International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 05, Volume 4 (May 2017) www.ijirae.com

Z-Source Based High Step-Up Chopper for Photovoltaic Panel

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Manuscript History
Number: IJIRAE/RS/Vol.04/Issue05/MYAE10085
Received: 25, April 2017
Final Correction: 18, May 2017
Final Accepted: 28, May 2017
Published: May 2017
Citation: Ansari Bilal Ahmed, 2017, " Z-Source Based High Step-Up Chopper for Photovoltaic Panel", doi:10.7910/DVN/3HMWVK, Harvard Dataverse, V1
Editor: Dr. A. Arul L.S, Chief Editor, IJIRAE, AM Publications, India

Abstract* — *The photovoltaic panel not only generates low DC voltage but also DC voltage which varies with time and environmental condition. Therefore design of electrical energy system with constant output voltage is a big challenge to designer. This project deals with the development of electrical energy system which consists of Z-source based high step up chopper. The chopper is basically based on coupled inductor which provides high voltage gain and physical isolation between input and output with small turn ratio. It also provides a low voltage stress on active components and small conduction losses due to low duty cycle. Due to the usage of a single switch, the control circuitry is less complex. The proposed chopper recycles the energy of leakage inductance hence enhancing system efficiency. This report consists of mathematical modelling and designing of proposed chopper circuit. The MATLAB simulation of proposed chopper circuit is to convert 25 volts dc to 400 volts dc with 300 watts power. The simulation results validate the theoretical results. The H-Bridge inverter circuit is used at the end of proposed chopper for converting DC voltage into AC voltage.

Keywords* — *Z-source, Coupled Inductor, Chopper, Inverter, Duty Cycle, MATLAB Simulink.

I. INTRODUCTION

The electricity generated by non-renewable sources has numerous problems; firstly non-renewable energy is a resource that does not renew itself in sufficient time period. Secondly it creates pollution due to its consumption, for example nuclear power plant which is costly and needs to take precautions as nuclear effects are not only harmful for human body but also on soil and eco cycle. On the other hand renewable energy resources are very eco-friendly, cheap and infinite source of energy. The voltage level of non-renewable energy sources is higher than renewable energy, except energy sources like wind turbines and hydro power (dam). But it's not easy to install at any place and also some time impossible. Therefore Photovoltaic panel is better renewable source of energy which converts solar energy into electric energy. Fig. 1 indicate complete block diagram of electrical energy generation system through PV panel. Photovoltaic panels can be used for domestic application. But the output voltage level of PV panel is low depending on size and power capacity as well as it varies with environment condition [1]. To increase output voltage of PV panel, many methods are available. Among all the methods, the simplest approach is that the photovoltaic panels are interconnected to increase the voltage level [2].

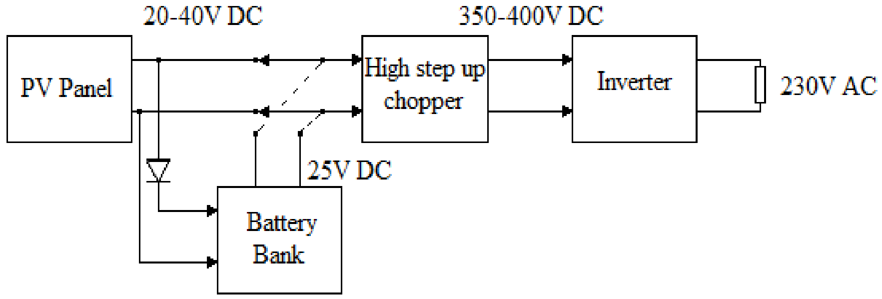

Fig.1. Electrical Energy Generation System

When photovoltaic panels are interconnected the system becomes more expensive, acquires large area and probability of shading is also increased. So to overcome this problem, step up chopper system is used to increase voltage level of PV panel before applying to an inverter system. The limitation of PV panel is its dependency on sun light which can be overcome by battery backup.

