A Fuzzy Controlled Dual Output Photovoltaic System.

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Abstract- This paper proposes a circuit that is capable of generating both dc as well as single phase ac from photovoltaic cells. The novelty of this system is that it makes use of fuzzy logic in order to obtain the desired voltage value. The ac voltage has to be used up immediately since it cannot be stored. When this ac voltage is not required, the dc voltage generated by the PV cells is regulated and stored in a battery which can be used as per the requirement. The ac voltage is generated by making use of a nine level cascaded H-Bridge type of multilevel inverter. Dc voltage generated from the solar panels is supplied to a buck-boost converter that uses buck or a boost operation in order to obtain the desired voltage level to be fed into the battery. The fuzzy logic controller is used for determining the duty cycle which defines the mode of operation of the converter. The circuits have been simulated in MATLAB Simulink and their control schemes have been analyzed and validated.

Index terms- Buck-Boost Converter, duty cycle, Fuzzy logic controller, multilevel converter topologies, photovoltaic (PV) systems, rule base, triggering pulses.

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1 INTRODUCTION

It has been noticed over the last 3 years that the price of imported coal has tripled, so has the price of copper wires which is the major constituent of the conventional grid. On the other hand, the price of solar panels and led bulbs has gone down. There has been a large shift in relative cost of renewable power versus relative cost of fossil power. Also the setting up of any new power plants will result in further increase in the cost of imported fossil fuel especially in developing countries like India and China. Since the major hindrance to the promotion of renewable sources of energy has always been its high cost, such statistics prove that this form of energy is viable in the long run.

Hence we can now observe greater impetus being given to research in the field of renewable energy. A major contributor of renewable energy sources is solar energy. It is not only abundantly available, but is a very convenient form of energy to work with. The voltage that is generated by the solar panels is dc and all of our domestic appliances make use of single phase ac voltage. Hence we make use of multilevel inverters to obtain 230V from the solar panels. But we might not need these domestic appliances to operate all day. In such instances, we make use of a dc converter to store the energy in a battery.

There are three different configurations of the multilevel inverter (MI) viz. neutral point clamped, flying capacitor and the cascaded H-bridge multilevel inverter[1]. Among these, the first two are single source MIs while the cascaded type requires large number of dc sources. This is usually considered as a drawback for the cascaded configuration, but while dealing with solar panels it is an ideal requirement. Also this configuration eliminates the need for a dc-dc booster circuit thus resulting in an increase in overall efficiency.The common feature among both these circuits is the fuzzy logic controller (FLC). In the ac circuit usually a PWM controller with a firing angle generator is required which immensely increases the complexity of the calculations [2]. On the other hand a fully fuzzy logic controller does not require any calculations and operates on the basis of a set of pre-defined rules. Hence it is obvious that the performance of the controller relies heavily on the framing of the rules which is done by experts with prior knowledge of the system operation. The fuzzy controller is required to make the system a closed loop control system where in the error signal (i.e. difference between the actual and the reference value) is minimized. The error signal is

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generated because the solar panels are subject to various factors such as cloud coverage, which could result in reduced output. The dc converter on the other hand operates in either buck or boost mode depending on whether the output from the panels is higher or lower than the reference value. The value of the output voltage is dependent on the duty cycle. Hence a controller would be required to evaluate the required duty cycle and thereby produce the triggering pulses to turn on the chopper. The fuzzy controller does this with relative ease since the rules dictate upon the duty cycle depending on the error signal

2 AC SYSTEM AND ITS COMPONENTS.

2.1 Multilevel Inverter and its Design.

The levels of a multilevel inverter determine the harmonic content present in the output voltage. Higher the number of H-bridges, lower will be the harmonics. But there is a trade-off between the accuracy desired and the number of devices being used in the circuit. Hence the acceptable value of harmonics needs to be evaluated and the number of levels decided thereby. It is seen that 9 levels is sufficient to obtain an acceptable sinusoidal waveform. The relation between the levels and the number of H-bridges is given as,

$$n = 2k + 1$$

where n is the number of levels and k is the number of bridges required.

