A Novel Control Strategy Using fuzzy Technique for Single Phase Nine-Level Grid-Connected Inverter for Photovoltaic system
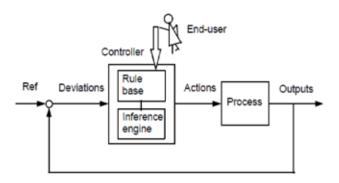
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Abstract— **This paper proposes fuzzy logic controller based a single-phase nine-level inverter for grid-connected photovoltaic systems, with a novel pulse width-modulation (PWM) control scheme. Four reference signals produces from fuzzy logic controller which are identical to each other are going to compare with the amplitude of the triangular carrier signal. The inverter is capable of producing of nine levels of output-voltage levels (Vdc , 3Vdc /4, Vdc /2,Vdc/4, 0, −Vdc , −3Vdc/4, −Vdc/2Vdc/4) from the dc supply voltage. The total harmonic distortion is reduces by this control strategy. The proposed system was verified through simulation The total harmonic distortion is reduces by this control strategy. The proposed system was verified through simulation**

Index Terms— **Fuzzy logic Controller, Grid connected, modulation index, multilevel inverter, photovoltaic (PV) system, pulse width-modulated (PWM), total harmonic distortion (THD).**

I. INTRODUCTION

Fuzzy controllers are uses for controlling consumer products, such as washing machines, video cameras, and rice cookers, as well as industrial processes, such as cement kilns, underground trains, and robots. Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as ''computing with words rather than numbers''; fuzzy control can be described simply as ''control with sentences rather than equations''. A fuzzy controller can include empiric al rules, and that is especially useful in operator controlled plants [1]. The objective here is to identify and explain design choices for engineers.

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Fig 1. Fuzzy logic process A single-phase grid-connected inverter is usually used for an engineering application which is controlled by a fuzzy system. Types of single-phase grid-connected inverters have been investigated [2]. A common topology of this inverter is full-bridge three-level. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence, also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation [3]. The input for a seven level inverter is photo voltaic cells which reduces the pollution level due to generation [4].

II. FUZZY LOGIC CONTROLLERS

A. Introduction to fuzzy logic:
The logic of an approximate reasoning continues to grow in importance, as it provides an in expensive solution for controlling know complex systems. Fuzzy logic controllers are already used in appliances washing machine, refrigerator, vacuum cleaner etc. Computer subsystems (disk drive controller, power management) consumer electronics (video, camera, battery charger) C.D. Player etc. and so on in last decade, fuzzy controllers have convert adequate attention in motion control systems. As the later possess non-linear characteristics and a precise model is most often unknown. Remote controllers are increasingly being used to control a system from a distant place due to inaccessibility of the system or for comfort reasons. In this work a fuzzy remote controllers is developed for speed control of a converter fed dc motor. The performance of the fuzzy controller is compared with conventional P-I controller.

B. Unique features of fuzzy logic
The unique features of fuzzy logic that made it a particularly good choice for many control problems are as follows, It is inherently robust since it does not require precise, noise – free inputs and can be programme to fail safely is a feedback sensor quits or is destroye. The output control is a smooth control function despite a wide range of input variations. Since the fuzzy logic controller processes user-define rules governing the target control system, it can be modify and easily to improve or drastically alter system performance. New sensors can easily be incorporates into the system simply by generating appropriate governing rules.

C. Fuzzification and Normalization
Fuzzification is relate to the vagueness and imprecision in a natural language. It is a subjective valuation, which

transforms a measurement into a valuation of an objective input space to fuzzy sets in certain input universes of discourse. In fuzzy control applications, the observed data are usually crisp. Since the data manipulation in a fuzzy logic controller is based on fuzzy set theory, fuzzification is necessary in an earlier stage.

D. Membership functions
Fuzzy system uses ‚4' different shapes of MF's., those are Triangular, Gaussian, Trapezoidal, sigmoid, etc.,
i. Triangular membership function
The simplest and most commonly used membership functions are triangular membership functions, which are Symmetrical and asymmetrical in shape Trapezoidal membership functions are also symmetrical or asymmetrical has the shape of truncated triangle

ii. Gaussian membership function
Two membership functions Triangular and Trapezoidal are built on the Gaussian curve and two sided composite of two different Gaussian curves.
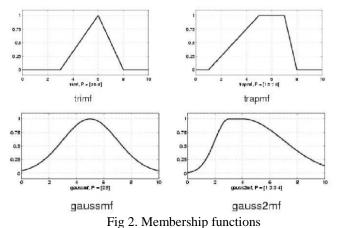
E. Fuzzy system
The fuzzy interface system Fuzzy system basically consists of a formulation of the mapping from a given input set to an output set using Fuzzy logic. The mapping process provides the basis from which the interference or conclusion can be made.

