COMPARITIVE ANALYSIS OF FUZZY LOGIC AND ANN CONTROLLER FOR A SINGLE STAGE GRID CONNECTED PHOTOVOLTAIC SYSTEM WITH SOFT SWITCHING

N.K.SAKTHIVEL

University College of Engineering Arni,India,

nksakthivelmtech@gmail.com,

S.SUTHA

University College of Engineering Dindigal,India

Suthapadmanaban@gmail.com

Abstract: A fuzzy and Artificial Neural Network (ANN) based photovoltaic power generation for single phase micro grid inverter system with employing flyback transformer is presented in the present study. To obtain maximum power from renewable source, the researchers introduce a Maximum Power Point Tracking Algorithm with new sampling method. Fuzzy Logic Generated Space Vector Pulse Width Modulation (FSVPWM) closed loop control scheme is used to generate the suitable switching frequency to the inverter switches. The motive of the mamdhani fuzzy logic approach and back propagation based neural network is implemented to achieve high quality and reliable output, very low Total Harmonic Distortion (THD) with inductive load. Also THD of the inverter result is compared with Proportional Integral (PI) controller. The present proposed study is designed with the help of MATLAB/ Simulink and the real time hardware were designed for 2Kw rating.

1. Introduction

Since the first step of the industrial age more than 150 years ago, the world profit making was depend on fossil fuels, which were low priced as there was no cost associated with their production, but only with their extraction and transportation. The negative effects on the environment became visible only in the last 30 years. Renewable energy resources will be increasingly important part of power generation in the new Millennium. Besides assisting in the reduction of the emission of greenhouse gases, they add the much needed flexibility to the energy resource mix by decreasing the dependence on fossil fuels. Due to their modular characteristics, ease of the installation and because they can be located closer to the user Photovoltaic (PV) systems have great potential as distributed power source to the utilities. PV systems are installed on the roof of the residential buildings and connected directly to the grid (grid-connected).

A grid-connected PV system consists of two main stages a PV module and power insertion system. In these PV systems, Power Conditioning System (PCS) should have high efficiency and low rate. The power produced from the renewable energy systems are connected to the utility grid [1] and [2]. In remote area where there is less/no possibility of utility grids, renewable energy systems provide electricity to the remote region. These remote renewable energy systems can be employed to power home applications. For renewable energy sources, the output voltage and output power typically depends on a variety of uncontrollable factors. For example, radiation intensity determines the obtainable voltage and power output of a solar panel, wind speed determines the voltage and power of a wind electrical generator; and the output voltage and power of a fuel cell changes with the operating temperature, fuel and air flow rates [3] to [5],[33]. To obtain the required output voltage for varying solar input conditions, power conditioning Systems (PCS) are introduced as interfacing scheme between the PV panels and grid.

The present power conversion schemes used in power conditioning system consist of boost converter and a pulse width modulation inverter or a multi level inverter. The boost converter raise the low voltage output from the renewable

energy sources during low input conditions. And the inverter converts the dc power into ac of required voltage and frequency. The two stage conversion system also increases the overall system cost and decreases the system efficiency. The present proposed project, an inverter scheme without the middling dc-dc converter has been presented. This scheme reduces the losses in system and increases the efficiency and increase of the energy in fuse into the grid.

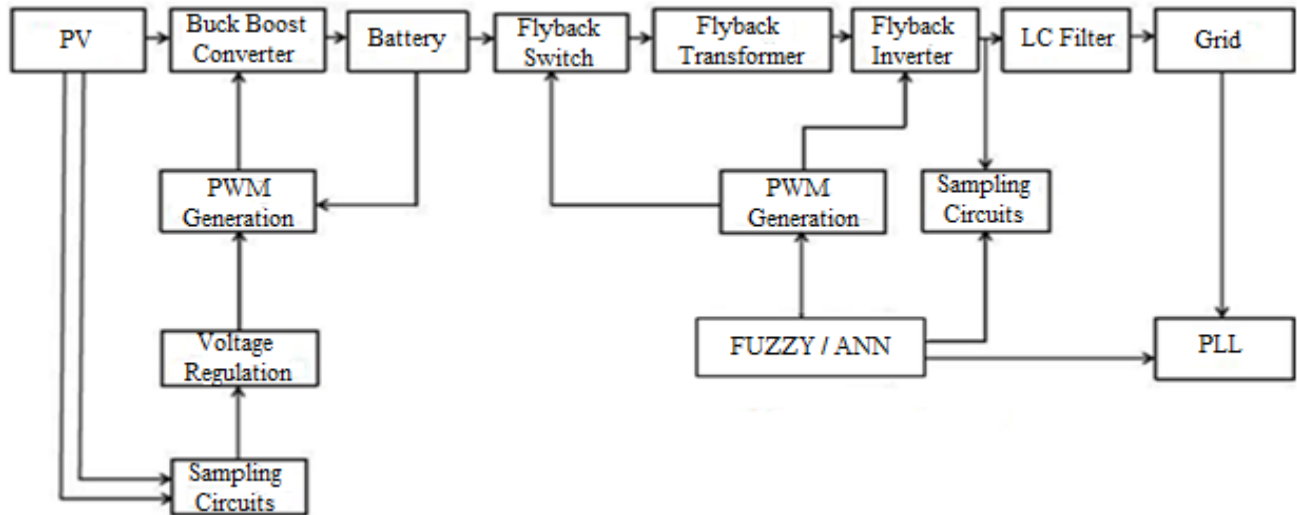## 2. Flyback Inverter Scheme with Controller