Hence we can deduce from the above expression that for a 9 level waveform we need to use 4 H-bridges. Each of these bridges requires 4 switches each. Hence we will be dealing with 16 switches in total. It is important to note here that a condition of redundancy exists between the switches. For any of the bridges to operate 2 switches must operate in unison. Hence we can observe that we would require 8 switching pulses for the MI.

Each of these bridges is connected in series such that the voltage generated by each bridge is added thus providing a step waveform, as shown in figure1.

The switching states for the H-bridge are listed in table1. The condition of redundancy can be verified from this table. A combination of switching on of these switches at appropriate instances of time results in the ac waveform.

TABLE 1
Switching states for the H-Bridge

S1	S2	S3	S4	Vout
1	0	0	1	Vdc
1	0	1	0	0
0	1	0	1	0
0	1	1	0	-Vdc

2.2 Fuzzy Logic Controller.

Fuzzy Logic control is known to be nonlinear and adaptive in nature which gives it faster and more robust performance under parameter variations and load disturbances. This is in line with the basis of FL itself that actually translates the knowledge and experience of the designer of a particular system into the control law. In general, the primary use of switches that are non-linear and time varying in nature in power electronics converter contributes to difficulty in modeling the system. But with FL, the mathematical model of the system may not be a requirement. Instead, with proper FL design and analysis, a high performance FL controller can be developed for a power converter [3].

This is precisely what is needed with solar panels. The output of the solar panels is dependent on various factors which are conditioned to climatic changes. The fuzzy logic controller ensures that the output of the multilevel inverter is close to the desired value, the error being within acceptable limits.