F. Steps for A Fuzzy interface process
i. Fuzzification of input variables.
ii. Application of Fuzzy operator.(AND, OR, NOT) In the IF (antecedent) part of the rule.
iii. Implication from the antecedent to the consequent(Then part of the rule).

Fig 2. Membership functions

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iii. Implication from the antecedent to the consequent (Then part of the rule).
iv. Aggregation of the consequents across therules.
v. Defuzzification.
Generally there will be a matrix of rules similar tot eh ES rule matrix for Ex: There are 7MF for input variables ‚x' and MF for input variable ‚y' then there will be all to get her35 rules.

G. Implication method
The implication step (3) introduces to evaluate the individual rules.
Methods:
1) MAMDANI
2) SUGENO
3) LUSING LARSON.
i. Mamdani

Mamdani, one of the pioneers in the application of ‚FL' in control systems, proposes this implication method. This Mamdani method is most commonly used method. The outputs of the Mamdani method is truncated Signals of the inputs; this output is depending on the minimum values in the inputs.
Ex: If X is zero (ZE) AND y is positive (PS) Then Z is negative.
ii. Sugeno

The sugeno or Takgi-Sugeno-Kang method of implication was first introduced in1985. The difference here is that unlike the Mamdani and Lusins Larson methods, the output MFS are only constants or have linear relations with the inputs with a constant output MF (Singleton), it is defined as the Zero-order Sugeno method; whereas with a linear relation, it is known as first order Sugeno method. The outputs of the sugeno method have a constant minimum value in the input.

H. Defuzzification and Denormalization

The function of a defuzzification module (DM) is as follows: Performs the so-called defuzzification, which converts the set of modified control output values into single point – wise values. Performs an output denormilization, which maps the pointwise value of the control output onto its physical domain. This step in not needed if non normalized fuzzy sets is used. A defuzzification strategy is aimesat producing a non-fuzzy control action that best represents the possibility of an inferred fuzzy control action. Seven strategies in the literature, among the many that have been proposed by investigators, are popular for defuzziffying fuzzy output functions:

i. Max-membership principle
ii. Centroid method
iii. Weighted average method
iv. Mean-max member ship
v. Centre of sums.
vi. Centre of largest area
vii. First (or last) of maxima.
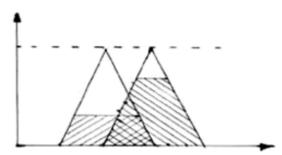The best well-known defuzzification method is Centroid method.

Fig 3. Center of – area, method of defuzzification

The above operation in a graphical way, it can be seen that this defuzzification method takes into account the area of U as whole. Thus if the area of two clipped fuzzy sets constituting _U' overlap, then the over lapping are isnot reflected in the above formula. This operation is computationally rather complex and therefore results in quite slow inference cycles. Denormalization is the process to convert per unit quantities into actual quantities. Membership shapes of I/O fuzzy sets and assignment of the control rules in the error phase plane.
i. Membership functions for inputs and output

I. Editing of fuzzy interface system

In this we edit the rules, ranges of each membership functions for inputs and outputs. The step by step procedure:
Step 1:- Edit the membership functions.
Input 1:- trimf, number 5, range
Input 2:- trimf, number 5, range
OUTPUT:-trimf, number 5, range
Step 2:- edit rules.
Step (a): first take the relating rules.
Step (b): add the rules respectively by selecting each Variable.
Step 3:- Export the FIS editor to the workspace
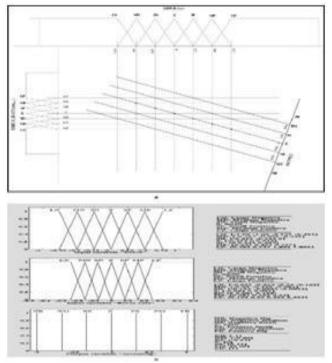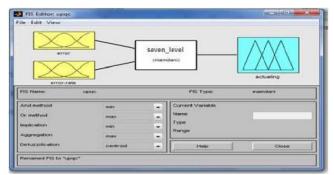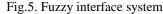Step 4:- Link this FIS editor to the FIS rule viewer.