Figure 2.1 Power Inserting System for a Single Stage Grid Connected Photovoltaic System with Soft Switching

Figure 2.1 shows the block diagram of flyback inverter scheme. This PV Generation system presents a new scheme of the Power Insertion System (PIS) that has the function of inserting the power produced by the photovoltaic cell groups, converting the energy from the original DC form to the final AC form with the desired electrical characteristics. The part of the PIS that carries out this conversion is the flyback inverter [6],[7],[35],[36]. Usually, Pulse Width Modulation (PWM) based inverters [6],[8] or multilevel topology inverters are used [6], [9]. The simple connection & construction of the proposed flyback scheme with fuzzy logic feedback control is the key motivation. The flyback converter is recognized as the low weight, compact size and good efficiency and well heat handling capacity among the present inverter topologies, since the researchers choose this for improved power quality grid connected inverter design. This advantage comes from the ability of the flyback scheme combining the energy storage inductor with the transformer.

The switch S1 is the main switch that is connected on primary side. It is switched with a train of pulses such that the transformer stores energy in its magnetizing inductance and releases it when the secondary switches are operated. For easy operation usually the switch S1 is connected on the lower side of the primary winding. The secondary side switches S1-2 and S3-4 operate reciprocally during each half cycle of the Vac. Therefore, for positive half cycle of the grid voltage Vac, the switch S1-2 operates and for the negative half cycle S3-4 is turned on. The operation of the secondary switches is thus to unfold the rectified sinusoidal voltage. The researchers choose fuzzy logic controller to produce a PWM signal for primary switch S1 and secondary side H bridge inverter. Grid voltage, phase angle, inverter output voltage are the input parameter for fuzzy logic controller. From this value and predefined rules it produces the PWM signal. These will help to improve the quality of real power deliver from the inverter to grid. Some of the key points of the proposed system are leakage inductance of the transformer contributes towards the system loss. Transformer design is very important for exact results. The transformer turns ratio affects the stress across the power switches. Usually the frequency of switching is as high as 10-30 kHz. The proper operation of this inverter means a unity power factor operation. There is always a significant difference in the amplitude of the ac current before and after the low pass filter. Finally the proposed system reduces the system losses and harmonics.
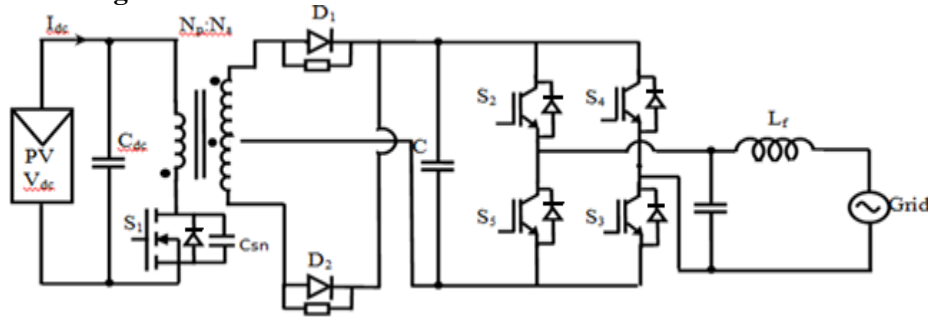
3. Proposed Circuit Diagram

Figure 3.1 Proposed Flyback Inverter Scheme

3.1 Maximum Current Sampling MPPT

The proposed MPPT circuit with maximum current sampling-and-hold method has been validated in as it produces high efficiency compared with existing methods. Here, researchers introduce the maximum current sampling method to find the exact requirement of duty cycle value for PWM generation. Also the PWM not only generated based on PV input, the output voltage of the converter also involved to obtain maximum power point tracking. Usually for MPPT boost converter is used it operates only during low power generated by PV panels, but the present proposed study is designed to operate wide voltage range. During full capacity power generation period, the MPPT system operates as an excess voltage to current conversion circuit circuit. The voltage rating of solar panel for our simulation purposes is 164.7V and current value is 0.168A, power rating is 27.76W for 25°C and1000W/cm². The researchers can obtain maximum power from the solar panel up to 10 hours per day in hardware from the method.
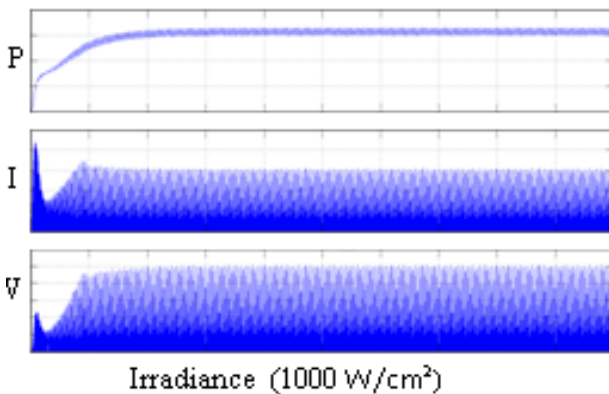

Fig. 3.2 Waveforms of Solar Voltage, Current and Power

3.2 Analysis of Switching Cycle

Fig. 3.1 shows the detailed modes of operation of the proposed circuit in one switching cycle. To optimize the amount of reactive current required for ZVS, a variable switching frequency is employed. In this section, the expressions for currents and voltages for a particular switching cycle are obtained. A switching cycle is divided into six modes. Since the switching frequency of the inverter is significantly higher than the grid frequency, the quantities varying with respect to the grid frequency such as the grid voltage, grid current, duty cycle, and reference currents are almost constant during one switching cycle.

