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Fuzzy Logic Controlled Buck Boost DC-AC Converter in Photovoltaic Svstems

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Abstract

DC-AC converters are used for many power conversion applications. Today, converters with bidirectional buck boost capabilities are gaining wide spread acceptance in various commercial and industrial applications. Various topologies for the bidirectional buck boost inverters are available. By investigating some of the available topologies and taking into consideration the pops and corns, a bidirectional buck boost inverter is modeled by cascading a buck stage and boost stage, and a control strategy is developed for the same. The inverter is found to have the following features: i) buck boost capability ii) bidirectional operation iii) reduced size and weight with only one main energy storage component. The controller is designed such that the inverter system has the following features: i) generates an output voltage according to our specification; ii) has reduced output distortion. This paper investigates the performance of the inverter with a fuzzy logic controller (FLC). Two FLCs are used to control the buck and boost stages respectively.

1. Introduction

Clean, economic and secure energy production gains importance with the increasing of the word's power demand. So, new type of energy sources has gained popularity. Solar energy is a commonly used renewable energy source[1]. Previously, they were used to supply local loads in remote areas, outside the national grid. Later, they have become a main source. Solar energy can be converted to electricity by using a photovoltaic system which consists of an array of solar cells. But, solar cells can produce only direct power. So they should be converted to alternating power and this process can be achieved by a DC/AC converter (inverter). Inverters are widely used today in various commercial and industrial areas such as uninterruptible power supplies, AC motor drives, induction heating, energy storage and renewable energy source systems. It is a device which converts a dc voltage source or a dc current source into an ac voltage or current. There are various configurations of inverters used in industry, of which buck boost inverter is a common choice. There are various topologies of buck boost inverters which are designed to operate in a photovoltaic application[2],[3].

One of the most popular topology is the boost+VSI topology[4] but it requires two main energy storage components which will increase the volume, weight, and cost of the system. Also, the control of the boost stage is not easy. Another alternative is to use a Z-source converter[5], but it increases the system volume and cost[6]. Also, with increased system order and complexity, it leads to complicated control and modulation strategies[7]. Another representative solution is to use a single-stage full-bridge series-resonant buck-boost inverter[8] which uses a LC resonant tank, that will increase the size and cost of the system. Also, it can only be used for single-phase power conversion. A different solution is to differentiate the outputs of two bidirectional, unipolar dc–ac inverters[9],[10], but its control is difficult.

Sometimes, the bidirectional power handling capability of the inverter is also desired in order to recover energy or adapt for back-to-back applications as in a wind power system [11]. Therefore it is useful to implement an inverter that can meet both of the two requirements i.e. the buck boost capability and bidirectional property. Hence we go for a bidirectional buck boost

