A DC-DC Boost Converter with Voltage Multiplier Module and Fuzzy Logic Based Inverter for Photovoltaic System

Abragam Siyon Sing M[1], Brindha S[2]

[1]Asst. Professor, Department of EEE, St. Xavier's Catholic College of Engineering, Nagercoil, Tamil Nadu, India.
[2]PG Scholar, Department of EEE, St. Xavier's Catholic College of Engineering, Nagercoil, Tamil Nadu, India.

***Abstract* – A DC-DC boost converter with voltage multiplier circuit is proposed for a PV system with Multi level inverter using Fuzzy logic. The voltage multiplier circuit consists of coupled inductors, capacitors, diodes for its operation. This circuit can be used to get wide range of voltage gain because of its coupled inductor. The system design not only reduces the voltage stress but also it reduces the output current ripple. Also this system reduces the conduction losses in the metal oxide semiconductor switches. It functions similar to the clamp circuit, which alleviates the voltage spikes across the switches. The boosted DC output obtained from this system is inverted to AC by a cascaded H-bridge multilevel inverter, whose switching is controlled by the Fuzzy logic controller, in which the harmonics are controlled thereby increasing the performance of the output.**

***Keywords* – step up converter, PV module, voltage multiplier, fuzzy logic, multilevel inverter.**

I. INTRODUCTION

Power generation in the world with the fossil fuels may cause adverse effects and may become difficult for the humans to live in the near future. So it is necessary to switch our energy by-products to the renewable energy resources. Generating the power from solar energy is readily available and it is reliable. Since the power generated from the renewable energy is very less, it is mandatory to boost the power by using converters like step-up converter and voltage multiplier modules[1]-[5].

The following fig.1 shows the typical photovoltaic systems, which is used to generate power from solar energy. The light energy is tapped from the sunlight, which when falls on the solar module, cause the electrons to flow in the circuit. So, the energy from the sun is converted into electrical energy. This energy can be stored in the battery set and it can be used by the step up converter and is boosted to a required amount, which is then inverter to AC and is given to grid for customers.

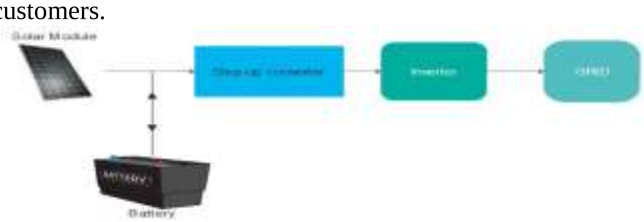


Fig.1. Typical PV System

There are some converters available for the commercial purpose, but they are not much efficient due to leakage inductance. Hence a boost converter with coupled inductor is proposed because of its high voltage conversion ratio [6]-[10]. The voltage gain of the coupled inductors can be adjusted by simply varying the windings in the inductor coil. Thus a wide range of voltage gain can be obtained. There is a wide use of interleaved structures in the some of the boost converters [11]-[14], in which asymmetrical interleaved converters are employed here. Such structure with capacitors reduces the current ripple and gives high voltage output. In this paper these advantages of DC-DC boost flyback converter with voltage multiplier module is considered and is implemented [15].

With this boost converter, multilevel inverters are adopted in this paper to get the AC power for the grid/load. Such inverter is preferred over the conventional PWM based inverters because of its added advantage of improved output, reduced total harmonic distortion, reduced filter size, etc [16]-[18]. Multilevel inverters are available with different topologies and they use different PWM strategies. Because of many attractive features like less distorted output, lower switching frequency, such inverters are preferred for commercial purpose [19]. However there is some efficiency issues in the inverter output regarding its shape and size of the waveform, interactions between different stages and hence the multilevel inverter is controlled by fuzzy logic systems, which reduces the efficiency issues in the system[20].

II. SYSTEM DESCRIPTION

Usually, step up transformers are used in ac circuits to boost the voltage to the required level, whereas here, voltage multiplier module, which is a distinct type of diode rectifier circuit. This module could produce a output voltage which is significantly greater than the applied voltage. Similarly in electronic circuits, which require a high voltage or low voltage, wherever it may be, corresponding transformers are used for the required voltage level depending on the type of applications. Here, with the help of diodes, coupled inductors, capacitors, the input voltage is increased without the use of such transformers.