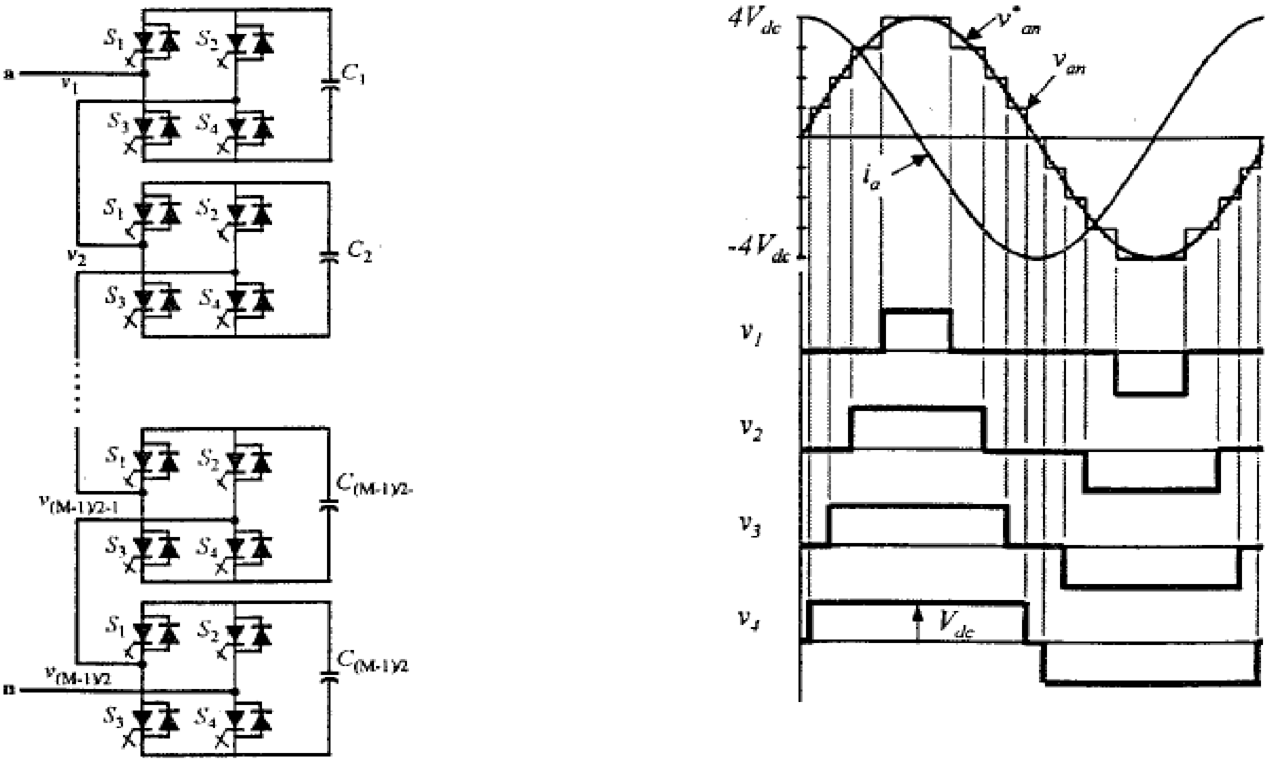


Fig 1. Cascaded 9 level multilevel inverter and output.

The fuzzy logic controller comprises of 3 basic parts as shown in figure 2.

(a) A fuzzifier that converts the crisp i.e. real world values into fuzzy values,

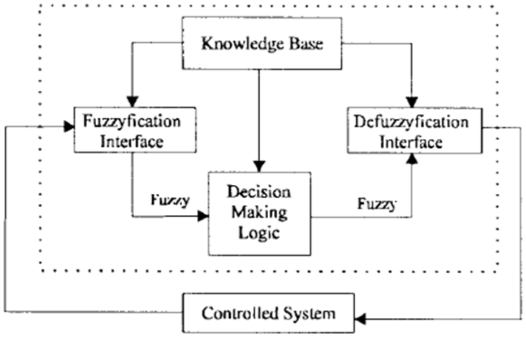


Fig 2. Basic Fuzzy Logic Controller.

(b) The inference engine that has the rule base in it and generates a fuzzy output depending upon the values of the input,

(c)The defuzzifier that converts the fuzzy value back to a crisp value.[4]

The output of the FLC is the controlled value of output voltage.

The first step for designing the FLC is defining the subsets and the membership functions for the variables. The number and type of membership functions (MFs) represent a key point for the controller, being a tradeoff among achievable performance, memory space occupation, and execution speed. Their shape depends on the input data distribution and can influence both the tracking accuracy and the execution time [5], [6]. Although any convex shape can be adopted, the most common are the triangular, trapezoidal, or Gaussian ones. The triangular MFs are used in this paper

The error signal has 5 MFs labeled “NB,” “NS,” “ZE,” “PS,” and “PB” as follows:
“NB” = negative–big, “NS” =negative–small,
“ZE” = zero, and so forth.

The input and output voltages are defined with 9 MFs i.e. *IV −*, *III−*, *II−*, *I−*, *ZE*, *I+*,*II+*, *III+*, and *IV +*, each indicating the voltage level.

A *Mamdani-based* system architecture was realized; *Max − Min*, composition technique, and the *center-of-gravity* method were used in the inference engine and in the defuzzification process, respectively. The latter was adopted because it is a good tradeoff between complexity and performance.

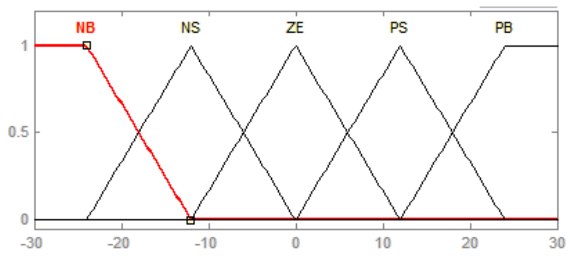


Fig. 3 The membership functions of the error signal.