Mode 1:

Primary switch S1 is turned ON at the start of a switching cycle. Secondary switch S2 remains ON during the entire positive half of the ac cycle, whereas S5 remains ON during the entire negative half of the ac cycle. During this mode, the input PV voltage is applied across the magnetizing inductance Lm of the transformer at the primary side. Hence, the primary current increases to peak value, the primary switch is turned OFF.
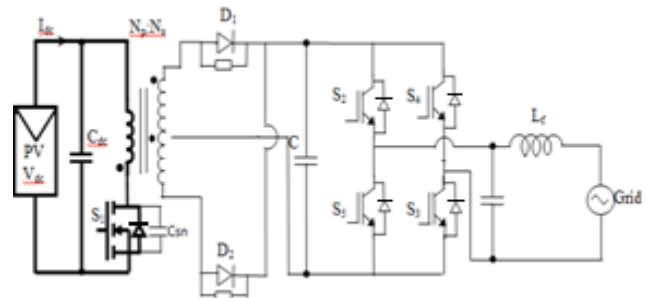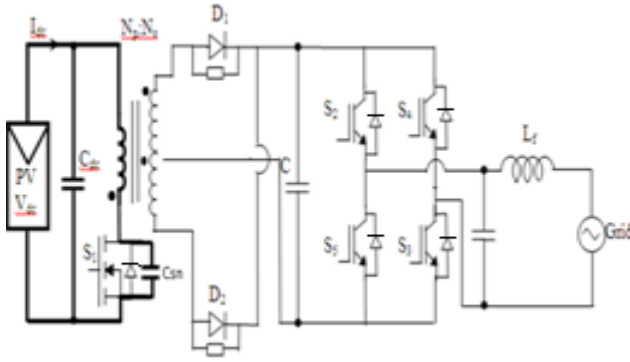

Fig. 3.3 Mode 1
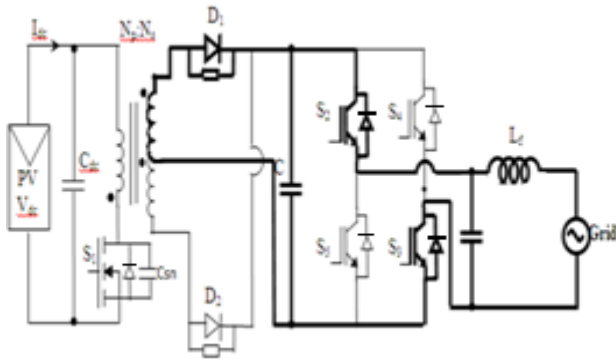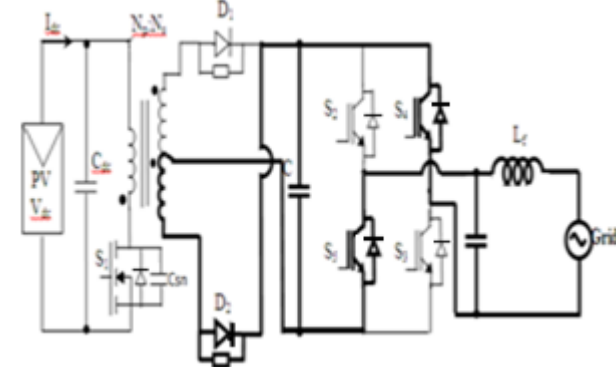
Fig. 3.4 Mode 2

Fig. 3.5 Mode 3

Fig. 3.6 Mode 4

Mode 2:

Switch S1 is turned OFF at the beginning of the interval, whereas the secondary switches remain ON, as shown above fig. Due to the presence of output capacitor across the primary MOSFET, the drain–source voltage cannot increase instantly to a high voltage. The rise of the drain–source voltage across the switch S1 is slowed down because of charging of capacitor Csn. This mode comes to an end when the capacitor has charged to its maximum value of Vdc + Nvac. This transition from the ON state to the OFF state of switch S1 occurs within a very short interval of time.

Mode 3:

Once the capacitor Csn is completely charged to its maximum value, the energy stored in the magnetizing inductor of the transformer is transferred to the grid. This is made possible by either the secondary switch S2 or S5 depending on the positive or negative half-cycle of the grid voltage being ON. Fig. 3.5 highlights the active switch S2 and switch S3 during this interval for the positive half of line cycle. The current in the secondary side changes direction and starts charging the magnetizing inductance in the opposite direction. At the instant the bidirectional switch S2 and S3 is turned OFF.

