Single-Stage Grid Connected Inverter With fuzzy Logic for Photovoltaic Energy Applications

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Abstract-The Demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. The definition of renewable energy includes any type of energy generated from natural resources that is infinite or constantly renewed. Examples of renewable energy include solar, wind, and hydropower. Renewable energy, due to its free availability and its clean and renewable character, ranks as the most promising renewable energy resources like Solar energy, Wind energy that could play a key role in solving the worldwide energy crisis. . This paper proposes a control method for a low cost GC micro-inverter with MPPT used in photovoltaic applications. A macro-model is proposed in order to test the proposed system and improve simulation times. In this way different MPPT algorithms can be developed and easily compared. Also, the macro-model speeds-up the tuning of the voltage loop and the design of the input filters used for maximum power point tracking.To increase the accuracy and enhancing the transient behavior of MPPT algorithm, a fuzzy logic controller based MPPT will be implemented. With minimum settling time, the maximum operating point will be reached

Keywords-*PV system; single-stage inverter; MPPT; fuzzy logic controller (FLC)*

I. INTRODUCTION

GC systems have been developed for more than 20years, as an alternative energy source to the electrical grid, especially in developing countries where the utility is not stable or in remote areas where a low/medium power backup energy source is needed solar energy source to the mains. The system has no galvanic isolation with the grid, and is being developed for low cost, high efficiency and high power factor (PF). In order to implement a simple and small inverter, the DC-DC stage (between solar panels and inverter) is left out, and there is only one DC-AC stage (between the PV module and the grid), which reduces the total losses. In this case, the inverter is responsible with both, MPP tracking, to maximize the energy harvesting, and convert the generated DC power into a suitable AC current source for the grid. Both tasks must be made with high efficiency, over a wide power range, due to the variable weather conditions. The current injected into the mains must obey the regulations, such as the EN61000-3-2 and the IEEE std. 1547 , which state the maximum allowable current harmonics. A typical solar-based inverter has two stages cascaded, with simpler controllers but lower efficiency. Usually, the first stage assures voltage boosting or MPPT function and high frequency link galvanic isolation, and the second stage inverts the rectified sinusoidal current into a sinusoidal waveform, synchronized with the mains. A single-stage inverter reduces components used, increases system efficiency and has lower costs than a conventional multiple-stage inverter. As new control techniques and topologies are developed, a single-stage inverter will become more and more popular .The basic block diagram of the proposed converter shows in the below fig.1

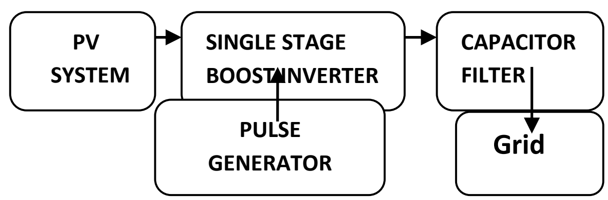

Fig.1:Block Diagram Of Proposed Grid Connected Systems

II. PV SYSTEM

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output

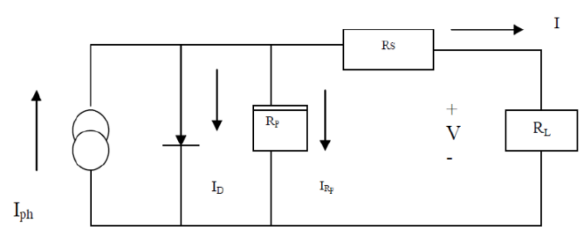

Fig.2:General Structure Of Pv Cell

An ideal is modelled by a current source in parallel with a diode. However, no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram above. RS is the intrinsic series resistance whose value is very small. RP is the equivalent shunt resistance which has a very high value.

In fig.2 ,Applying Kirchhoff's law to the node where Iph, diode, Rp and Rs meet, we get

Iph=ID+IRp+I

We get the following equation for the photovoltaic current:

I= Iph-IRp-ID

$$I = I_{ph} - I_o.\left[exp\left(\frac{V+I.R_S}{V_T}\right) - 1\right] - \left[\frac{V+I.R_S}{R_p}\right]$$

Where, Iph is the Insolation current, I is the Cell current, I0 is the Reverse saturation current, V is the Cell voltage, Rs is the Series resistance, Rp is the Parallel resistance, VT is the Thermal voltage, K is the Boltzman constant, T is the Temperature in Kelvin, q is the Charge of an electron.

A. Efficiency Of Pv Cell

The efficiency of a PV cell is defined as the ratio of peak power to input solar power.

$$\eta = \frac{Vmp.Imp}{I\left(\frac{KW}{m^2}\right).A(m^2)}$$

where, Vmp is the voltage at peak power, Imp is the current at peak power, I is the solar intensity per square meter, A is the area on which solar radiation fall.

