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A NOVEL PV SYSTEM CONSTRUCTED WITH FIVE LEVEL INVERTER USING SPWM TECHNIQUE

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Abstract - In this research article, the proposed system presents power-control strategies of a grid-connected PV generation system with different power transfer capabilities. This system allows maximum utilization of freely available photovoltaic energy. The efficiency of the photovoltaic system may be increased by effective utilization of Maximum Power Point Tracker (MPPT). In this article a Fuzzy Logic Controller is applied for the maximum power point tracking (MPPT) of a photovoltaic system. The output is compared with the results obtained by using PI method. The result shows that the fuzzy logic controller exhibits a better performance compared to that of conventional method. A five-level inverter is modeled with conventional cascaded H- Bridge (CCHB) multilevel inverter control with SPWM technique fed to the renewable energy system. The inverter converts the DC output from non-conventional energy into useful AC power connected to the load. The simulation results are presented to illustrate the feasibility and reliability of this system under study for renewable resources.

I. INTRODUCTION

At present, photovoltaic (PV) energy appears more attractive for electricity generation because of its pollution-free, noiseless, scale flexibility, and very less maintenance. As the PV power generation depends on the level of sun irradiation, temperature, and unpredictable shadows, a PV-based power system should be supplemented by other alternative sources of energy to ensure a reliable power supply. The extraction of maximum available power from a photovoltaic module is called Maximum Power Point Tracking and is done by Maximum Power Point Tracking Controller. The efficiency of the photovoltaic system may be substantially increased by using Maximum Power Point Tracker (MPPT). Many number of algorithms are developed to track the maximum power point in an efficient manner. Out of the existing MPPT algorithms, many of them suffer from the drawback of being slow tracking. Due to this the utilization efficiency is reduced. Many tracking control techniques have been proposed such as perturb and observe, incremental conductance, parasitic capacitance, constant voltage, neural network and fuzzy logic controller (FLC). These strategies have some disadvantages such as high cost, difficulty, complexity and instability. The general requirements for MPPT are simplicity, low cost, quick tracking under changing conditions, and small output power fluctuation. A more efficient method to solve this problem becomes crucially important. Hence, this paper proposes a method to track maximum power point using adaptive fuzzy logic controller (AFLC). FLC is appropriate for non-linear control. Behaviour of FLC depends on shape of membership functions and rule base. There is no standard method to determine accurately the parameters of the controller. However, choosing fuzzy parameters to yield optimum operating point and a good control system depends on the experience of designer. FLC with fixed parameters are inadequate in application where the operating conditions change in a wide range and the available expert knowledge is not reliable. AFLC can solve this problem because it can re-adjust the fuzzy parameters to obtain optimum performance.

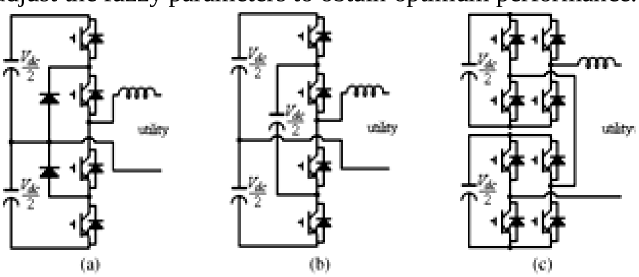

Fig 1 Circuit configuration of conventional single-phase multilevel inverter.(a) Diode clamped. (b) Flying capacitor. (c) Cascade H-bridge.

II. THE SYSTEM UNDER STUDY

The system consists of a PV panel connected to a boost converter to enhance and regulate the output voltage. It drives the DC load by using the power tracked from the solar panel. The MPPT controller is used to track the maximum power from solar panel. The block diagram of the system under consideration is shown in Fig.2.

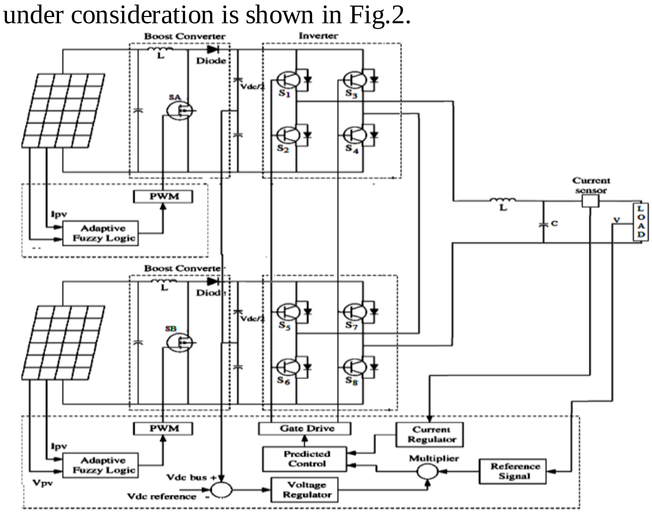

Fig.2 Block Diagram of the Proposed System

A. Photovoltaic System

Photovoltaic's (PV) are solid-state, semi-conductor devices which produce electricity when exposed to Sun light. The word photovoltaic means "electricity from light." The building block of a solar panel is solar cell. A photovoltaic module is formed by connecting many solar cells in series and parallel. The single diode model of a solar cell is shown in Fig. 3.