Mode 4:

At the beginning of this mode of operation, the switches S2 and S3 are turned off under ZCS depending on the polarity of grid voltage. Since the bidirectional switches S4 and S5 are turned on under ZVS depending on the negative polarity of grid voltage

4. Simulation Results

The PV system and the flyback inverter modules are simulated with the parameters given in appendix. The simulation results of the PVGS and flyback inverter are studied individually and the overall system performance for varying solar intensities and modulation indices are observed.

4.1 Fuzzy with PI Controller

When the inverter connected with liner loads the exact power and pulse modulation can be easily calculated. But during the nonlinear load connected with inverter consume irrespective current value in each cycle, so the feedback controller must have the fast dynamic response with precious decision. To obtain soft switching a Fuzzy logic based modulation has been proposed in this inverter modeling. Initially, output voltage of inverter starts from zero, so that the error value is falls. It forms one of these cases to satisfy the lower membership (low), now according to, predefined rule based fuzzyfication process starts. After obtain the rule based error corrected value using defuzzyfication block a new numerical result corresponding to pulse modulation is generated. Now the new value of modulation signal amplitude is used to generate eradicated PWM signal. The whole processes support to maintain the stabilized current on load, so the current and voltage stress across the switches are to be reduced.[34]
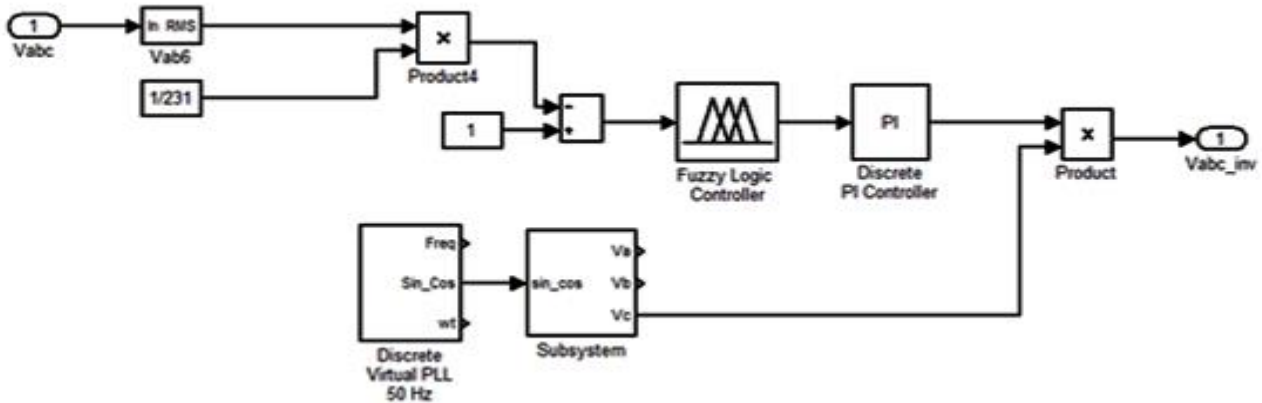
Fig.4.1 Controller Loop for Fuzzy with PI

In the present study, the input and output signal is unique, for the input parameter voltage amplitude is considered. In fuzzy tool a mamdhani rule base method is selected and three input membership functions (low, mid, and high), three output membership functions are used. All the input and output ranges bounded between zero to one. To form the rules input membership function related proportional with output membership function. After completing fuzzy formation the inverter error signal is connected as input for fuzzy logic block and the output port is connected with PWM generation block.

4.2 Fuzzy with PI Controller Results

A direct connection to the inverters without a previous DC/DC converter has been chosen. The flyback inverters share the DC bus, which is connected to the PVGS. The capacitor between the PVGS and the PIS must absorb the active power fluctuations (that always exist in a single-phase system). Therefore, it achieves constant power extracted from the PVGS, by keeping the DC voltage at the output terminal of the PVGS constant under these power fluctuations. The Flyback inverter is responsible for injecting the energy produced by the PVGS. This inverter is operated with a Fuzzy Logic generated SPWM technique. The motive of the mamdhani fuzzy logic approach is to achieve high quality and reliable output, very low THD with inductive load resulting in lower losses. This inverter injects a current with a high quality and low THD into the grid. (THD>5%)
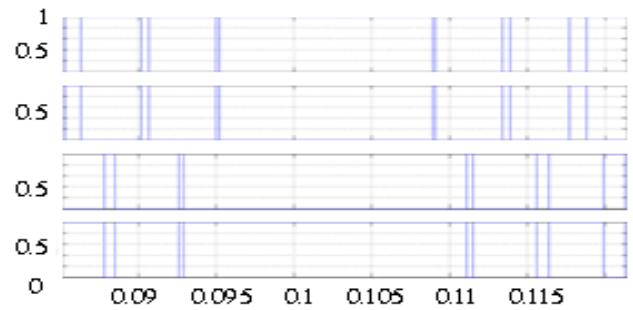