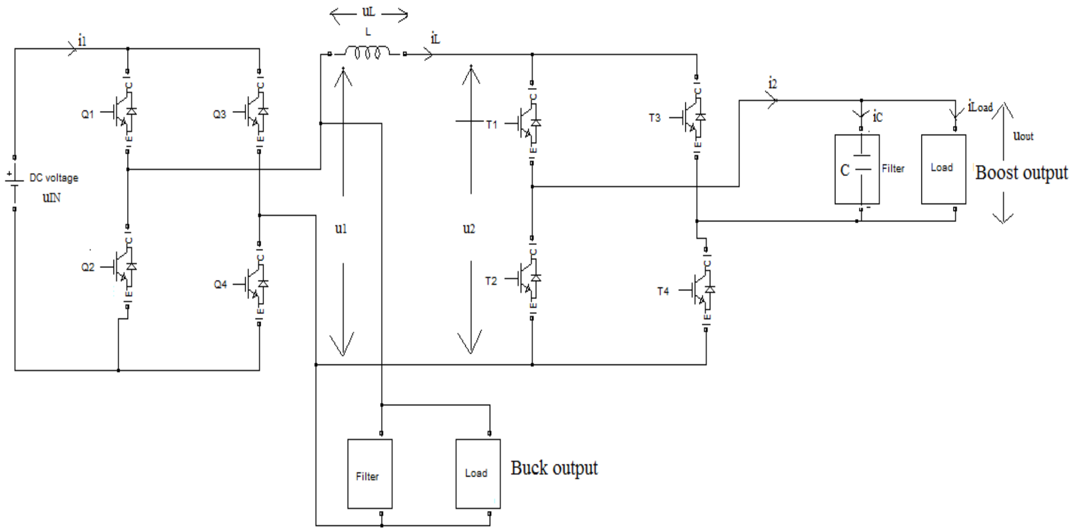


Figure 1. Circuit diagram of bidirectional buck boost inverter

inverter. Various control methods are available for buck boost inverters.

One method of control is to use sliding mode control, but it lacks effective control[11]. Another alternative is a decoupled control scheme using PI controllers[12]. For high-performance applications, a PI controller cannot guarantee a perfect tracking in the case of a periodic reference, according to the internal model principle. So a non linear control method using fuzzy logic is proposed in this paper. Various types of fuzzy logic controllers used in inverters are reviewed in the literature[13]-[16].

This paper is organized as follows. First, the principle of operation of the inverter is explained. Then, a control method using a simple fuzzy logic controller is proposed. Finally, the results are verified through device level simulations.

2. Inverter Operation

The circuit diagram of the bidirectional buck boost inverter[12] is shown in Fig. 1. The switching devices in the buck stage consist of four transistors Q_1-Q_4 and the switching devices in the boost stage consist of four transistors T_1-T_4. The variables and parameters for the inverter are listed in Table 1. Here the buck stage is basically a voltage source inverter and the boost stage is basically a current source inverter.

The buck stage goes through three phases of operation: positive bucking phase, negative bucking phase and freewheeling phase. As shown in Fig. 2.a, in the positive bucking phase, Q_1 and Q_4 are conducting and the energy is transferred from the battery to the inductor as well as the load of the buck stage (i.e., the boost stage). Therefore $u_1 = u_{IN}$ and $i_1 = i_L$.

In the negative bucking phase shown in Fig. 2.b, Q_2 and Q_3 are conducting and the energy is

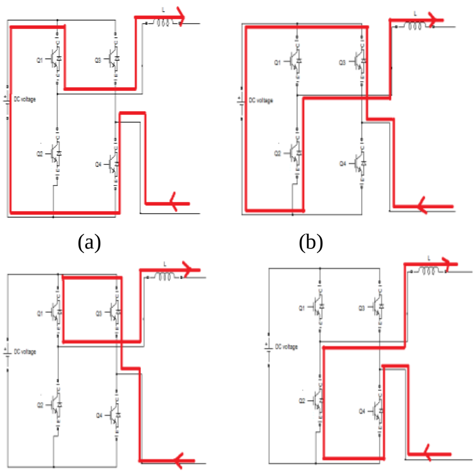
Table 1. System variables and parameters

System Variables and Parameters	Definition
u_{IN}	Input to the system
u_1	Output voltage of buck stage
u_2	Input voltage of boost stage
u_L	Inductor voltage
u_{OUT}	Load voltage
i_1	Input current of buck stage
i_2	Output current of boost stage
i_L	Inductor current
i_C	Capacitor current
i_{Load}	Load current
L	Energy storage inductor
C	Filter capacitor

transferred from the inductor and the boost stage back to the battery.
Therefore $u_1 = -u_{IN}$ and $i_1 = -i_L$

2.1. Operation of Buck Stage

As shown in Fig. 2.c, in the freewheeling phase, either Q_2 and Q_4 or Q_3 and Q_1 are conducting and the energy is transferred from the inductor to the boost stage, so $u_1 = 0$ and $i_1 = 0$.
The switching pattern for a positive output voltage and current- Q1, Q4 ON and Q2, Q4 ON
The switching pattern for a negative output voltage and current- Q2, Q3 ON and Q2, Q4 ON



(a) (b)

(c)

Figure 2. Phases of operation of buck stage (a)positive bucking phase, (b) negative bucking phase, (c) freewheeling phase