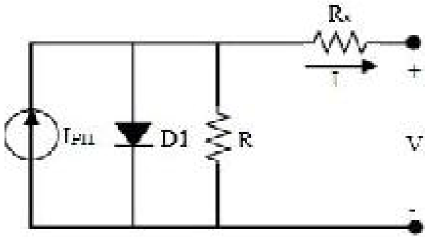

Fig.3 single diode model of a solar cell

$$I = I_{ph} - I_s\left(\exp\left(\frac{q(V+IR_s)}{kTA}\right) - 1\right) \quad \text{....... (1)}$$

The characteristic equation of a solar module is primarily dependent on the number of cells in parallel and number of cells in series. The current variation occurs is less dependent on the shunt resistance and is more dependent on the series resistance. Fig.4 shows the P-V, I-V curve of a solar panel. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current

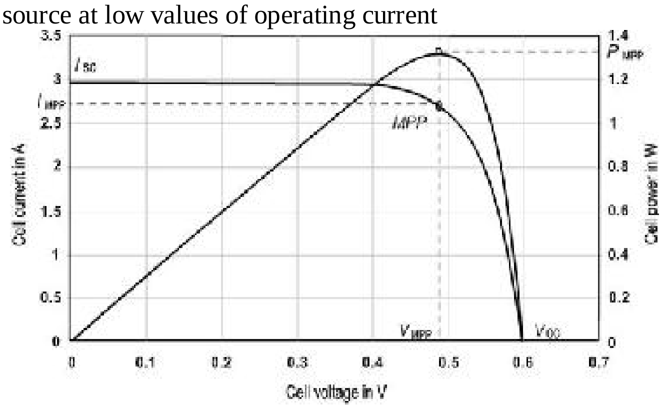

Fig.4 P-V I-V Curve Of a Solar Cell at Given Temperature and Solar Irradiation

B. Boost Converter

A boost converter (step-up converter) is a dc – dc power converter with an output voltage greater than its input voltage. Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. Since power must be conserved, the output current is less than the source current.

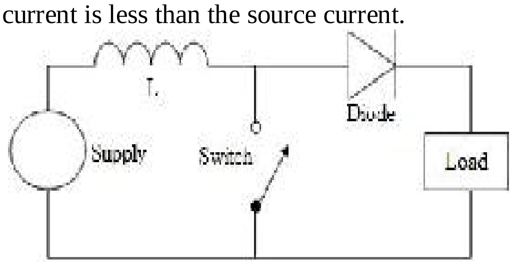

Fig.5 Shows the Circuit Diagram of a Boost Converter

Boost converter steps up the input voltage to a required output voltage level without the using a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These components are arranged in a coordinated manner to supply power to the load at a voltage greater than the input voltage magnitude. The control strategy lies in the manipulation of the duty cycle of the switch which causes the voltage change. When the switch is closed and the inductor is charged by the source through the switch. The charging current is exponential in nature but for the sake of simplicity it is assumed to be linearly varying. The diode restricts the flow of current from the source to the load and the demand of the load is met by the discharging of the capacitor. When the switch is open and the diode is forward biased, the inductor now discharges and together with the source charges the capacitor and meets the load demands. The load current variation is very small and in many cases is assumed constant throughout the operation.

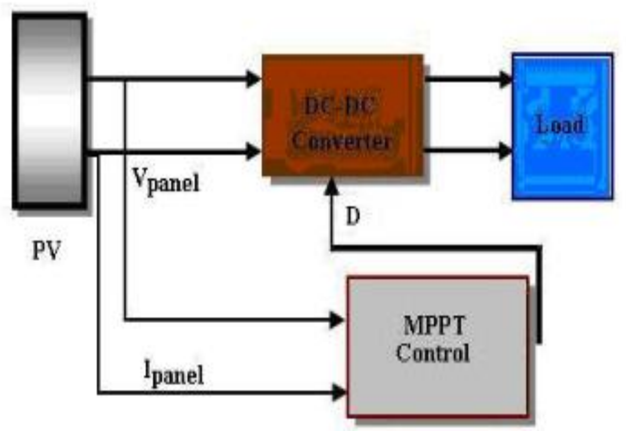

Fig.6 Block Diagram of PV system with MPPT

C. Maximum Power Point Tracking Controller

MPPT controller used in this paper is FLC. FLC is an appropriate way to map an input space to output space. Fuzzy logic uses fuzzy set theory, in which a variable is a member of one or more sets, with a specified degree of membership. In recent years fuzzy logic controllers have been introduced in the tracking of the MPP in PV systems. They are relatively simple to design as they do not require the knowledge of the exact model. They do require in the other hand the complete knowledge of the operation of the PV system by the designer. Fig 7 shows the block diagram of Fuzzy Logic Controller.