II. PROBLEM DEFENATION

A. Motivation

Electric energy system based on Photovoltaic panels has low voltage, hence constant and high voltage gain chopper is needed to boost the low output voltage of photovoltaic panel at desired level. But these types of chopper have some drawbacks such as high switching losses and high input current. As large input current high rating devices are used it increases conduction losses and dissipate large amount of heat. Basically Isolated and non-isolated choppers are used to step up low input voltages. But choppers also have number of drawbacks such as gain of non-isolated choppers like boost, buck boost and cuck which are low for high duty cycle [3]. The high voltage losses are shown on the parasitic components such as internal resistance of inductors and capacitors. Non-isolated choppers have high voltage stress on switches.

The isolated choppers have high voltage gain by properly calculating the turn ratio of the coupled inductor or transformer. The leakage inductance energy of the coupled inductor or transformer generates high voltage stress on the chopper components. Various choppers with high voltage gain and different configurations have been proposed in literature [3]–[9]. The gain of chopper system can be enhanced by properly switching across capacitors and inductors, [6] and voltage multiplier or voltage lift cell [7] configurations. But, these configurations have high complexity with low efficiency. For highly efficient chopper, leakage inductance energy should be recycled properly and should not increase the voltage stress on power devices [5], [8]. The switching losses can be reduce by using a resonant chopper circuit [4], but it will be more complex control circuit and high stress on the power components. Thus z-source based high step up chopper is much better than all of the above choppers.

B. Objective

The aim of this project is to show how to boost the output of photovoltaic panel to desire level with low rating devices. The proposed chopper has number of features such as the low turn ratio of the coupled inductor, recycling of the energy stored in leakage inductor, less voltage stress on switch and diodes, and the low voltage rating components are used.

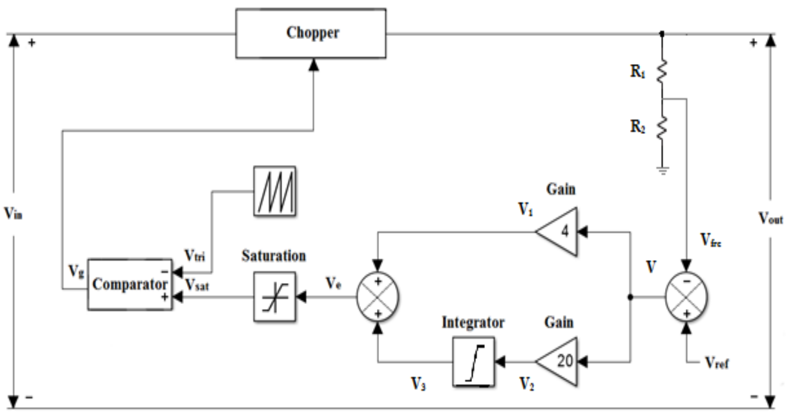

Fig.2. Closed Loop Duty Cycle Control System

The isolation is present between input and output [8]. To implement this chopper, the other aim of this project is to have a strong and substantial amount of literature about the different choppers so as to get acquainted with the characteristics and parameters of different choppers. Also this project is to design mathematical model, calculate the value of components and design of control circuit. Fig. 2 indicates complete closed loop duty cycle control system.

The control circuit is simple it consists of PI controller which maintains PWM signal for controlling duty cycle. Fraction of output voltage V_{frc} is applied to subtractor with reference voltage V_{ref}. The output voltage of subtractor V is applied to gain circuit along with integrator circuit which will generate error signal Ve. Error signal is saturated for minimum and maximum limit of duty cycle and generate saturated voltage V_{sat}. The triangular voltage V_{tri} and saturated voltage V_{sat} is applied to comparator circuit which in turn generates duty cycle pulses V_g. The simulation of proposed chopper circuit is done in MATLAB Simulink. This model is simulated for different input values with varying duty cycle and different turn ratio of coupled inductor. The simulation results validate the mathematical model. The H-Bridge inverter circuit is used at the end of proposed converter for converting DC voltage into AC voltage.