The efficiency will be maximum if we track the maximum power from the PV system at different environmental condition such as solar irradiance and temperature by using different methods for maximum power point tracking.

III. MAXIMUM POWER POINT TRACKING

MPPT or Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called 'maximum power point' (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature.(Fig 4)

Typical PV module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day.in fig 3 represent the p-v& v-I chara of a pv cell

A.Maximum power; Pm
B. Maximum power voltage; Vpm
C.Open circuit voltage; Voc
D.Maximum power current; Ipm
E.Short circuit current; Isc

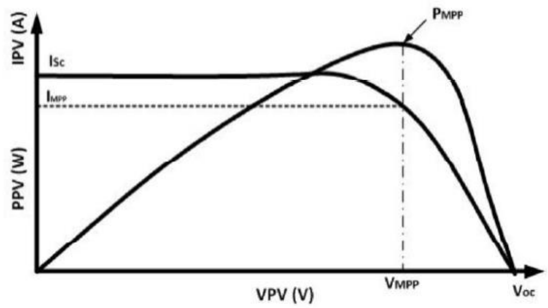

Fig.3: Diagram P-V & V-I Curve Pv Cell

How it works

The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage maximum power point that is to say: MPPT checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. It can also supply power to a DC load, which is connected directly to the battery.

MPPT is most effective under these conditions: Cold weather, cloudy or hazy days: Normally, PV module works better at cold temperatures and MPPT is utilized to extract maximum power available from them.

When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lowers.

How a Maximum Power Point Tracker Works:

The Power Point Tracker is a high-frequency DC to DC converter. They take the DC input from the solar panels, change it to high-frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the batteries. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high-frequency circuits is that they can be designed with very high-efficiency transformers and small components. The design of high-frequency circuits can be very tricky because of the problems with portions of the circuit "broadcasting" just like a radio transmitter causing radio and TV interference. Noise isolation and suppression becomes very important. There are a few non-digital (that is, linear) MPPT's charge controls around. These are much easier and cheaper to build and design than the digital ones. They do improve efficiency somewhat, but overall the efficiency can vary a lot - and we have seen a few lose their "tracking point" and actually get worse. That can happen occasionally if a cloud passed over the panel - the linear circuit searches for the next best point but then gets too far out on the deep end to find it again when the sun comes out. Thankfully, not many of these around anymore. The power point tracker (and all DC to DC converters) operates by taking the DC input current, changing it to AC, running through a transformer (usually a toroid, a doughnut looking transformer), and then rectifying it back to DC, followed by the output regulator. In most DC to DC converters, this is strictly an electronic process - no real smarts are involved except for some regulation of the output voltage. Charge controllers for solar panels need a lot more smarts as light and temperature conditions vary continuously all day long, and battery voltage changes.

Implement maximum power point tracking algorithms for photovoltaic systems using MATLAB and Simulink Maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) inverters to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and load. Engineers developing solar inverters implement MPPT algorithms to maximize the power generated by PV systems. The algorithms control the voltage to ensure that the system operates at "maximum power point" (or peak voltage) on the power voltage curve, as shown below.MPPT algorithms are typically used in the controller designs for PV systems. The algorithms account for factors such as variable irradiance (sunlight) and temperature to ensure that the PV system generates maximum power at all times.

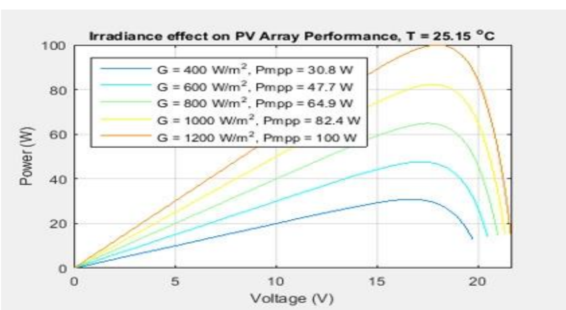

Fig.4:Irradiance Effect On Pv Systems

The three most common MPPT algorithms are:

1) *Perturbation and observation (P&O)-* This algorithm perturb the operating voltage to ensure maximum power. While there are several advanced and more optimized variants of this algorithm, a basic P&O MPPT algorithm is shown below Fig 4
2) Incremental conductance: This algorithm, shown below, compares the incremental conductance to the instantaneous conductance in a PV system. Depending on the result, it increases or decreases the voltage until the maximum power point (MPP) is reached. Unlike with the P&O algorithm, the voltage remains constant once MPP is reached.
3) Fractional open-circuit voltage: This algorithm is based on the principle that the maximum power point voltage is always a constant fraction of the open circuit voltage. The open circuit voltage of the cells in the photovoltaic array is measured and used as in input to the controller.