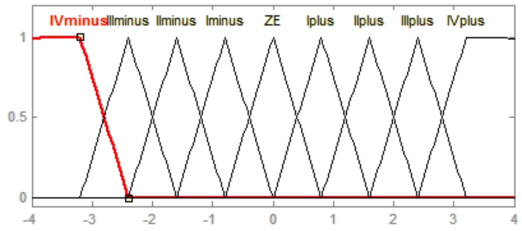


Fig. 4 The membership functions for both the normalized value of voltage and the output voltage.

The logic adopted for the framing of the rules can be summed up as stated below:

1) If *V*diff is equal to ZE, the current state is correct, and the inverter preserves its current state.

2) If *V*diff is positive *V*out >*V*ref , then the inverter state should be reduced; if *V*diff is negative *V*out < *V*ref , the inverter state should be increased[7].

This logic results in the following inference table shown in table 2.

The rules and membership functions have been shown for standalone applications wherein the inverter is controlled such as to supply the assigned active and reactive powers. In this mode of operation the control parameter is a voltage. The same principle can be extended for grid connected loads, wherein the inverter supplies the load with fixed voltage and frequency. In this mode of operation, the current is taken to be the reference parameter.

TABLE 2
Inference table.

Vdiff

Vn	**NB**	**NS**	**ZE**	**PS**	**PB**
IV+	IV+	IV+	IV+	III+	III+
III+	IV+	IV+	III+	II+	II+
II+	III+	III+	II+	I+	I+
I+	II+	II+	I+	ZE	ZE
ZE	I+	I+	ZE	I-	I-
I-	ZE	ZE	I-	II-	II-
II-	I-	I-	II-	III-	III-
III-	II-	II-	III-	IV-	IV-
IV-	III-	III-	IV-	IV-	IV-

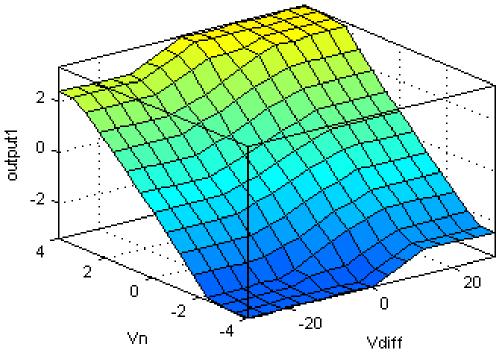


Fig. 5 Surface Rules.

The switching pulses for the switches of the MI are obtained by comparing the output of the FLC to a reference waveform consisting of 8 level shifted triangular waveforms. This is known as the SHPWM technique. The pulses generated as per THE stated PWM technique is shown in figure 6.

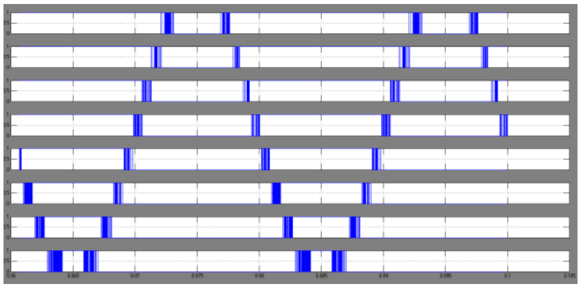


Fig. 6 The 8 switching pulses generated from the FLC output via SHPWM technique.

3 DC SYSTEM AND ITS COMPONENTS.

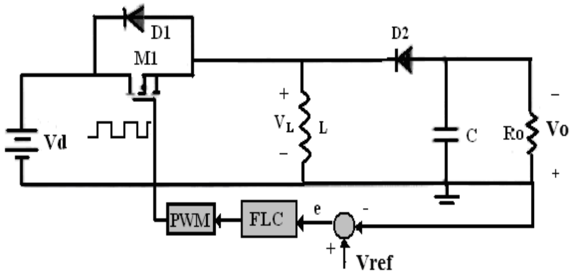
3.1 The Buck-Boost Converter.