Rectifiers are used in many electrical as well as electronic circuits where high dc voltage is generated equivalent to that of the input ac voltage, in which they convert the alternating voltage into the DC voltages with the help of diodes. Such rectifiers are similar to the working of voltage multipliers. As mentioned above, the output of the rectifiers is much limited by its input voltage, but in voltage multiplier circuit, the output voltage is boosted or gets multiplied with the help of rectifiers, diodes, capacitors, coupled inductors. So we can be able to achieve the output voltage which will be some multiples of the peak input alternating voltage.

The following diagram shows the block diagram of the entire proposed system.

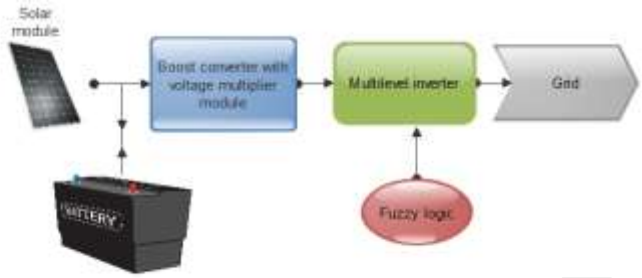


Fig.2. Block Diagram of Proposed system

A. Boost Converter With Voltage Multiplier Module

The proposed circuit diagram of voltage multiplier module is shown below. A conventional boost converter and two coupled inductors are located in the voltage multiplier module, which is stacked on a boost converter to form an asymmetrical interleaved structure. Primary windings of the coupled inductors with Np turns are employed to decrease input current ripple, and secondary windings of the coupled inductors with Ns turns are connected in series to extend voltage gain.

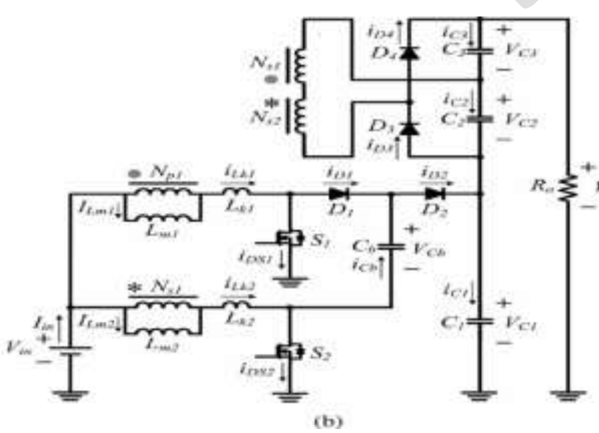


Fig 3. Circuit diagram of Voltage multiplier circuit

The turns ratios of the coupled inductors are the same. The coupling references of the inductors are denoted by " . " and " * " in the equivalent circuit of the proposed converter shown above, where Lm1 and Lm2 are the magnetizing inductors, Lk1 and Lk2 represent the leakage inductors, S1 and S2 denote the power switches, Cb is the voltage-lift capacitor, and n is defined as a turns ratio Ns /Np . The proposed converter operates in continuous conduction mode (CCM), and the duty cycles of the power switches during steady operation are interleaved with a 180◦ phase shift; the duty cycles are greater than 0.5. The key steady waveforms in one switching period of the proposed converter contain six modes at different time periods starting from t0 to t5, which are as follows.

At time t0, the power switches S1 and S2 are turned ON and All the diodes in the circuit are reversed-biased. Thus, Magnetizing inductors Lm1 and Lm2 as well as leakage inductors Lk1 and Lk2 are linearly charged by the input voltage source Vin.

After some time t1, the power switch S2 is switched OFF, thereby turning ON diodes D2 and D4. During this period, energy stored in the magnetizing inductor Lm2 is transferred to the secondary side thereby charging the output filter capacitor C3. The input voltage source, magnetizing inductor Lm2, leakage inductor Lk2, and voltage-lift capacitor Cb release energy to the output filter capacitor C1 via diode D2, thereby extending the voltage on C1.