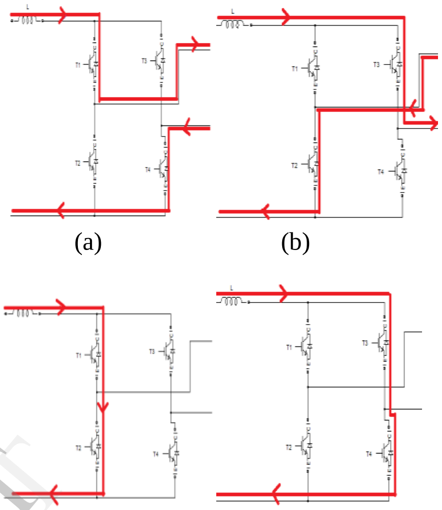
2.2. Operation of Boost Stage

At the output of the boost stage we get a signal whose amplitude is greater than the input signal amplitude. Again, since the inductor current i_L is positive, there are four main conducting patterns for the boost stage ie. a positive boosting phase, two charging phases and a negative boosting phase.

As shown in Fig. 3.a, in the positive boosting phase, T_1 and T_4 are conducting and the energy is transferred from the source of the boost stage (i.e., the buck stage) as well as the inductor to the load, so $i_2 = i_L$ and $u_2 = u_{OUT}$.

The negative boosting phase shown in Fig. 3.b, is equivalent to positive boosting except that the output polarity is negative, $i_2 = -i_L$ and $u_2 = -u_{OUT}$.

In the charging phase as shown in Fig. 3.c, one of the bridge legs is conducting (e.g., T_1 and T_2 or T_3 and T_4) and the energy is transferred from the buck stage to the inductor, so
$i_2 = 0$ and $u_2 = 0$.
The switching pattern for a positive output voltage and current - T1, T4 ON and T1, T2 ON
The switching pattern for a negative output voltage and current - T2, T3 ON and T1, T2 ON



(a) (b)

(c)

Figure 3. Phases of operation of boost stage (a) positive boosting phase, (b)negative boosting phase, (c) charging phase

3. Fuzzy Logic Control

Fuzzy logic control theory provides a different way to approach a control problem. It is based on vagueness and uncertainty. It can use non-precise or ill-defined concepts. Fuzzy logic control is also nonlinear and adaptive in nature and so it gives robust performance under parameter variation and load disturbances. FLC focuses on what the system should do rather than trying to model how it works. One can concentrate on solving the problem rather than trying to model the system mathematically ie. detailed analysis and modeling of the system is not required in case of FLC. Classical controllers, which are fixed-gain feedback controllers, can neither compensate the parameter variations in the plant nor adapt to changes in the environment. Further, mathematical modeling of the plants and parameter tuning of the controller have to be done before implementing the controller. Most real systems, exhibit nonlinear behavior, and so it is often difficult to model these systems using the laws of physics. In a fuzzy logic control system, there is no necessity for a plant model. The human experience and the expertise derived from the association with the plant leads to the design of the plant and its controller. The fuzzy control method yields better dynamic performance and less steady state error compared to conventional controller.

The block diagram of FLC is shown in Fig. 4. It has four main components:

Fuzzification: It simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base ie. it convert crisp values to fuzzy values. Fuzzy values are specified using linguistic variables (Example: error, load voltage, modulation index etc). Linguistic variables are assigned a set of linguistic values (Example: positive, zero, negative). Meaning of the linguistic values is quantified using membership functions. The value of the membership function ranges from 0 to 1. There are different types of membership functions: Triangular, Trapezoidal, Gaussian, Bell, Sigmoidal, S, pi etc.

Rule Base: It holds the knowledge, in the form of a set of rules, of how to achieve good control. The rules are formulated as IF-THEN statements.

Inference mechanism: It is a decision making mechanism. Based on the inputs, it evaluates which control rules are relevant at the current time and then decides what the input to the plant should be, ie. it arrives at a goal on how best to control the plant. There are two types of fuzzy inference system: Mamdani and Sugeno. Mamdani's method is widely accepted for capturing expert knowledge. It allows to describe the expertise in more intuitive, more human like manner. But it has computational burden. Sugeno is computationally efficient. It is highly attractive in control problems particularly dynamic non linear systems. The main difference between Sugeno and Mamdani is that the Sugeno output membership functions are either linear or constant.

