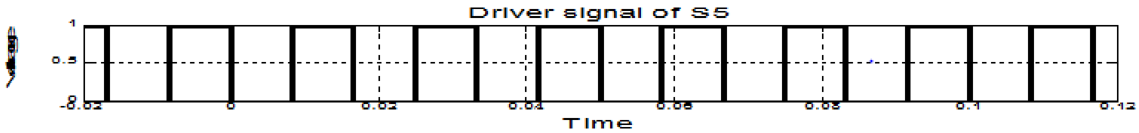

Figure.16. Driver signal of S5

Figure.15 and Figure.16 shows the simulation results of the pulse generation of switches S4 and S5. The switching frequency of switches is 60Hz.

Figure.17. Output voltage of dual-buck converter

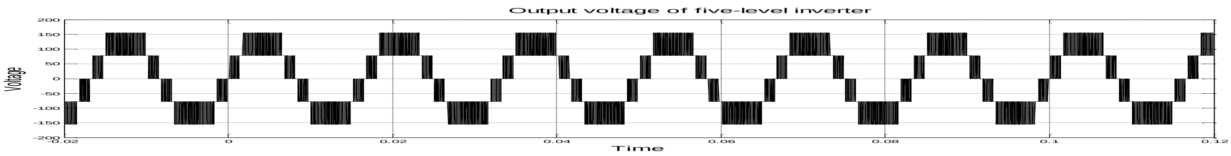

Figure.18. Output voltage of five-level inverter

Figure.17 and Figure.18 Shows the simulation results of output voltage of dual buck converter and output voltages of five level inverter. The dual-buck converter outputs a dc voltage with three levels *V*dc, *V*dc/2, and 0. The output voltage of the dual-buck converter is further converted to an ac voltage with five voltage levels *V*dc, *V*dc/2, 0, −*V*dc, and –*V*dc/2 by the full bridge inverter. The voltage variation of each level is *V*dc/2. The output voltage waveform indicates the maximum voltage of 170V. The power electronic switches of full-bridge inverter are switched in low frequency. The power electronic switches of the dual-buck converter is switched in high frequency.

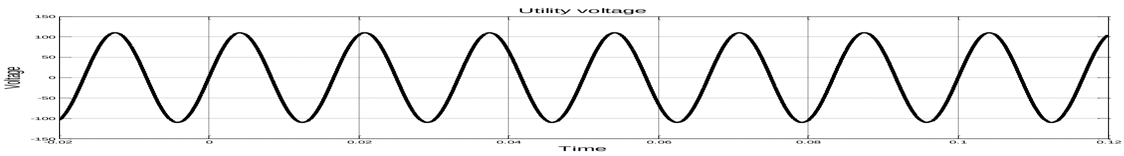

Figure.19. Utility voltage waveform

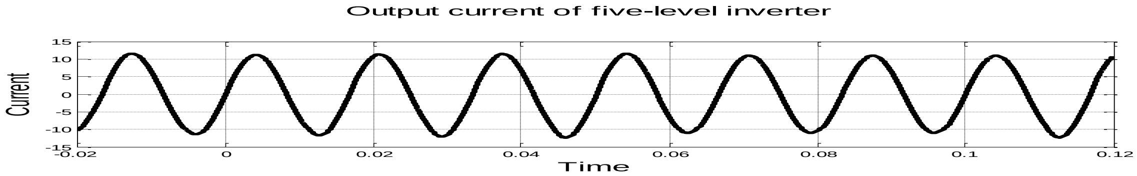

Figure.20. Output current of the five-level inverter

Figure.19 and Figure.20 shows the simulation results of utility voltage i.e., 110V and output current of five-level inverter. This waveform is generated to match the obtained five-level output voltage with peak voltage of the utility by converting the real power that is obtained for PV system.

Table2. Comparison table for PI and FUZZY controllers

	PI	Fuzzy
Efficiency	95.74%	97.04%
Current (THD)	2.ss34%	2.01%
Voltage (THD)	4.744%	2.48%

V. CONCLUSION

In this project, grid connected photovoltaic system with Fuzzy logic controller is developed. The conventional proportional integral control technique is also implemented to the system. The total harmonic distortion of both topologies is analyzed and compared. The simulation results shows that the FLC has more efficiency and less total harmonic distortions than PI controller. In particular, it is noted that the oscillation of the dc bus voltage with FLC controller is smaller compared to PI. The fuzzy logic controller outperforms the conventional PI due to robustness and the superior transient response

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