At new time t2, diode D2 automatically switches OFF because the total energy of leakage inductor Lk2 has been completely released to the output filter capacitor C1. Now the Magnetizing inductor Lm2 transfers energy to the secondary side charging the output filter capacitor C3 via diode D4 until t3.

At time t3 seconds, the power switch S2 is switched ON and all the diodes are turned OFF as similar to the first mode, during which the inductors are linearly charged from the input supply.

At time t4, the operation is similar to that of the mode 2 but here the power switch S1 is switched OFF, which turns ON diodes D1 and D3. The energy stored in magnetizing inductor Lm1 is transferred to the secondary side charging the output filter capacitor C2. The input voltage source and magnetizing inductor Lm1 release energy to voltage-lift capacitor Cb via diode D1, which stores extra energy in Cb.

During time t5, diode D1 is automatically turned OFF because the total energy of leakage inductor Lk1 has been completely released to voltage-lift capacitor Cb. Magnetizing inductor Lm1 transfers energy to the secondary side charging the output filter capacitor C2 via diode D3 until t0.

Thus the operation can be clearly understood with the different modes. That is, during each time period, the corresponding diode operates and in that operation, the magnetizing and leakage inductors gets charged, which is sufficiently discharged to the voltage lift capacitor and it is further released into the output filter capacitor from which the output can be obtained by connecting the load or scope. The output of this multiplier circuit is boosted to the required level through different modes and with the help of Mulitlevel inverter, the alternating voltage is obtained from the multiplier circuit through Fuzzy logic controller.

B. Multilevel Inverter And Fuzzy Logic Controller

The multilevel inverters used here consist of semiconductor device called thyristors, which are arranged in H-bridge fashion and the switching pulse for these thyristors are provided by the fuzzy logic system. A single H-bridge level consists of four thyristors and the input is given to them from the boost converter. The thyristors need a gate pulse to switch on, which is given as PWM techniques. The efficiency is increased by increasing the levels of the inverter circuit. When there is infinity level, then the total harmonic distortion approaches zero but however increasing the number of levels of the inverter will result in complexity of the system and its cost will increase considerably. Hence selecting the number of levels is much important, which will not increase the conduction losses and switching losses.

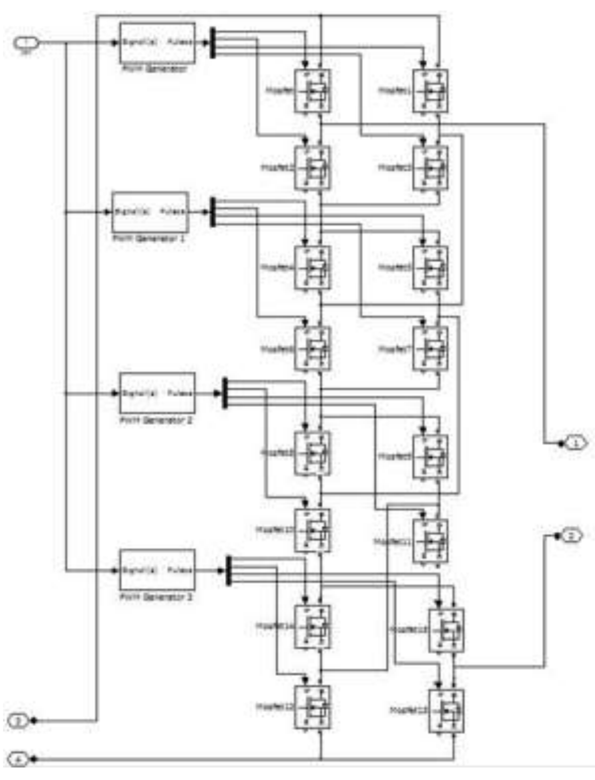


Fig.4. Section of Multi level H- bridge inverter

The following block diagram shows how a Single Phase Cascaded H-bridge multilevel inverter is administered by the fuzzy logic controller using photovoltaic power source. It comprises of inverter module, filter, reference voltages for implementing control strategies, fuzzy logic controller and finally to the load. Feedback signals are also included in the FLC, the outputs of which are continuous waveforms. The input variables for the fuzzy logic controller are inverter output voltage, the difference between actual and reference signals of both voltage and current. For measuring the voltage difference, the actual value is taken as the output signal from the filter at the load terminals and the reference signal is some fixed voltage or current.