In many industrial applications, it is required to convert a fixed-voltage dc source into a variable-voltage dc source. A dc-dc converter converts directly from dc to dc and is simply known as a dc converter. A dc converter can be considered as dc equivalent to an ac transformer with continuously variable turns ratio. Like transformer, it can be used to step down or step up a dc voltage source.[8]

A buck-boost converter provides an output voltage that may be less than or greater than the input voltage hence the name „"buck-boost"; the output voltage polarity is opposite to that of the input voltage. This converter is also known as an inverting regulator. The circuit arrangement of a buck-boost convertor is shown in figure 6.

The converter shown is a closed loop control system that includes the FLC in its feedback loop to obtain the desired results. This control loop is required because the operation of this system requires the controller to operate either in buck or in boost mode depending on the output of the controller. The mode of operation of the converter is defined by the dutycycle. If the dutycycle is <0.5 then it is operating in buck mode and in boost mode when >0.5[9].

This value of the dutycycle is determined by the fuzzy controller which is equipped with a set of well defined rules.



. Fig. 7 The Buck-Boost Controller with FLC

3.2 Design of Fuzzy Logic Controller.

The fuzzy controller is fed with two input viz the error signal (difference between the actual output of the controller and the reference value) and the rate of change of error. The output of the FLC is the dutycycle, which when compared to a reference triangular wave produces the triggering pulses for the switch in the chopper.

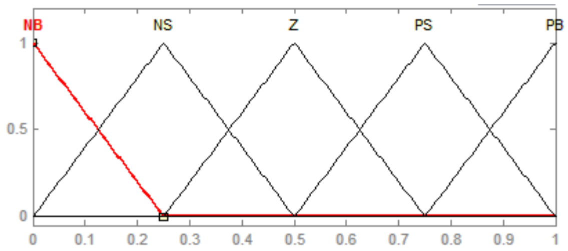


Fig. 8 The Membership Function for the error signal.

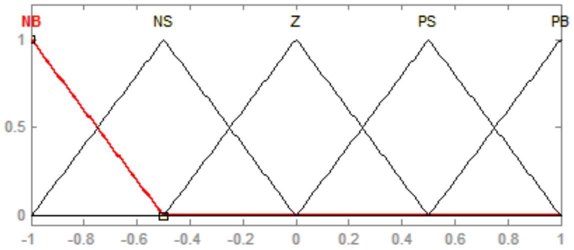


Fig. 9 The Membership Function for the change in error signal and the output of the FLC.

The rule base is generated in a way similar to that as explained in the ac system design. The resulting inference table and the rules surface is shown in table 3 and figure 10.

TABLE 3
Inference table.
ERROR(e)

D(e)	**NB**	**NS**	**Z**	**PS**	**PB**
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

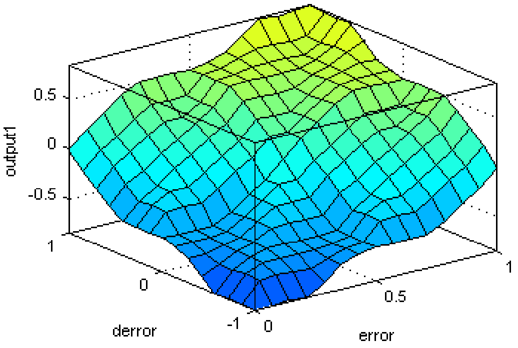


Fig.10 3 D image of the rules.

4 SIMULATIONS AND RESULTS.

To test the efficiency of the system we consider a case wherein there is cloud cover at a particular instant of time which passes over after 0.1s. The waveform is as shown below in figure11.