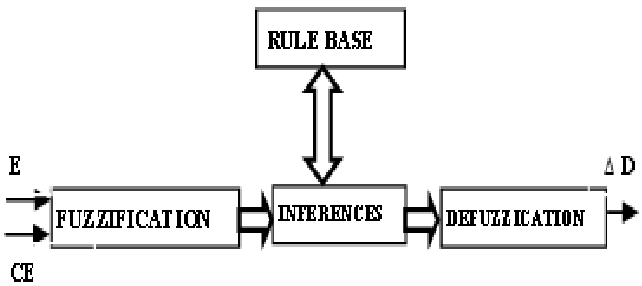

Fig.7 Block Diagram Of Fuzzy Logic Controller

A FLC is basically a three step approach. They are Fuzzification, Inference and Defuzzification. The FLC requires that each input/output variable which define the control surface may be expressed in fuzzy set notations using linguistic levels. The process of converting input/output variable to linguistic levels is termed as Fuzzification. The behavior of the control surface which relates the input and output variables of the system are given by a set of rules. A typical rule would be–"If x is A THEN y is B". When all the rules are fired, the resulting control surface is expressed as a fuzzy set that represent the constraints output. This process is termed as inference. Defuzzification is the mechanism of conversion of fuzzy quantity into crisp quantity. There are many methods available for defuzzification. The commonly used is centroid method.

III. PROPOSED FUZZY LOGIC CONTROLLER

Fuzzy logic is implemented to obtain the MPP operating voltage point faster and also it can reduce the voltage fluctuation after MPP has been recognized. The proposed fuzzy logic based MPPT controller has two inputs and one output. The error E(k) and change in error CE(k) are the input variables to Fuzzy Logic Controller and is given below in equation 2 & 3 for kth sample time

E (k) = dP/dV = [PPV (k)-PPV (k-1)]/ [VPV (k)-VPV (k-1)]... (2)

CE (k) = E(k) - E(k-1)... (3)

Where Ppv(k) denotes the power of photovoltaic panel.
The input variable E (k) represents the error which is defined as the change in power with respect to the change in voltage. Another input variable CE (k) expresses the change in error. The output of the Fuzzy Logic Controller is duty cycle (D) which should be given to the boost converter. Fig.6 represents the Fuzzy Logic Controller in which E (k) and CE (k) are the input variables and D as the output variable.

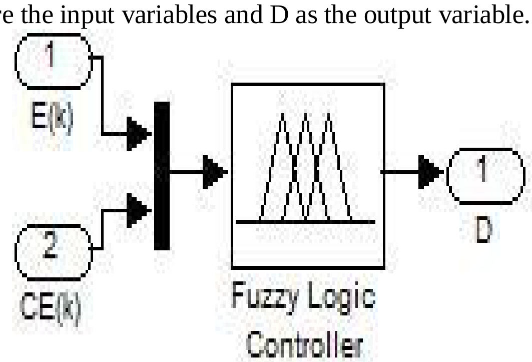

Fig.8 Fuzzy Logic Controller

To design the FLC, variables which can represent the dynamic performance of the system to be controlled, should be chosen as the inputs to the controller. The input and output variables are converted into linguistic variables. In this case, five fuzzy subsets, NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big) are chosen.

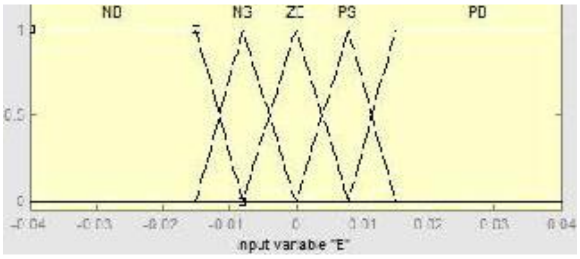

Fig. 9(a) Membership Function for e (k)