Defuzzification: It converts the conclusions of the inference mechanism into the actual inputs to the plant ie. it converts the fuzzy value to crisp value. There are various defuzzification techniques like centroid method, max membership principle method, mean-max membership method, centre of sums method, weighted average method, centre of largest area method etc.

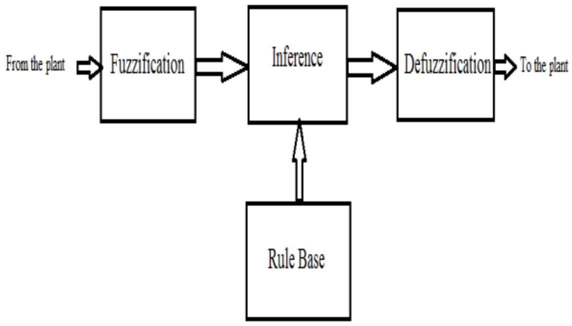


Figure 4. Block diagram of fuzzy logic controller

3.1. FLC for buck boost inverter

Fuzzy logic controllers are frequently used in the control of power electronic converters, as it does not need mathematical models, and since it is insensitive to the parameters and to the change in operating points. This paper presents a method of controlling the inverter using fuzzy logic controller. The block diagram of fuzzy logic controlled buck boost inverter is shown in Figure 5. It consists of a photovoltaic array system, a dc-ac converter system (inverter), filter, fuzzy logic controller, and a pulse generation circuit for triggering the switches. Sine wave filters / LC filters are used to extract the sinusoidal component from the inverter output.

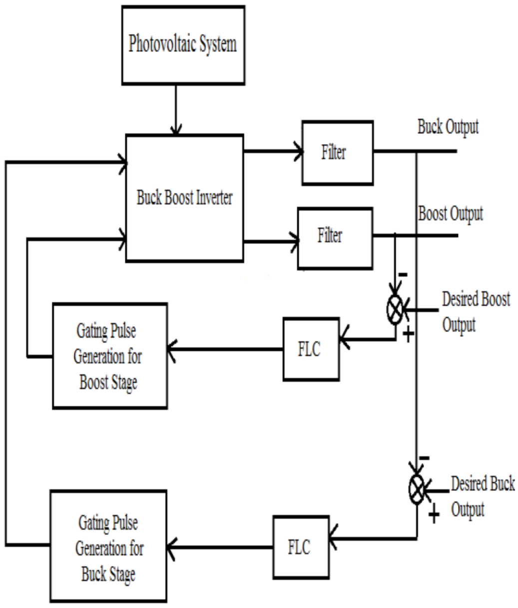


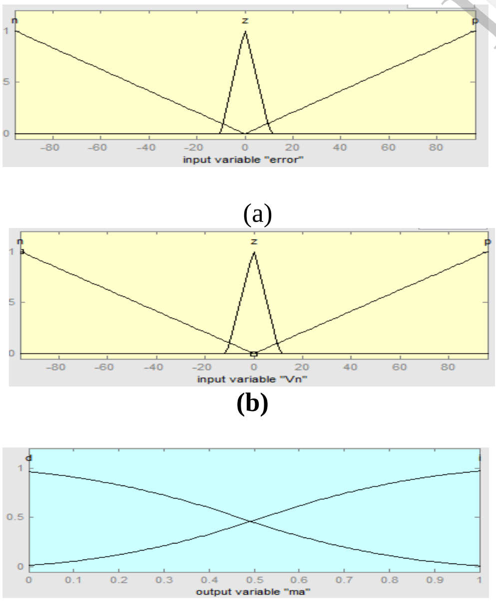
Figure 5. Block diagram of the system with the controller