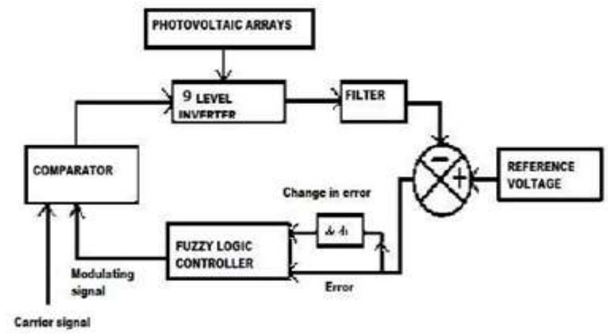


Fig.5 Block Diagram of Inverter and Fuzzy logic

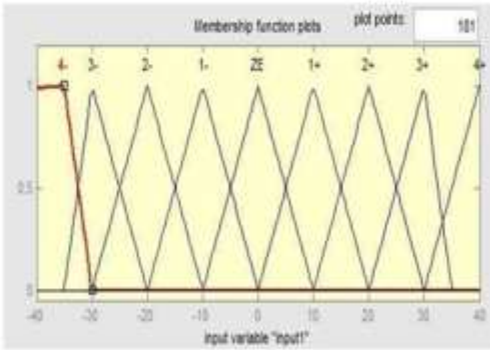
Measuring the output voltage at the load terminals improves the quality of the control without introducing delays. Filter bandwidth is chosen to be around 1 kHz with resistive load. The output of fuzzy logic controller is applied to the inverter gate drivers. The Fuzzy logic controller output may perhaps assume nine different states, which depends on the number of levels used in the inverter. While designing the fuzzy logic controller, the First step was the creation of rules called fuzzy rules, which are expressed in terms of corresponding statements, conditions and their actions. Starting from the condition “TRUE”, a set of rules has been formed for the error conditions and they were defined accordingly, obtaining variable reactions. The number and type of membership functions represent a key point for the controller.

In fuzzy logic system, a membership function (MF) is a simple curve that outlines how each point in the input space is plotted to a membership value (or degree of membership) between 0 and 1. Their shape depends on the input data distribution and can influence both the tracking accuracy and the execution time. In this paper, the number and type of the control rules were decided by conducting a sensitivity analysis made by wavering the number and type of rules. The following fig.6 shows the Membership Functions chosen for the two input parameters.

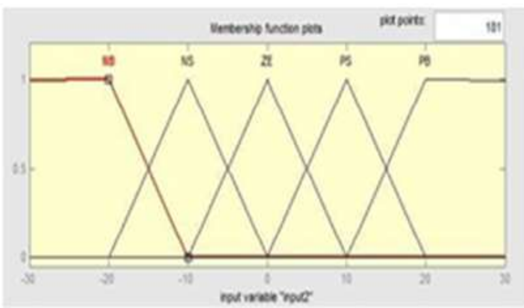
Here is the list of labels used,

“NB,” “NS,” “ZE,” “PS,” and “PB” - AVdiff
Where “NB” denotes negative big,
“NS” denotes negative small,
“ZE” denotes zero

Different inference rules have been formed to implement the fuzzy logic system. The number of rules depends on the performance of the system, number of input variables, selected membership functions, response time of the system and the system’s adaptability. Here, the number of rules is selected by conducting the sensitivity analysis.



(a)



(b)

Fig.6. Membership functions of (a)Vn (b)Voltage differences

Assume input voltage=40v

Operating frequency =50Hz

Duty ratio :(d) $d=\frac{T_{on}}{T}$, $T=\frac{1}{f}=\frac{1}{50}=0.02$ d=0.5

Output voltage: $V_0=\frac{2n+2}{1-D}V_{in}=\frac{2+2}{1-0.5}*40=320v$

III. SIMULATION MODEL

The experiment is done in the MATLAB software and is simulated and the output is obtained.