Fig. 4.2 Waveforms of Firing Pulses

The fig. 4.2 shows that the gate pulses are produced by using Fuzzy Logic generated SPWM technique. The secondary diagonal switches S1-2 are applied by positive gate signal and S3-4 is by negative gate signal.
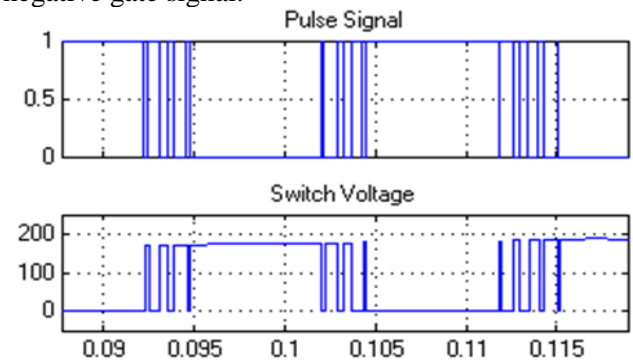

Fig. 4.3 Waveforms of Firing Pulse and Switch Voltage

The fig. 4.3 shows that the gate pulse 3 compares with their switch voltage. In that, the switching voltage is zero when the pulse is given. Hereby, soft switching is achieved by fuzzy logic controller.
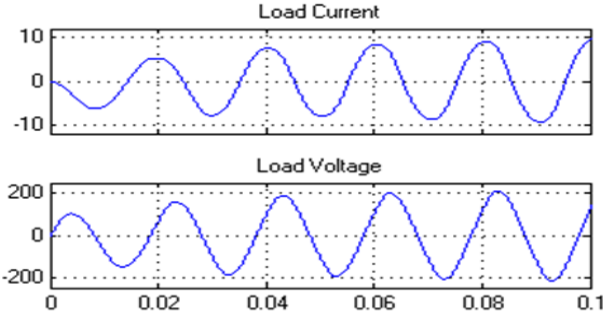
Fig. 4.4 Waveforms of Load Voltage and Load Current

The fig. 4.4 shows that the Output Current and Output Voltage of flyback inverter. Both are sinusoidal in shape for inductive load. The flyback inverter is working as a power injecting system and it corrects the current produced by improving its THD, also correct the current demanded by a non-linear load connected to the same Point of Common Coupling (PCC) than the PVGS.
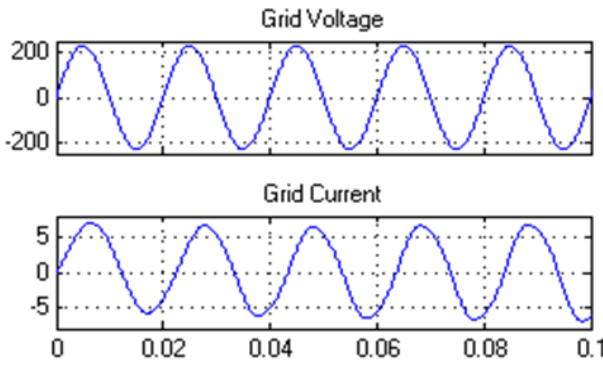

Fig. 4.5 Waveforms of Grid Voltage and Output Current

The fig. 4.5 shows that the grid voltage and grid current are in phase with each other. The energy stored in the magnetizing winding of the transformer is injected to the grid by turning ON either the secondary switch S1-2 or S3-4 during the positive or negative half cycle, respectively
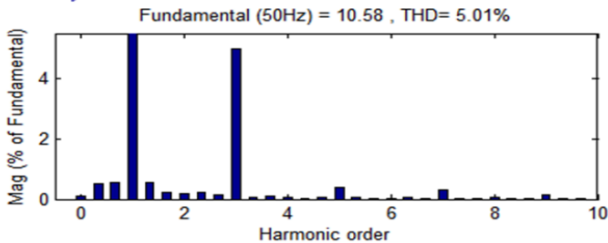

Fig. 4.6 Waveforms of Total Harmonic Distortion

4.3 ANN Controller

To reduce the switching loss, voltage stress of the inverter and achieve the maximum voltage regulation during dynamic load, a four layer back propagation classified artificial neural network controller is designed. The error signal is not fed directly to the artificial neural network controller. The feedback signal from output is converted to rms, value also the signal converted into per unit value. In a neural network layer, a design Maps all element of input (X) from its relevant minimum, maximum value. The feedback signal (error voltage) is fed to the neural network as an input parameter. In this first step the carrier signal value is choose for minimum and maximum value to perform the sinusoidal modulation[37],[38].
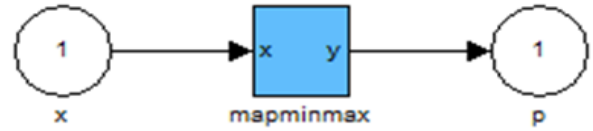