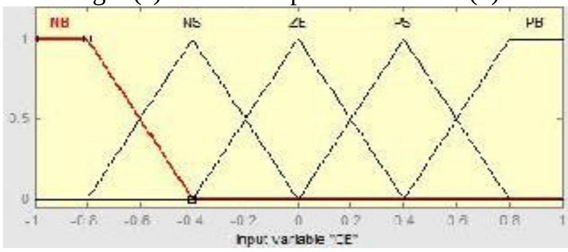

Fig .9(b) Membership function for CE (k)

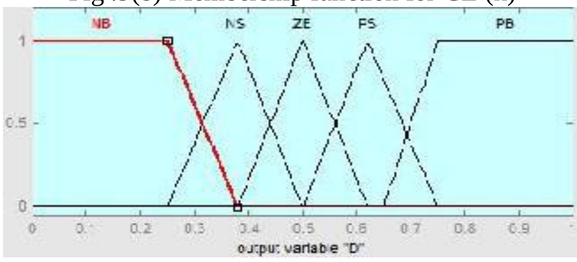

Fig.9(c) Membership function for D

Membership functions are used for the input and output variables are shown in Fig.9 (a), Fig.9 (b) and Fig.9(c) respectively. A fuzzy rule base is framed for the present application and is given in Table 1. The fuzzy inference of the FLC is based on the Mamdani's method which is associated with the max-min composition. The defuzzification technique is based on the centroid method which is used to compute the crisp output.

Table 1. Fuzzy Rule Table

ECE	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NS	NB	NB	ZE	ZE

IV. IV SIMPLIFIED MULTILEVEL INVERTER STAGE

To assist in solving problems caused by complex control circuits for conventional multilevel inverters, this work reports a new single-phase multi string topology, presented as a new basic circuitry in Fig. 10. It should be assumed that, in this configuration the two capacitors in the capacitive voltage divider are connected directly across the DC bus, and all switching combinations are activated in an output cycle. The dynamic voltage balance between the two capacitors is automatically controlled by the preceding high step-up converter stage. Then, we can assume Vs1=Vs2=Vs. This topology includes with eight power switches. The PD PWM control scheme is introduced to generate switching signals and to produce five output-voltage levels: zero, VS, 2VS, -VS, and - 2VS.

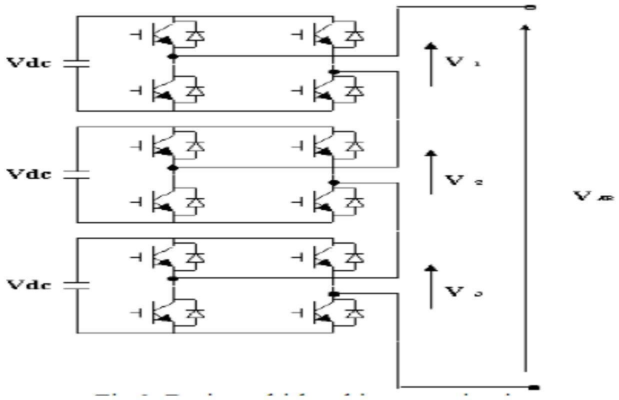

Fig.10. Basic multi-level inverter circuitry

The inverter topology uses two carrier signals and one reference to generate PWM signals for the switches. The modulation strategy and its implemented logic scheme in Fig.12 (a) are a widely used alternative for phase disposition modulation. With the exception of an offset value equivalent to the carrier signal amplitude, two comparators are used in this scheme with identical carrier signals Vtri1 and Vtri2 to provide high-frequency switching signals for switches Sa1, Sb1, Sa2 and Sb2. Another comparator is used for zero crossing detection to provide line-frequency switching signals for switches Sa2 and Sb2. For convenient illustration, the switching function of the switch in Fig. 3 is defined as follows

$$S_{aj} = \begin{cases} 1, & S_{aj}\ \text{ON} \\ 0, & S_{aj}\ \text{OFF} \end{cases} \quad ,j=1,2,3$$

$$S_{bj} = \begin{cases} 1, & S_{bj}\ \text{ON} \\ 0, & S_{bj}\ \text{OFF} \end{cases} \quad ,j=1,2,3 \qquad (4)$$

Table I. lists switching combinations that generate the required five output levels. The corresponding operation modes of the multilevel inverter stage are described clearly as follows.