Fig 4. Membership figures for input and output

Fig.5. Fuzzy interface system
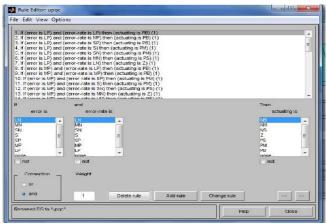

Fig.6. Fuzzy Rule Viewer

Fig 7. Fuzzy Rule Editor

III. PROPOSED MULTILEVEL INVERTER :

The proposed single-phase nine-level inverter was developed from the seven-level inverter in. It comprises a single-phase conventional H-bridge inverter, two bi-directional switches, and a capacitor voltage divider formed by C1, C2, C3, and C4 as shown in Fig. 8.
The modified H-bridge topology is significantly advan-tageous over other topologies, i.e., less power switch, power diodes, and less capacitors for inverters of the same number of levels. Photovoltaic (PV) arrays were connected to the inverter via a dc–dc boost converter.
The power generated by the inverter is to be delivered to the power network, so the utility grid, rather than a load, was used.
The dc–dc boost converter was required. The because the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the grid.

A filtering inductance Lf was used to filter the current injected into the grid. Proper switching of the inverter can produce seven output-voltage levels (Vdc, 3Vdc /4, Vdc /2, Vdc/4, 0, −Vdc, −3Vdc /4, −Vdc/2, Vdc/4) from the dc supply voltage.
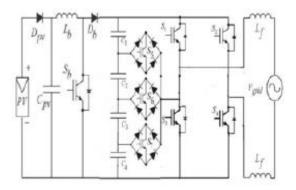

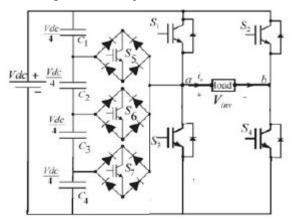**Fig.8.Proposed single phase nine-level grid-connected inverter for photovoltaic systems.**

Fig. 9. Nine-level inverter for switching operation.

The single-phase nine-level inverter was developed from the seven-level inverter as shown in Fig.8. It comprises a single-phase conventional H-bridge inverter, three bidirectional switches, and a capacitor voltage divider formed by C1, C2,C3 and C4, , as shown in Fig. 1. The modified H-bridge topology is significantly have advantages converter.

The dc–dc boost converter was required because the PV arrays had a voltage that was lower than the single-phase voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the single-phase induction motor. The LC-filter is modeled to obtain pure sine-wave and is given to drive a single-phase induction motor.. Proper switching of the inverter can produce nine-output-voltage-levels (Vdc, 3Vd c /4, V d c /2, V d c /4, 0 ,-Vdc/4, -Vdc/2, -3Vdc/4, - Vdc) from the dc supply voltage. The proposed inverter's operation can be divided into nine switching states. The required nine levels of output voltage were generated as follows.

Maximum positive output (Vdc): S1 is ON; connecting the load positive terminal to Vdc, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc.

Three-fourth positive output (3Vdc/4): The bidirectional switch S5 is ON, connecting the load positive terminal, and

S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is 3Vdc/4.

Half of the positive output (Vdc/2): The bidirectional switch S6 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc/2.

One-fourth of the positive output (Vdc/4): The bidirectional switch S7 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc/4.

Zero output: This level can be produced by two switching combinations; switches S3 and S4 are ON, or S1 andS2 are ON, and all other controlled switches are OFF; terminal ab is a short circuit, and the voltage applied to the load terminals is zero.

	S1	S2	S3	S4	S5	S6	S7
Vdc	On	Off	Off	On	Off	Off	Off
3Vdc/4	Off	Off	Off	On	On	Off	Off
Vdc/2	Off	Off	Off	On	Off	On	Off
Vdc/4	Off	Off	Off	On	Off	Off	On
0	Off	Off	On	On	Off	Off	Off
-Vdc/4	Off	On	Off	Off	On	Off	Off
-Vdc/2	Off	On	Off	Off	Off	On	Off
-3Vdc/4	Off	On	Off	Off	Off	Off	On
-Vdc	Off	On	On	Off	Off	Off	Off

TABLE 1 Out Put Voltage According To The Switches On Off:

IV.   CLOSED LOOP CONTROL SYSTEM:

The control system comprises a fuzzy logic controller, a dc-bus voltage controller, reference-current generation and a current controller.