Fig. 4.7 ANN Mapping Element

Second step, the result of the min-max value is multiplexed into many neurons with their own weight. Every neurons weight is dot product with predefined base value, now it's called dot product neurons. In this stage neurons are trained based on previous value of carrier signal, base value (depends on modulation index).
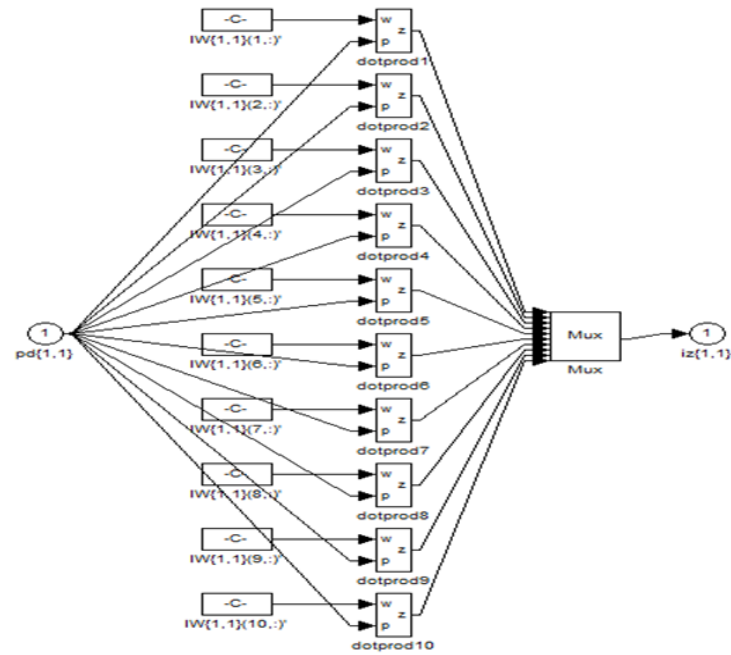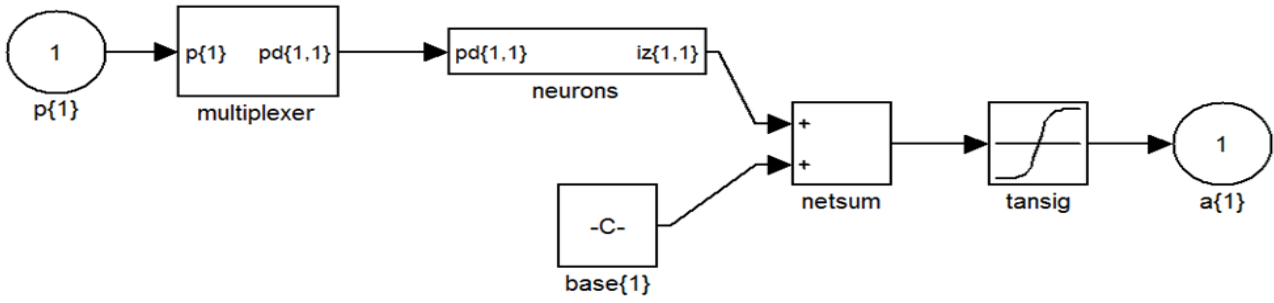

Fig. 4.8 ANN Multiplexer

Fig. 4.9 ANN Error Minimization Block

Output (Y) = weighted inputs + bias

sum=(p(1n)w{1,1}n)+(a(1)W{1,1}n)

$Y = (W_{Bias} + \sum_{n=1}^{m} WnXn)$

where,

Y: the output of controller

X_n: the nth input to the neuron

W_n : the nth connection weight

W_{bias}: the bias weight

m: the number of neurons preceding layer

Third step, the first stage neurons output layer has the process input of second stage or hidden layer. In this layer repeats the first layer operation again to minimize the error ratio. In fourth step, output layer perform the sum the weighted inputs and predefined bias value. The final scalar value is considered as neural network output.

4.4 ANN Controller Results

A direct connection to the inverters without a previous DC/DC converter has been chosen. The Flyback inverters share the DC bus, which is connected to the PVGS. The capacitor between the PVGS and the PIS must absorb the active power fluctuations (that always exist in a single-phase system).Therefore it achieves constant power extracted from the PVGS, by keeping the DC voltage at the output terminal of the PVGS constant under these power fluctuations. Flyback inverter is responsible for injecting the energy produced by the PVGS. This inverter is operated with a Fuzzy Logic generated SPWM technique. The motive of the mamdhani fuzzy logic approach is to achieve high quality and reliable output, very low THD with inductive load resulting in lower losses. This inverter injects a current with a high Quality and low THD into the grid (THD < 1%).
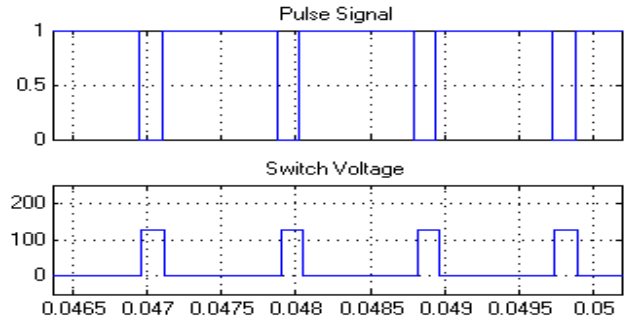
Fig. 4.10 Waveforms of Firing Pulse and Switch Voltage

The fig. 4.10 shows that the gate pulse 3 compares with their switch voltage. In that, the switching voltage is zero when the pulse is given. Hereby, soft switching is achieved by fuzzy logic controller.