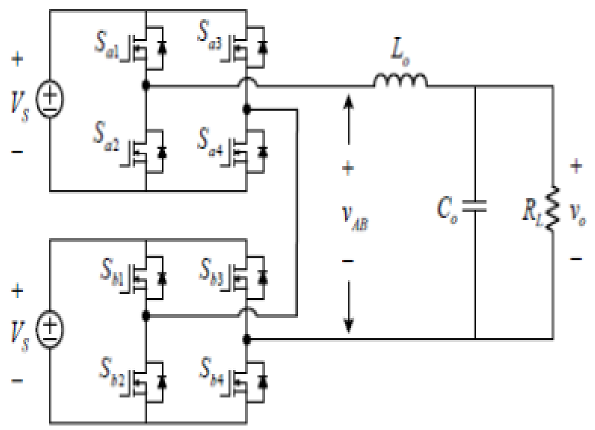

Fig.11.Five-level inverter topologies of CCHB inverter

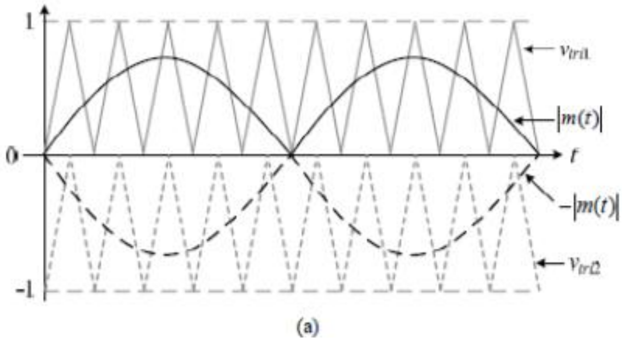

Fig.12 Modulation strategy :(a)carrier/reference signals

Table-2: Switching Combinations

Switching states	Sa1	Sa2	Sa3	Sa4	Sb1	Sb2	Sb3	Sb4	V_N
4	on	on	on	on	off	off	off	off	V_{dc}
3	off	on	on	on	on	off	off	off	$3V_{dc}/4$
2	off	off	on	on	on	on	off	off	$V_{dc}/2$
1	off	off	off	on	on	on	on	off	$V_{dc}.4$
0	off	off	off	off	on	on	on	on	0

To verify the feasibility of the single-phase five-level inverter, a widely used software program PSIM is applied to simulate the circuit according to the previously mentioned operation principle. The control signal block is shown in Fig. 12. m(t) is the sinusoidal modulation signal. Both Vtri1 and Vtri2 are the two triangular carrier signals. The peak value and frequency of the sinusoidal modulation signal are given as mpeak=0.8 and fm=50Hz, respectively. The peak-to-peak value of the triangular modulation signal is equal to 1, and the switching frequency ftri1 and ftri2 are both given as 1.8 kHz. The two input voltage sources feeding from the high step-up converter is controlled at 150V, i.e. Vs1=Vs2=150V. The simulated waveform of the phase voltage with five levels is shown in Fig. 13. The switch voltages of Sa1, Sa2, Sb1 and Sb3 are all shown in Fig. 14. It is evident that the voltage stresses of the switches Sa1, Sa2, Sb1, and Sb2are all equal to 150V, and only the other two switches Sa2, Sb2must be 300V voltage stress.

Fig.13 simulated waveforms of phase voltage VAB of inverter stage [Scale: 100V/div]

$$P_s = 0.5 V_{DS} I_0 f_s \left[t_{c(on)} + t_{c(off)}\right] \qquad ...... (5)$$

VDS is the voltage across the switch; and Io is the entire current which flows through the switch.

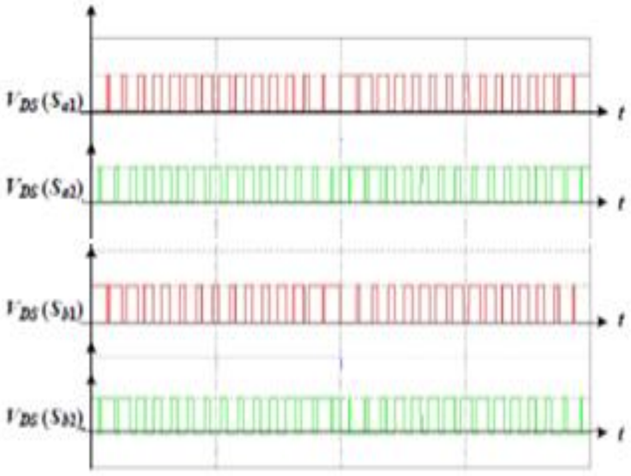

Fig.14 Simulated waveforms of switch voltage for inverter stage with in a line period [Scale: 100V/div]

For simplification, both the proposed circuit and CCHB inverter are operated at the same turn-on and turn-off crossover intervals and at the same load Io. Then, the average switching power loss Ps is proportional to VDS and fs as

Ps α VDS .fs (6)

According to Eq. (6) and Table-2, the switching losses of the CCHB inverter from eight switches can be, obtained as

Ps, H-bridge α 8Vsfs ..... (7)

Similarly, the switching power loss of the proposed single-phase five-level inverter due to six switches can also be obtained as