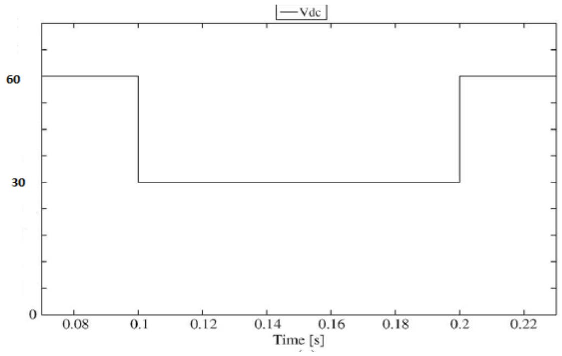


Fig.11 Input test signal .

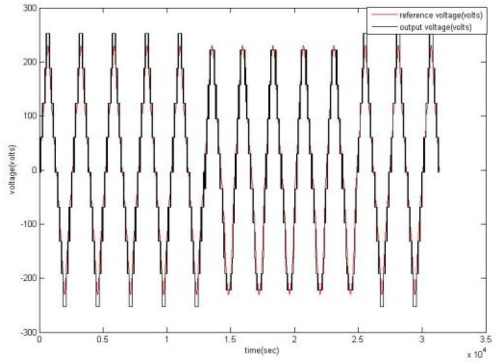


Fig.12 The output from the multilevel inverter.

The resulting voltage waveform when this is applied to the ac system is shown in figure 12.

In this figure, with a change in voltage of 30V we can observe that the output is satisfactory. This system can provide controlled voltage up to a limited loss of generation of 30V.

The test signal when applied to the dc system provides a voltage waveform as shown in figure 13. The drop in voltage has also been indicated.The various parameters used for the simulation of the Buck-Boost converter are shown in table 4.

TABLE 4
SIMULATION PARAMETERS.

Switching frequency	25 kHz
Filter inductance	2mH
Filter capacitance	870UF
Output resistance	10ohm

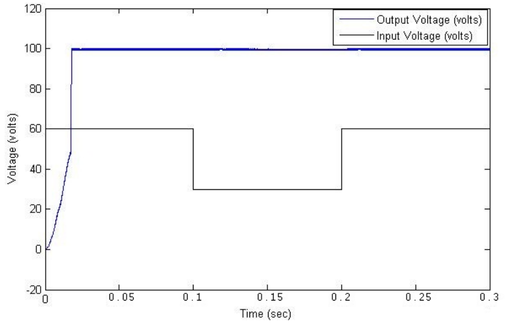


Fig.13 The output from Buck-Boost converter in Boost mode.

It can be clearly be observed that the system is robust enough to withstand a drop in voltage upto 30 V. Here we have taken the reference voltage to be 100V.

Now we consider a case wherein photovoltaic strings are used thus the voltage being generated is greater then what is desired. It is here that the buck operation comes into play. Shown in figure 14 is the voltage waveform of 100V generated when the input varies from 120 and 60V.

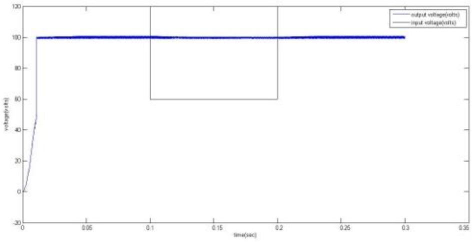


Fig.14 The output from Buck-Boost converter in Buck mode.

5 CONCLUSIONS.

A novel configuration involving generation of AC as well as DC voltage depending on the requirement has been proposed in this paper. The robustness the entire system has been validated by making use of MATLAB Simulink.

The modularity of the system makes the entire set up highly flexible. With the addition of more number of H-bridges, the number of levels of the waveform can be increased thus reducing the THD.

The DC system is highly adaptable. The amount of voltage generated can be varied as per the specifications of the batteries available. Hence during implementation of the hardware circuit we can string up all the available solar panels to obtain the voltage waveform of much higher value.

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