The block diagram of the buck boost inverter with the controllers is shown in Fig. 5. In the proposed FLC system, two fuzzy logic controllers are used to control the buck and boost stages respectively. Both the FLCs have two inputs and one output where error, e (desired output – buck/boost output) and output of buck/ boost stage, Vn, are the inputs and modulation index, ma is the output. Membership function values for inputs are assigned using three fuzzy subsets: positive (P), negative (N) and zero (Z) and the output using two fuzzy subsets: increase (I) and decrease (D) as shown in Fig. 6

The fuzzy mapping of the input variables to the output is represented by the following IF-THEN rules:
IF e is N and Vn is N, THEN ma is I
IF e is N and Vn is Z, THEN ma is I
IF e is N and Vn is P, THEN ma is D
IF e is P and Vn is N, THEN ma is D
IF e is P and Vn is Z, THEN ma is I
IF e is P and Vn is P, THEN ma is I

For the inference mechanism Mamdani's max–min (or sum–product) method is used. The center of the gravity (centroid / centre of area) method is used for defuzzification to obtain ma, as given in Equation 1, where Ci is the area and μi is the membership value of the area.

$$ma = \frac{\sum_{i=1}^{n} \mu i C i}{\sum_{i=1}^{n} \mu i} = \qquad (1)$$



(a)

(b)

(c)

Figure 6. Membership function values for (a) error, e, (b) inverter output, Vn, and (c) controller output,ma.

3.2. PWM inverter

PWM inverters are quite popular in industrial applications [17],[18]. Pulse generation circuit of the buck boost inverter uses PWM (Pulse Width Modulation) technique to generate the gating pulses.

The advantages of PWM techniques are:
(i) Output voltage control can be obtained without any additional components.
(ii) Lower order harmonics can be eliminated or minimized along with its output voltage control. As higher order harmonics can be filtered easily, the filtering requirements are minimized.

Of the various PWM techniques, sinusoidal pulse width modulation (carrier based pulse width modulation technique) is used here. In this PWM technique, a carrier signal is compared with a modulating signal where the modulating signal is a sinusoidal wave with frequency fsine and amplitude Vsine and the carrier signal is a triangular wave of frequency ftri and amplitude Vtri.

The modulation index ma (amplitude modulation ratio) is defined as

$$ma = \frac{\text{Vsine}}{\text{Vtri}} \qquad (2)$$

and the normalized carrier frequency mf (frequency modulation ratio

$$mf = \frac{\text{ftri}}{\text{fsine}} \qquad (3)$$

The ac output voltage is basically a sinusoidal waveform plus harmonics, where the amplitude of the fundamental component of the output voltage is V_{01}= maVdc. When ma<1, the ac output voltage will be of lower amplitude than the input dc(Vdc) and in the over modulation region where ma > 1, some intersections between the carrier and the modulating signal are missed, which leads to the generation of low order harmonics but a higher fundamental ac output voltage is obtained.

4. Simulation and results

In order to validate the performance of the fuzzy logic controlled buck boost inverter, a model of the system has been designed and simulated as shown in Fig. 7 using MATLAB/Simulink (version 7.10).

The steady-state performance of the system under resistive (R) load and inductive resistive (RL) load is analyzed. First a resistive load of 110 Ω and next a RL load of R= 2Ω and L= 1mH is connected to the output of the inverter. A dc voltage of 96-V is given as the input, and the buck stage is commanded to generate an output voltage of 54Vrms and the boost stage reference voltage is set as 220Vrms Simulation results are summarized in Fig. 8-11