Ps, proposed α 4Vsfs+2(2Vs) fm α 4Vs (fs+fm). (8)

Because switches Sa2, Sb2 can only be activated twice in a line period (50Hz) and the switching frequency is larger than the line frequency (fs>>fm), the switching losses of the proposed circuit is approximated to 4Vsfs. obviously, the switching power loss is nearly half that of the CCHB inverter. By considering the harmonics in the inverter output voltage VAB, the amplitude of the fundamental and harmonic components in the output voltage VAB are calculated by PSIM software. The phase shift PWM technique is adopted for the CCHB Inverter. Both of the CCHB multilevel inverter and the studied multilevel inverter are operated in the same condition, including the same switching frequency 18kHz, the same modulation index ma ,the same input voltage VS=150V and output L-C filter, Lo=420uH, Co=4.7uF. Fig24 and fig25 show the harmonic components and THD for the pi CCHB multilevel inverter and the fuzzy multilevel inverter, respectively. One can find that the fuzzy system have lower THD than the pi controlled system. It implies that the output waveform is improved and smaller filter size can be used.

V. SIMULATION RESULTS

The PV module is modeled in MATLAB using equation 1 with the assumption that the PV module has constant temperature of 250C. Electrical characteristics of the modeled PV are given in the Table 3.

Table 3. Electrical Characteristics of PV Cell

Maximum power	150W
Voltage at P_{max}(V_{max})	34.5V
Current at P_{max}	4.35A
Warranted minimum P_{max}	140W
Short circuit current	4.75A
Open circuit voltage	43.5

P-V and I-V characteristics of PV module at an insulation level of 1000W/m2 and 25oC temperature is shown in Fig. 15 and Fig. 16 respectively.