Fig. 4.11 Waveforms of Load Voltage and Load Current

The fig. 4.11 shows that the Output Current and Output Voltage of flyback inverter. Both are sinusoidal in shape for inductive load. The flyback inverter is working as a power inserting system and it corrects the current produced by improving its THD, but also correct the current demanded by a non-linear load connected to the same point of common coupling (PCC) than the PVGS.

Fig. 4.12 Waveforms of Grid Voltage and Output Current

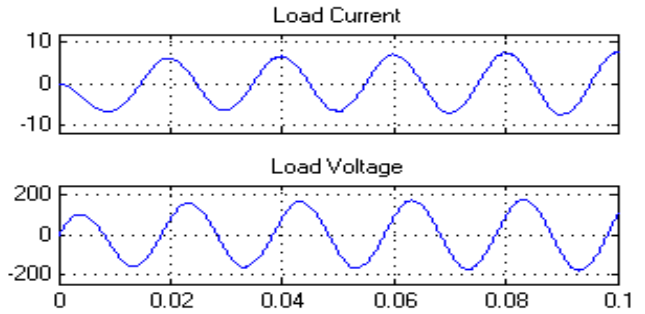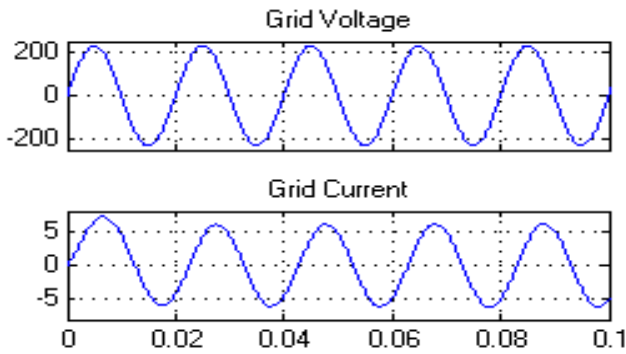The fig. 4.12 shows that the grid voltage and grid current are in phase with each other. The energy stored in the magnetizing winding of the transformer is injected to the grid by turning ON either the secondary switch S1-2 or S3-4 during the positive or negative half cycle, respectively.

Fig. 4.13 Waveforms of Total Harmonic Distortion

4.5 Integrated System Results

Control Technique	Solar voltage	DC Link Voltage	DC Link Current	Inverter Voltage	Inverter Current	Switching Stress	THD
ANN	120	220	23	200	8	210	0.57
Fuzzy with PI	120	210	21.5	200	10	230	5.01

Table .1.THD Comparison of Controllers

The closed loop flyback inverter system has been developed in the present study. It is simulated in the MATLAB Simulink tool, with the parameter values specified in the above table. The currents and voltage obtained in dynamic load conditions, with fuzzy, artificial neural network are shown in above figures (i.e 4.6 and 4.13) and have a THD of 5.01%, 0.57% respectively. In order to find the current harmonics compensation, soft switching performance, a single phase 2kw non-linear load is connected with output filter.

The main advantage of the proposed system is the inverter loss decrease, because they have low losses which are due principally to conduction. The switching losses are small because the switching frequency matches the grid frequency, near 50Hz. The conduction losses could be even further reduced if a low ON- voltage semiconductor is selected, since no high speed switching semiconductors are needed

for this inverter. If one assumes that the switching losses are proportional to the maximum instantaneous current value, these losses will be reduced to approximately 20%. Therefore, the high switching semiconductors used in this inverter will have a current ratio of about five times lower than the semiconductor used in a conventional PWM inverter for the same task.

Leakage inductance of the transformer contributes towards the system loss. Transformer design is very important for correct results. The transformer turns ratio affects the stress across the power switches. Usually the frequency of switching is as high as 20-30kHz.The proper operation of this flyback inverter means a unity power factor operation. There is always a significant difference in the amplitude of the ac current before and after the low pass filter.

5. Hardware Results

In the hardware, a 500W and 12V poly-crystalline solar panel are used as renewable source. The output of solar panel connected with MPPT flyback dc to dc converter. With the help of shunt resistor the current feedback analog signal is connected with Dspic controller. And by using voltage divider the output voltage of dc to dc converter analog value is connected to controller. To drive the power switch of dc to dc converter sg 3525 gate driver were used between controller and mosfet. Filtered constant output DC supply is connected as source for H-Bridge inverter and to fine tune the output AC supply and LC filter were connected in the output. The researchers choose mosfet as a power switch with the rating of 55amps, 100 volt (IRFz44) for inverter operation. All this mosfet are connected with gate driver circuit. Dspic controller generates the SVPWM and it is given to gate driver. Initially, controller chooses 50% duty cycle for flyback converter, after the output voltage feedback it will change accordingly.

During the 20Kz switching speed one sample current value is taken for account to calculate new duty cycle. When the measured current is high then the duty cycle is decreased vice versa. It operates for low current .After the flyback converter outputs the rectifier and filters circuits eliminate the oscillation. Now, 320 volt boosted output is inverted into ac in the H bridge block. Here, researchers used SVPWM and closed loop operation. So the pulses for H bridge inverter is fine tuned for each cycle output. If there is a change in output, it will compare with set value then the value is different and it is calculated as error signal. According to, fuzzy logic rules and or ANN algorithm modulation index value will be changed. Now, the eradicated new PWM is generated for H bridge.