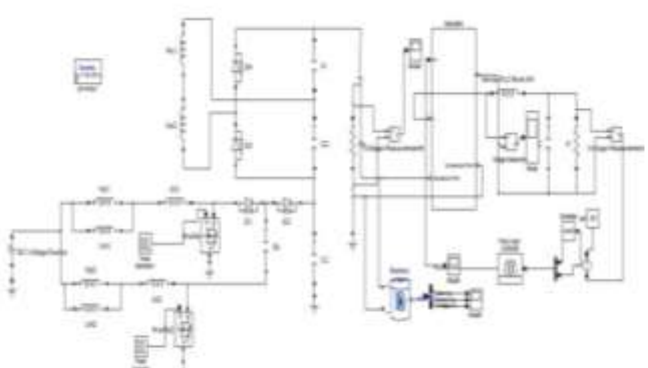


Fig. 7. Simulation Model of the entire proposed system

The above simulation consists of two phases. One is the converter phase with voltage multiplier module and the other is inverter phase with fuzzy logic controller.

IV. RESULTS AND DISCUSSIONS

The purpose of this study is to improve the voltage gain of the boost converter and voltage multiplier module which reduces the voltage ripple, which in-turn reduces the conduction losses. The results have been analysed for continuous conduction mode under steady state conditions and the total harmonic distortion was reduced by using nine level inverter.

A dc-dc boost converter with voltage multiplier module was designed according to the following specification:

Table: 2 converter parameters

Parameters	Values
Vg	40v
Vo	380v
L	133mH
C	220µF
Ro	200Ω
Fs	50kHz

Initially, when the gate signal is on, switch S conducts, and the diode 2 will conduct the inductor current is charged the output voltage maintained by using capacitor. When the gate signal is off the inductor current discharges and the diode 1, 2, 4 will conduct and the output voltage maintained by using diodes. Hence the output DC is maintained at constant level.

Fig 8. input and output waveform of voltage multiplier circuit

The output waveform of nine level inverter with multiplier module is shown in which the harmonics are reduced by using multilevel inverter.

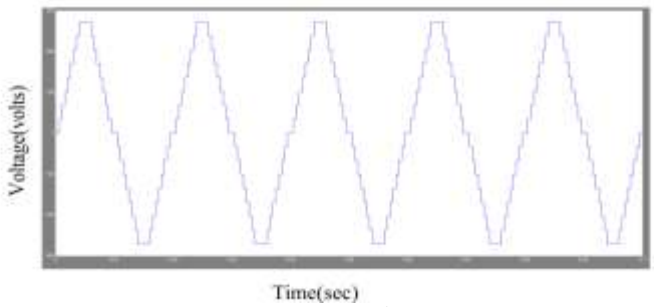


Fig.9 Overall Output of the system

V. CONCLUSION

Often for renewable energy applications a low voltage is obtained from the renewable energy sources. It has to be boosted up to a higher voltage level in order to be used by the consumer. There exists a wide range of step up converters. In this work a high efficiency boost converter is designed for a given output power, voltage and input voltage. The output from the multiplier was given as input to the nine level inverter and it was controlled using fuzzy logic controller. The interleaved structure reduces the input current ripple and distributes the current through each component. In addition, the lossless passive clamp function recycles the leakage energy and constrains a large voltage spike across the power switch. Meanwhile, the voltage stress on the power switch is restricted. The total harmonic distortion is reduced by using the multilevel inverter. Thus, the proposed converter is suitable for high-power or renewable energy applications that need high step-up conversion.

REFERENCES

[1]. C. Hua, J. Lin, and C. Shen, "Implementation of a DSP-controlled photovoltaic system with peak power tracking," IEEE Trans. Ind. Electron., vol. 45, no. 1, pp. 99–107, Feb. 1998.

[2]. J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. C. P. Guisado, M. A. M Prats, J. I. Leon, and N. Moreno-Alfonso, "Power-electronic systems for the grid integration of renewable energy sources: A survey," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1002– 1016, Jun. 2006.

[3]. J. T. Bialasiewicz, "Renewable energy systems with photovoltaic power generators: Operation and modeling," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2752–2758, Jul. 2008.