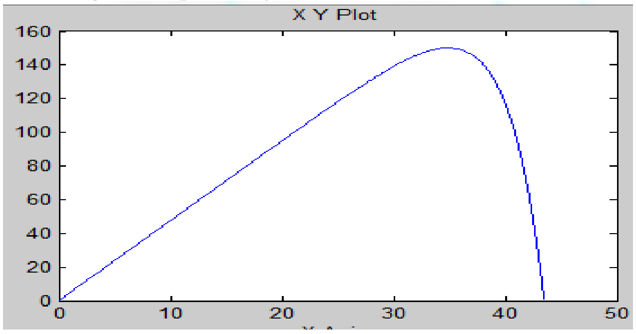

Fig.15 P-V Characteristics Of A PV Module

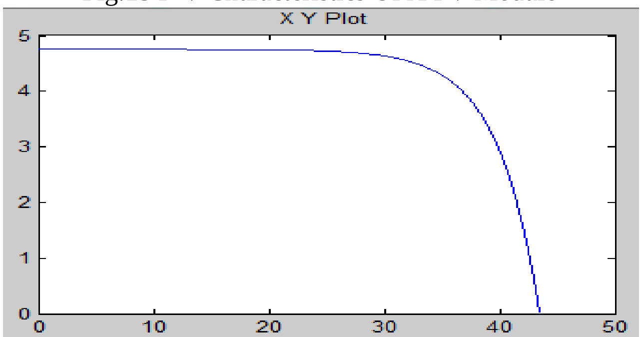

Fig.16 I-V Characteristics Of A PV Module

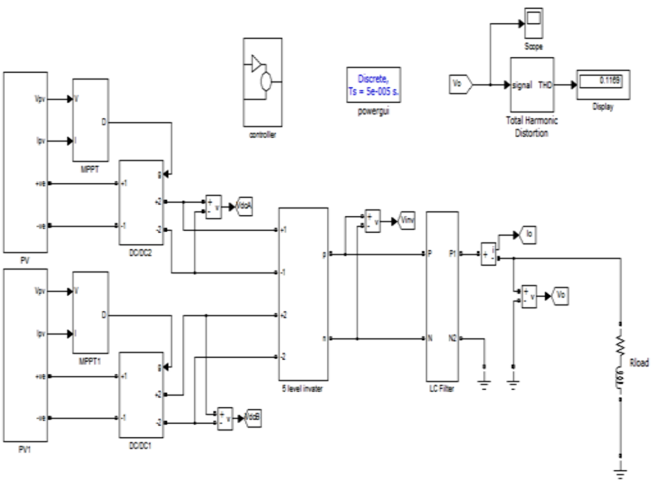

Fig. 17 PI controlled MPPT PV system with 5level inverter SPWM technique

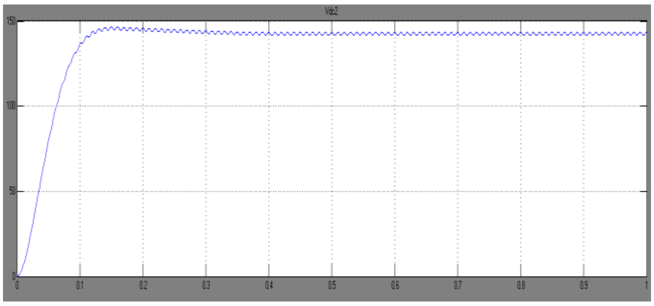

Fig. 17 DC-DC Boost Converter output

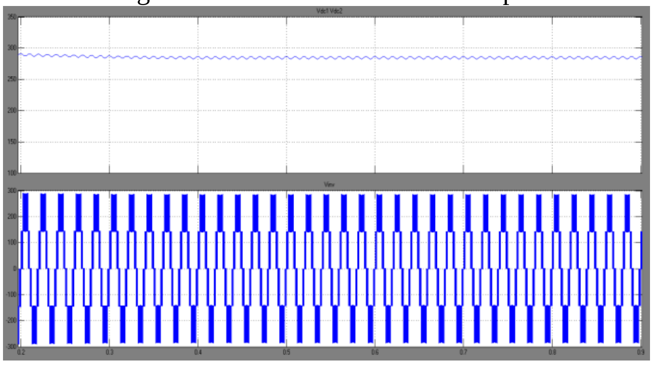

Fig. 18 5-level Inverter Input & output voltages

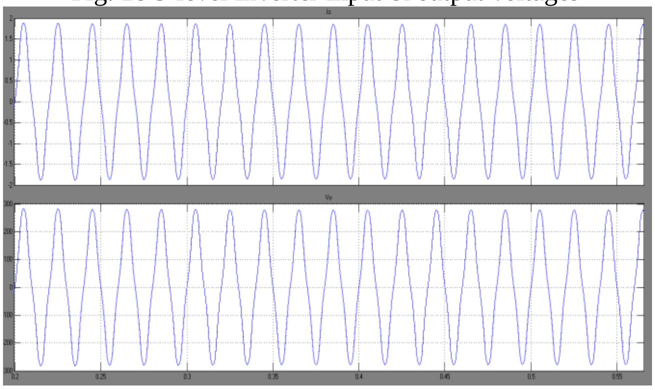

Fig. 19 Load current & Load voltage

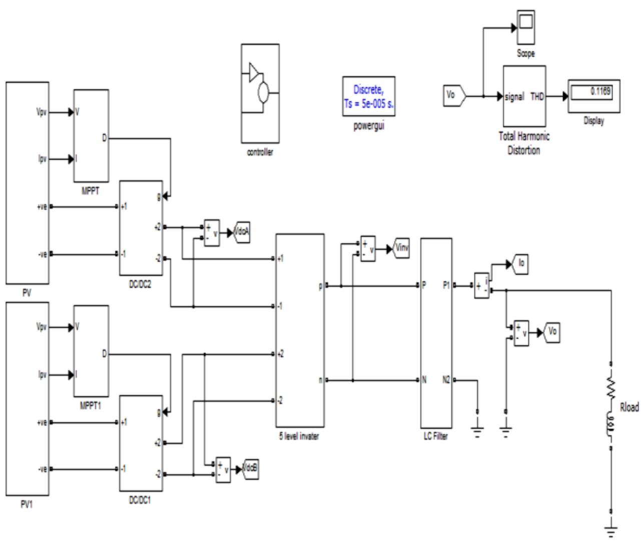

Fig. 20 Fuzzy controlled MPPT PV system with 5level inverter SPWM technique

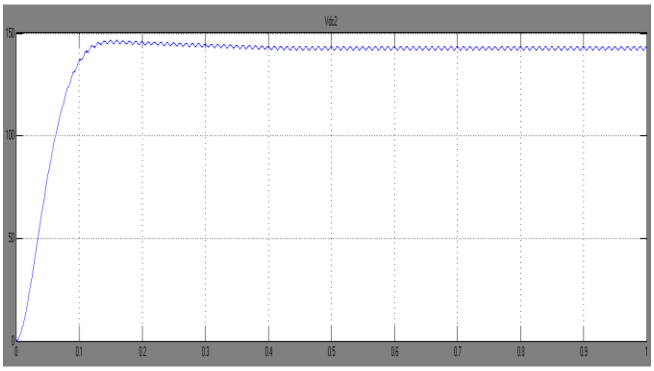

Fig. 21 DC-DC Boost Converter output with Fuzzy

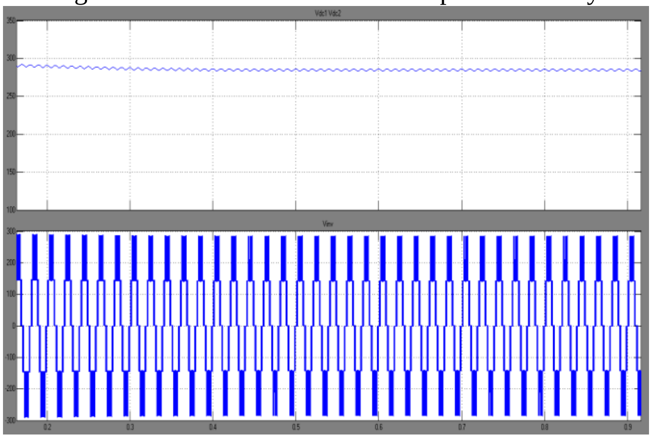

Fig. 22 5-level Inverter Input & output voltages with fuzzy

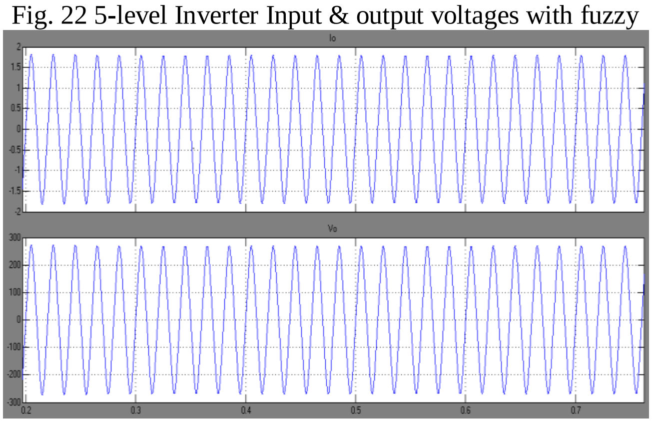

Fig. 23 Load current & Load voltage with fuzzy