This operation ensures the correct sequence of power switches operation. This process leads to stabilize the process across switches, so soft switching is done here. The output current and voltage has distorted due to switching action. To reduce this distortion LC filter connected to output. Inductor eliminates the current distortion and capacitor eliminates the voltage distortion. Finally, the pure ac supply is connected with inductive element.

5.1 Hardware is tested on 11am [Light Condition]

Parameter	Results
Solar Voltage	15.8V
Current	43.5A
MPPT Output Voltage	320V
MPPT Output Current	2.03A
Dc link voltage	320V
Switching frequency	25 KHz
Output voltage	230V, 50Hz
Maximum output current	8A
Efficiency	94.55 %

Table .2. Data Obtained From Hardware
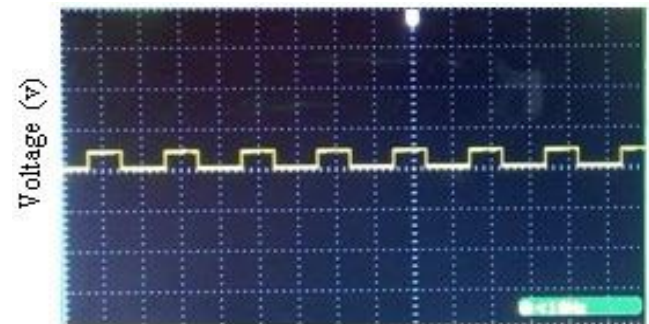

Fig. 5.1 Hardware Prototype Model

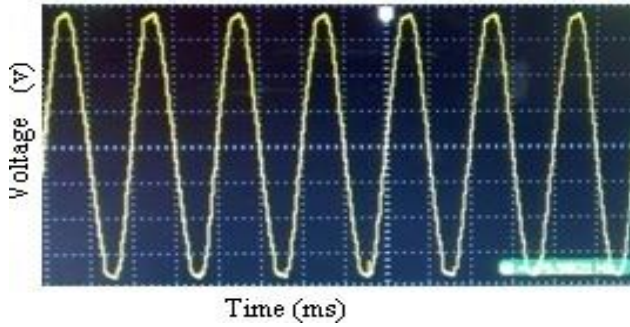Fig. 5.2 Gate Voltage

Fig. 5.3 Gate Current
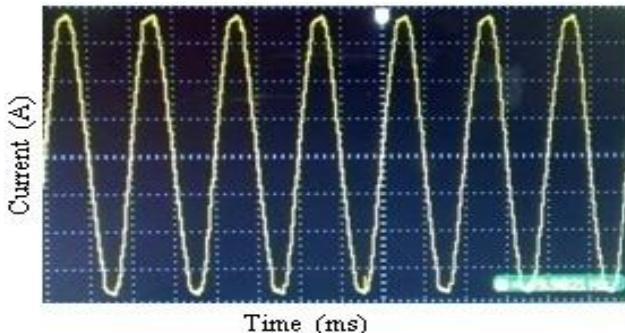
Fig. 5.4 Output voltage

Fig. 5.5 Output Current

6. Conclusion

A soft switching high efficiency inverter suitable for renewable source is proposed in the present study. This topology is based on the flyback inverters operating at soft switching technique using Fuzzy with PI Controller and ANN Controller. Comparative study of artificial neural network based closed loop inverter system and fuzzy logic based closed loop inverter system simulation results were discussed. By implementing ANN controller the current harmonics was reduced with low switching stress, thereby increases the inverter performance. To increase overall renewable power system efficiency, MPPT technic for PV panel, LC filter at AC output, output voltage feedback, constant dc link were used. The Total Harmonic Distortion of proposed system is low (0.57%) when compared with Fuzzy with PI Controller. Based on this simulation result, Designed Hardware result produces smooth operation on inverter. With small size heat sink, the power switches work for long duration with full load. The overall renewable power system efficiency is re

defined. The proposed system optimizes the system design, permitting the reduction of the system losses (conduction and switching losses, and Joule effect losses in inductors) and so, increases the energy effectively injected into the grid. There will consequently be an increase in profit when selling this energy.

Appendix

PV Generation System -Simulation	
Parameter	Value
Number of series connected cells	460
Number of parallel connected cells	1
Photovoltaic cell reference	SHELL SP150P
Short circuit current (25°C,1000W/cm²)	12A
Open circuit voltage(25°C, 1000W/cm²)	300V
MPP current(25°C, 1000W/cm²)	11.5A
MPP voltage (25°C, 1000W/cm²)	230V
Power rating at rated intensity of 1000(W/cm²)	3kW
Power Insertion System	
Filter inductance L	9mH
Filter capacitance C	0.1μF
Switching frequency	20 kHz
Load voltage	230V
Load power	2Kw

Table .3. Listing of Simulation details

Items	Specification	Quantity
MOSFET- IRFz44	55A, 100V	5
Coupled Inductor	5mH, 50A	1
Dc filter	100μF/400V	1
Gate driver	SG3525	1
Controller	dsPIC30F6014A	1
Ac Filter inductor	10μH/10A	1
Ac filter capacitor	4.7mfd/400V	1

Table .4. Listing of Hardware details

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