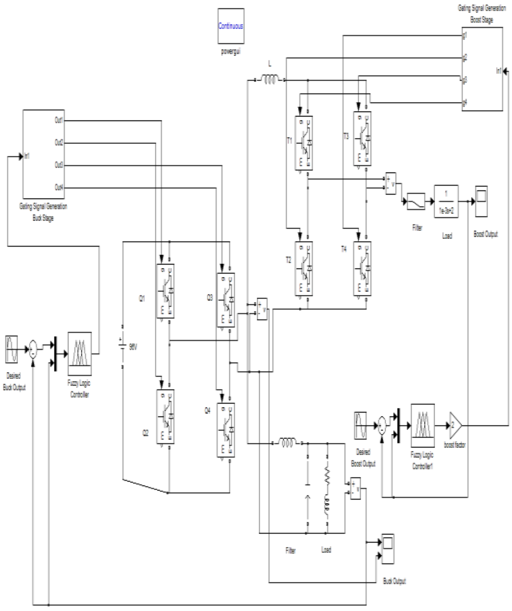


Figure 7. Simulation model of fuzzy logic controlled buck boost inverter

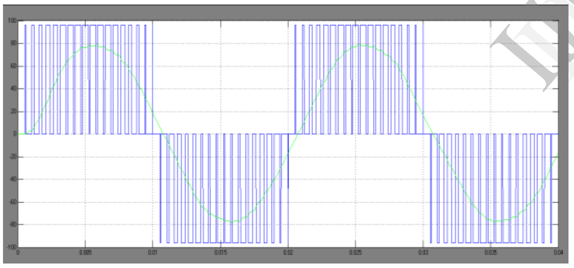


Figure 8. Simulation results: Output voltage, $u_{buckout}$ (R load)

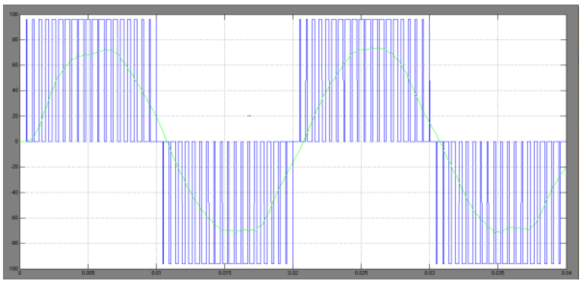


Figure 9. Simulation results: Output voltage, $u_{buckout}$ (RL load)

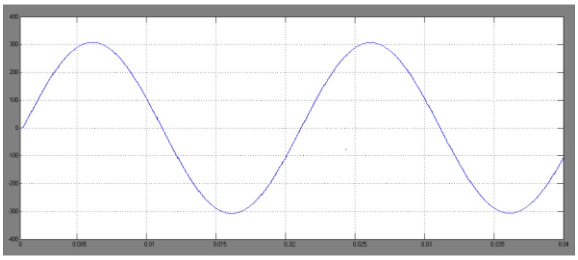


Figure 10. Simulation results: Output voltage, $u_{boostout}$ (R load)

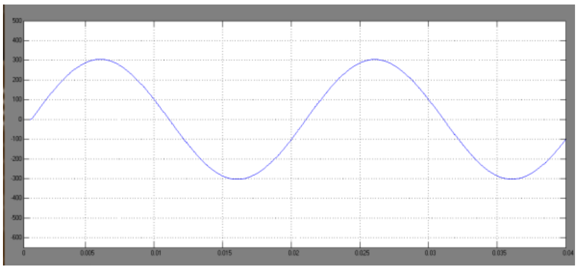


Figure 11. Simulation results: Output voltage, $u_{boostout}$ (RL load)

From Fig. 8 and Fig. 9 it can be concluded that with a 96V dc input and with both the R load and RL load, the buck stage of the inverter has successfully generated an ac output waveform of 54Vrms, which shows that it has tracked the given reference with minimum distortion.

Fig. 10 and Fig.11 shows the boost output under R load and RL load with a fuzzy logic controller, given a Vref of 220Vrms. It is seen that it has successfully generated the required output.

5. Conclusion

A fuzzy logic controlled buck boost inverter is presented in this paper. The inverter has the following features: i) buck boost capability ii) bidirectional operation iii) reduced size and weight with only one main energy storage component. The fuzzy logic controller is designed such that the inverter system possesses the following features: i) generates an output voltage according to our specification ii) has reduced output distortion. Simple fuzzy logic controllers are implemented in both the sections: buck and boost stages. It has minimum number of membership functions and rules which makes the design simple. Further, the controller results are found to produce accurate results with minimum distortion.

6. References

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