[4]. Y. Xiong, X. Cheng, Z. J. Shen, C. Mi, H.Wu, and V. K. Garg, "Prognostic and warning system for power-electronic modules in electric, hybrid electric, and fuel-cell vehicles," IEEE Trans. Ind. Electron., vol. 55, no. 6, pp. 2268–2276, Jun. 2008.

[5]. F. S. Pai, "An improved utility interface for micro-turbine generation system with stand-alone operation capabilities," IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1529–1537, Oct. 2006.

[6]. K. C. Tseng and T. J. Liang, "Novel high-efficiency step-up converter," IEE Proc. Elect. Power Appl, vol. 151, no. 2, pp. 182–190, Mar. 2004.

[7]. T. J. Liang and K. C. Tseng, "Analysis of integrated boost–flyback step-up converter," IEE Proc. Elect. Power Appl., vol. 152, no. 2, pp. 217–225, Mar. 2005.

[8]. R. J.Wai and R. Y. Duan, "High step-up converter with coupled-inductor," IEEE Trans. Power Electron., vol. 20, no. 5, pp. 1025–1035, Sep. 2005.

[9]. R. J. Wai, C. Y. Lin, R. Y. Duan, and Y. R. Chang, "High-efficiency DC–DC converter with high voltage gain and reduced switch stress," IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 354–364, Feb. 2007.

[10]. S. K. Chang chien, T. J. Liang, J. F. Chen, and L. S. Yang, "Novel high step-up DC-DC converter for fuel cell energy conversion system," IEEE Trans. Ind. Electron., vol. 57, no. 6, pp. 2007–2017, Jun. 2010.

[11]. W. Li and X. He, "An interleaved winding-coupled boost converter with passive lossless clamp circuits," IEEE Trans. Power Electron., vol. 22, no. 4, pp. 1499–1507, Jul. 2007.

[12]. W. Li and X. He, "A family of isolated interleaved boost and buck converters with winding-cross-coupled inductors," IEEE Trans. Power Electron., vol. 23, no. 6, pp. 3164–3173, Nov. 2008.

[13]. D.Wang, X. He, and J. Shi, "Design and analysis of an interleaved fly back– forward boost converter with the current auto balance characteristic," IEEE Trans. Power Electron., vol. 25, no. 2, pp. 489–498, Feb. 2010.

[14]. W. Li, Y. Zhao, Y. Deng, and X. He, "Interleaved converter with voltage multiplier cell for high step-up and high-efficiency conversion," IEEE Trans. Power Electron., vol. 25, no. 9, pp. 2397–2408, Sep. 2010.

[15]. Kuo-Ching Tseng, Chi-Chih Huang, and Wei-Yuan Shih, "A High Step-Up Converter With a Voltage Multiplier Module for a Photovoltaic System IEEE Trans. Power Electron.,, vol. 28, no. 6, june 2013

[16]. Bakhshai.A, Jain.P and, Khajehoddi, "The application of the cascaded multilevel converters in grid connected photovoltaic systems," In Proc. IEEE Epc, Montreal, Qc,Canada. July 2007.

[17]. M. Tolbert, F. Z. Peng, T. G. Habetler, 1999,"Multilevel converters for large electric drives," IEEE Transactions on Industry Applications, vol. 35, no. 1, pp. 36-44.

[18]. L. G. Franquelo, J. Rodriguez, J. I. Leon, S. Kouko, R. Portillo, and M. A. M. Prats, "The age of multilevel converters arrives," IEEE Ind.Electron. Mag., vol. 2, no. 2, pp. 28–39, Jun. 2008.

[19]. Jose Rodriguez, Jin-Sheng Lai and Fang Zheng, 2002, "Multi level Inverters: A survey of topologies, Control applications," IEEE transactions on Industrial Electronics, Vol.49, No. 4, pp. 724-738.

[20]. Carlo Cecati, Fabrizio Ciancetta, Pierluigi Siano, "A Multilevel Inverter for Photovoltaic Systems with Fuzzy Logic Control", IEEE Trans. Ind. Electron., vol. 57, no. 12, pp. 4115 –4125, Dec. 2010.