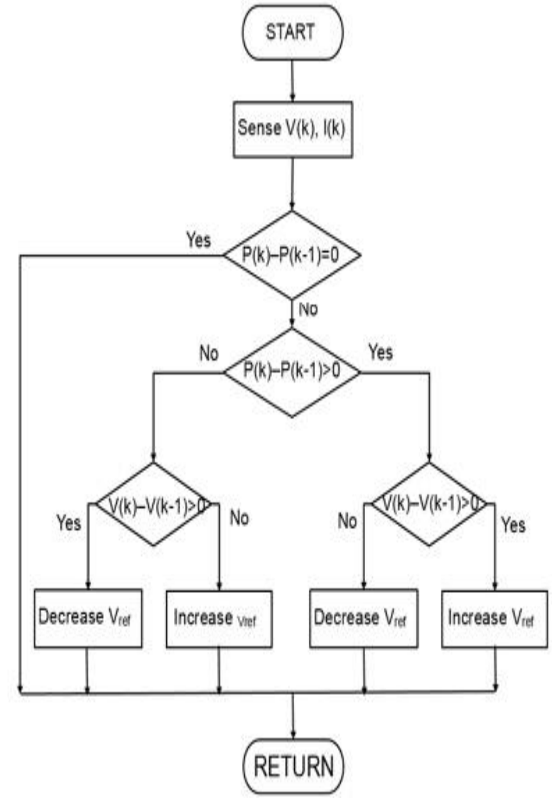

Fig.5:Flow Chart Of P&O Algorithm

IV. FUZZY LOGIC CONTROLLER

Fuzzy logic is one of the most powerful control methods. It is known by multi-rules-based resolution and multivariable consideration. Fuzzy MPPT is popular for over last decade. Fuzzy logic controllers

(FLC) have the advantages of working with imprecise inputs, no need to have accurate

Mathematical model, and it can handle the

Nonlinearity. The FLC consists of two inputs and output. The two FLC input variables are the error (E) and change of error (CE) that expressed by equation

E(j)=Ppv(j)-Ppv(j-1)/Vpv(j-1)

CE(j)=E(j)-E(j-1)

The fuzzification is the process of converting the system actual inputs values E and CE into linguistic fuzzy sets using fuzzy membership function. These variables are expressed in terms of five linguistic variables (such as ZE (zero), PB (positive big), PS (positive small), NB (negative big), NS (negative small)) using basic fuzzy subsets.

V. SINGLE-STAGE INVERTER TOPOLOGY

Single or multiple-stage GC inverters can be developed around different converter topologies, such as: full bridge inverters, as in, push-pull or boost converters, but most of them are flyback or buck boost based converters. Zero voltage switching or zero current switching mode controls are typically used in these converters in order to reduce the switching losses. The proposed control technique is implementing a hysteretic current mode control (HCMC) applied to a flying inductor converter. The topology was chosen to provide the AC output voltage (230V/50Hz) even if the PV module voltage is above or below it, without using transformers or voltage inversion. Variable frequency HCMC has the main advantage of a good robustness and stability control, without needing a compensation ramp. Furthermore, the absorbed current from the PV module has reduced distortions compared to other current control techniques, which makes the input power decoupling easier. Also, the implementation of this control strategy is relatively simple and low cost. The proposed control strategy will be detailed in the next sections.

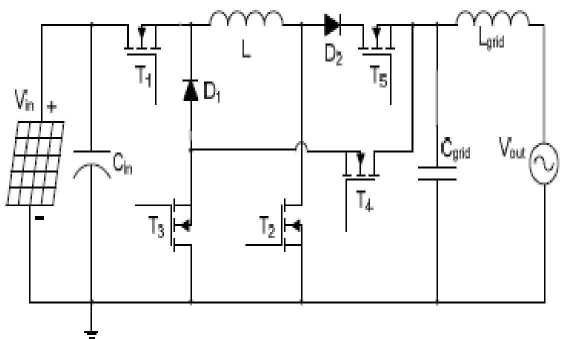

Fig.6:Single Stage Inverter

A. Positive Half-Cycle Inverter Operation

During the positive half-cycle of the AC line, T3 and T5 switches are turned ON, and T4 is OFF(Fig7a). In this stage, the inverter is equivalent with a non-inverting buck-boost converter.