The two main tasks of the control system are maximization of the energy transferred from the PV arrays to the grid, and generation of a sinusoidal current with minimum harmonic distortion, also under the presence of grid voltage harmonics.

As the dc-link voltage Vdc was controlled in the dc–ac seven level PWM inverter, the change of the duty cycle changes the voltage at the output of the PV panels.

A fuzzy controller was implemented to keep the output voltage of the dc–dc boost converter (Vdc) constant by comparing Vdc and Vdc ref and feeding the error into the fuzzy controller, which subsequently tries to reduce the error. In this way, the Vdc can be maintained at a constant value and at more than √2 of Vgrid to inject power into the grid. To deliver energy to the grid, the frequency and phase of the PV inverter must equal those of the grid; therefore, a grid synchronization method is needed. The sine lookup table that generates reference current must be brought into phase with the grid voltage (Vgrid). For this, the grid period and phase must be detected.

The proposed inverter provides an analog zero-crossing detection circuit on one of its input ports where the grid voltage is to be connected. The zero-crossing circuit then produces an in-phase square-wave output that is fed into the digital I/O port on eZdsp board TMS320F2812. A fuzzy controller was used as the feedback current controller for the application. The current injected into the grid, also known as

grid current Igrid, was sensed and fed back to a comparator that compared it with the reference current Igridref .

Igridref is the result of the inverter current . The error from the comparison process of Igrid and Igridref was fed into the fuzzy controller. The output of the fuzzy controller, also known as Vref, goes through an anti windup process before being compared with the triangular wave to produce the switching signals for S1–S7 Eventually, Vref becomes Vref1; Vref2; Vref3 and Vref4 can be derived from Vref1 by shifting the offset value, which was equivalent to the amplitude of the triangular wave.
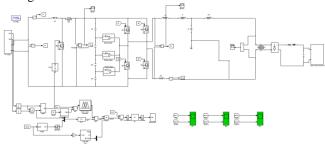

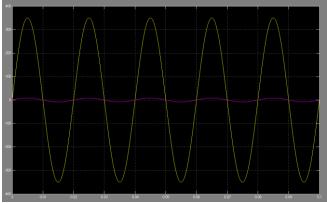Fig.10. shows the simulation result of inverter output voltage Vinv.
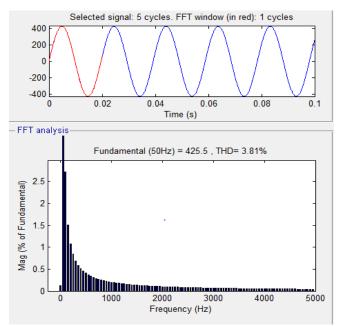

Fig 11 inverter voltage and current

Fig 12: FFT for nine level Inverter.
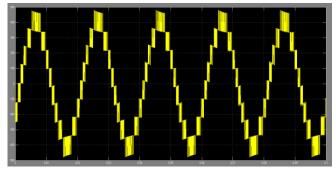

Fig 13 inverter output voltage

The dc-bus voltage was set at 300 V ($>\sqrt{2}$Vgrid; in this case, Vgrid was 120 V). The dc-bus voltage must always be higher than $\sqrt{2}$ of Vgrid to inject current into the grid, or current will be injected from the grid into the inverter.

Therefore, operation is recommended to be between Ma = 0.66 and Ma = 1.0. Vinv comprises seven voltage levels, namely, Vdc, 3Vdc/4, Vdc/2, Vdc/4, 0; −Vdc, −3Vdc/4, −Vdc/2, and Vdc/4.The current flowing into the grid was filtered to resemble a pure sine wave in phase with the grid voltage see Fig. 11. As Igrid is almost a pure sine wave at unity power factor, the total harmonic distortion (THD) can be reduced compared with the THD.

V. CONCLUSION:

Multilevel inverters offer improved output waveforms and lower THD. This paper has presented a novel PWM switching scheme for the proposed multilevel inverter. It utilizes four reference signals and a triangular carrier signal to generate PWM switching signals.

The behavior of the proposed multilevel inverter was analyzed in detail. By controlling the modulation index, the desired number of levels of the inverter's output voltage can be achieved.

From the simulataion shows the less THD in the nine-level inverter compared with that in the seven- level is an attractive solution for grid-connected PV inverters

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