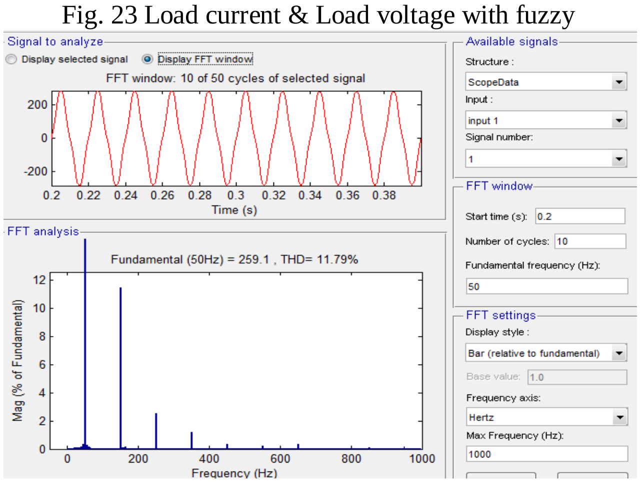

Fig. 24 THD of load voltage with PI Controller (THD=11.79%)

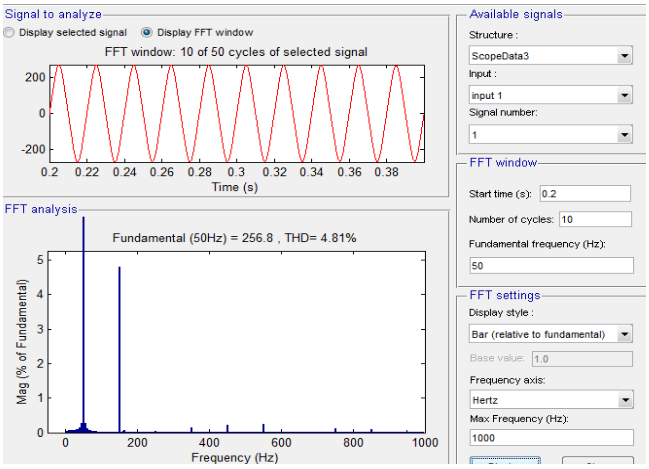

Fig. 25 THD of load voltage with FUZZY Controller (THD=4.81%)

VI. CONCLUSION

A MPPT photovoltaic power generation system with a five-level inverter is developed in this paper. The five-level inverter can perform the functions of regulating the dc bus voltage, converting solar power to ac power with sinusoidal voltage & current, balancing the two dc capacitor voltages. The simulation results verify the developed photovoltaic power generation system with PI & FUZZY controllers. A couple of control algorithms, namely FLC and PI were discussed and reviewed. The study presents a simulation comparison of the maximum power produced for FLC based method and PI method. The FLC method provides a simpler way to arrive at a definite conclusion.

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