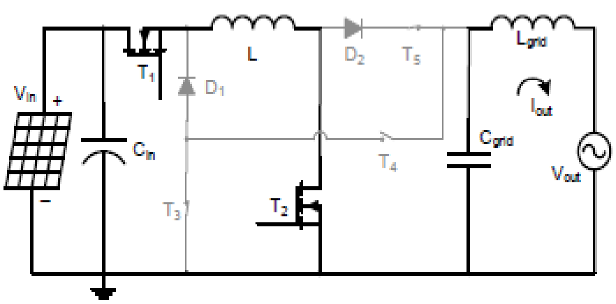

Fig.7:Positive Half Cycle Operation

An input decoupling capacitor Cin and an output L grid-C grid filter are used to assure proper operation of the inverter. When T1 and T2 are ON, D1 and D2 are OFF, being reverse biased. The ON time of the transistors is sinusoidal modulated. The inductor current is rising until reaches an upper envelope threshold, when T1–T2 turn OFF, D1–D2 turn ON (Fig. 7.b). Next, the inductor current ramps down to a lower envelope threshold, and the process repeats itself.

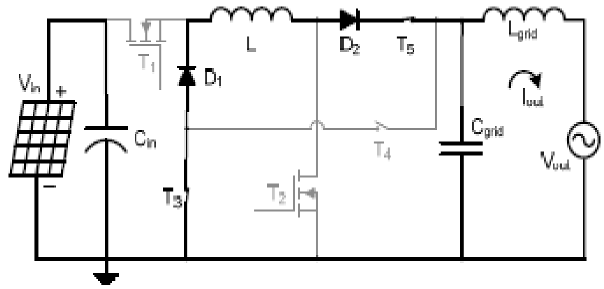

Fig.7:B.

B. Negative Half-Cycle Inverter Operation

During the negative half-cycle of the mains, T2 and T4 are turned ON, T3 and T5 are OFF, and the inverter operates as an inverting buck-boost converter. The circuit stages for this case are presented in Fig. 8.

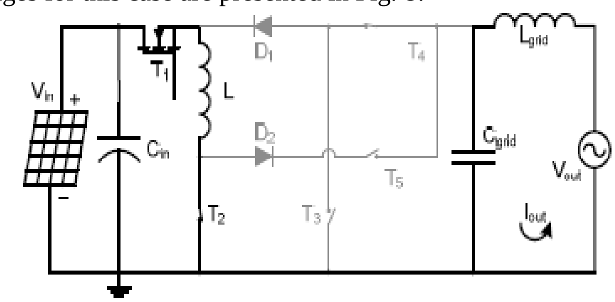

Fig.8:

When transistor T1 is ON, diodes D1 is OFF, the inductor accumulates energy from solar panel, and the Lgrid-Cgrid group assures the negative current flow through the grid (Fig. 3.a). When T1 turns OFF, D1 turns ON, thus allowing the inductor to transfer energy to theoutput, (Fig. 8.b).

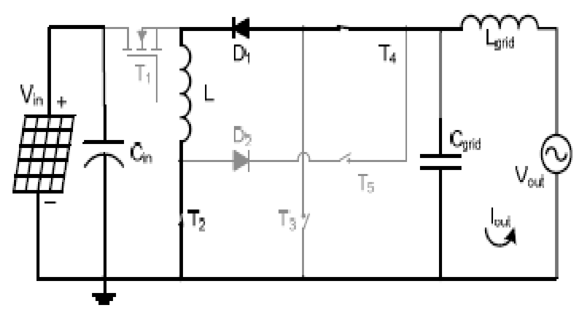

Fig.8:B

VI. INVERTER DESIGN

The inductor current never drops to zero due to theHCMC. This makes the converter work in continuous conduction mode and makes (1) always valid.

$$V_{out} = \frac{D}{1-D} \cdot V_{in}$$

Where Vout is the amplitude of the output voltage, Vin is the input voltage, and D is the duty cycle. This type of control is a generalization of Critical Conduction Mode (CRM) in which the zero threshold level is replaced by an envelope. The envelopes are obtained from the output voltage by multiplying it with gains K1 and K2. The envelopes of the controller have two times the frequency of the grid which is very small compared with the switching frequency. Because of this statement, on a switching period the ripple current through the inductor can be approximated with the difference between the two envelopes:

$$\Delta I = \frac{2 \cdot (1-K_p) \cdot I_L}{1+K_p}$$

whereKp represents the ratio between K2 and K1, ΔI is the inductor current ripple and IL is the average amplitude of the inductor current. Making Kpzero CRM is obtained. The voltage on the inductor is given by:-

$$V_{out} = L \cdot \frac{\Delta I}{T_{off}}$$

From (2) and (3) it results that the off time of the control signal is constant for a certain load condition and grid output voltage and is equal to:

$$T_{off} = L \cdot \frac{2 \cdot (1-K_p) \cdot I_L}{(1+K_p) \cdot V_{out}}$$

Equation (1) and (4) show how the HCMC works. The duty cycle of the converter changes according to (1) in order to keep the right ratio between Vin and Vout, and the frequency changes according to D for keeping Toffconstant. The inductor current waveform is illustrated in Fig. 4. The inductor limits the switching frequency thus lowering the switching losses. The highest switching frequency is when the grid voltage crosses through zero. The value of the inductance can be computed with:-

$$L = \frac{V_{out(\min)}^2 \cdot V_{in}^2 \cdot (1+K_p)/(1-K_p)}{f_{\min} \cdot P_{\max} \cdot (4V_{in} + \pi \cdot V_{out(\min)}) \cdot (V_{in} + V_{out(\min)})}$$

Where fmin is the minimum switching frequency of the converter, Pmax is the maximum power of the converter and Vout(min) is the minimum peak output voltage.

VII. SIMULATION

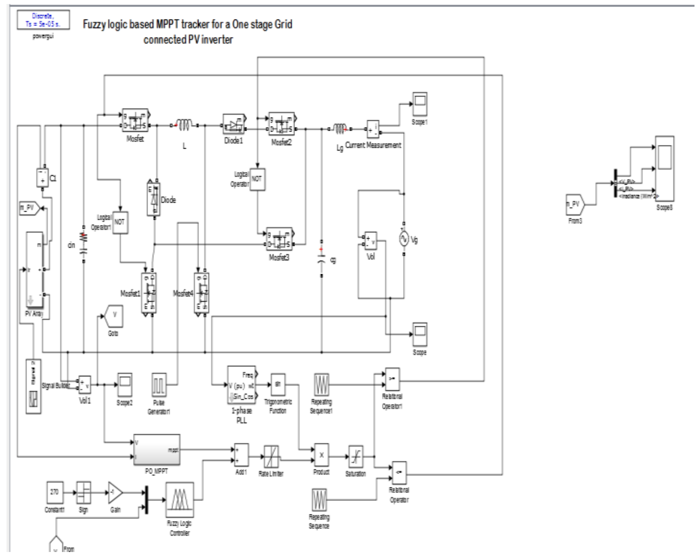

Fig.9:Simulation Diagram

VIII. WAVEFORMS

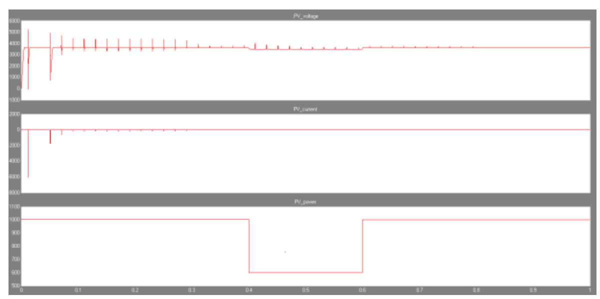

Fig.10: Pv Cell Voltage ,Current, Power

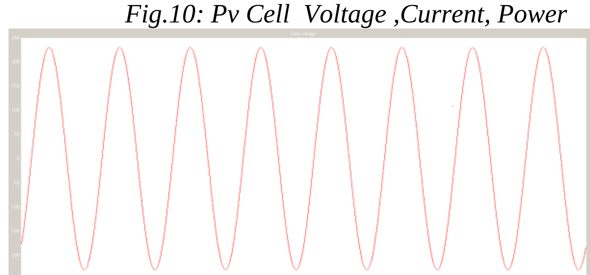

Fig.11:Output Voltage

The fig 10. Shows the input voltage , current and power wave form of the simulated circuit and the fig .11 shows the output voltage of the simulated circuit .As we use fuzzy logic along with the MPPT it will decrease the THD of the circuit more than PI controller it will observe in the below table

CONTROLLER	PI	FUZZY
THD	0.62%	0.11%

Table.1:Table Of Thd

IX. CONCLUSION

This paper proposes a control method for a low cost GC micro-inverter with MPPT used in photovoltaic applications .In order to improve the conversion efficiency of photovoltaic cells, and make it work at the maximum power point, a modeling analysis of the output characteristics of the photovoltaic power system has been given in this paper. And a fuzzy control strategy based on duty ratio perturbation has been presented. The duty cycle is taken as the only control.

According to the magnitude of the output power variation, the duty cycle is adjusted adaptively..Using fuzzy will decrese the thd in the proposed system than PI controllers

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