III.METHODOLOGY

Fig. 3 indicates proposed step up chopper system. This system consists of Z-Source based configuration with the help of coupled inductors coils L_1 and L_2 and capacitors $C_1$and C_2. These coils are wound on core T_1 and T_2, in actual all coils are wound on same core T with turn ration N_2:N_1. The coupled inductors provide isolation between input and output as well as its form resonance tank circuit with capacitor C_1 and C_2 which will reduce stress on switch S. The circuit is controlled by single MOSFET switch S. So the controlled circuit is simple [7]. The operational analysis of proposed chopper can be simplified with assumption and considering all devices as ideal.

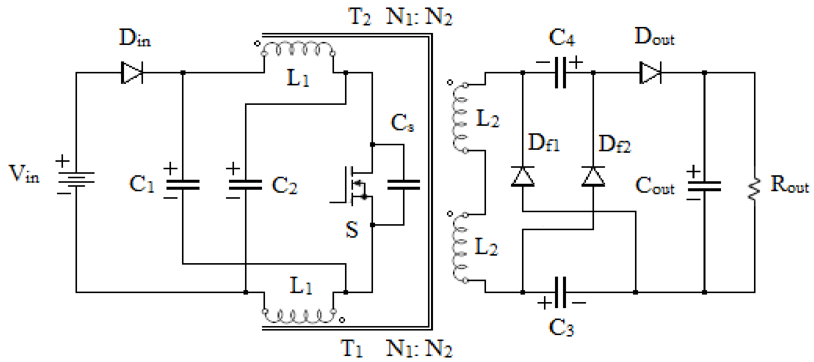

Fig.3. Z-Source Based High Step-Up Chopper

The equivalent model of coupled inductor is represented by magnetizing inductance (L_{m1}= L_{m2}= L_m), leakage inductance (L_{lk1}, L_{lk2}) and ideal transformer on the basis of cantilever model. Coupling co-efficient ($K_1 = K_2 = K$) and turn ratio $N_2/N_1 = n$. The circuit is dividing into two side primary side and secondary side.

A. Operation Analysis of Proposed Chopper

In CCM operation, assume that capacitor C_1, C_2, C_3 and C_4 are charged initially. The operation is divided into two states ON and OFF state. In ON state the diodes D_{in}, D_{f1}, D_{f2} remain off and diode D_{out} conduct, and at primary side The Capacitor C_1 and C_2 starts discharging though magnetizing L_m and leakage L_{lk1} inductors. The L_m and L_{lk1} are charged by Vc voltage. The I_{Lm} and I_{L1} current increase linearly. The magnetizing inductor of primary side L_m transfers the stored energy to coupled inductors of secondary side. The coupled inductors at secondary sides are in series with capacitor C_3 and C_4 and transfer energy to load through diode D_{out} and charged capacitor C_{out}. When switch is OFF, the diodes D_{in}, D_{f1}, D_{f2} conduct current whereas diode D_{out} is off and does not conduct. At primary side the magnetizing inductor L_m and L_{lk1} discharge through capacitor C_1 and C_2 through diode D_{in} and voltage source. At secondary side L2 is in parallel with capacitor C_3 and C_4. So L_2 discharges on capacitor C_3 and C_4 through diode D_{f1}, D_{f2}. The power is delivered to load during off time by capacitor C_{out}.

B. Block Diagram and Operational Analysis of Inverter

Fig. 4 indicates proposed H-Bridge inverter system.
The H-Bridge Inverter circuit consist of four N channel MOSFETs and PWM generator circuit. The MOSFET switches in the bridge generate a positive voltage, negative voltage, or zero potential voltage across a load. The reference sine wave oscillator, triangular wave generator, summing amplifier, comparators (A1, A2, A3, and A4), MOSFET driver and an output filter are the necessary circuits to generate a 50Hz, 230V AC sine wave across a load.

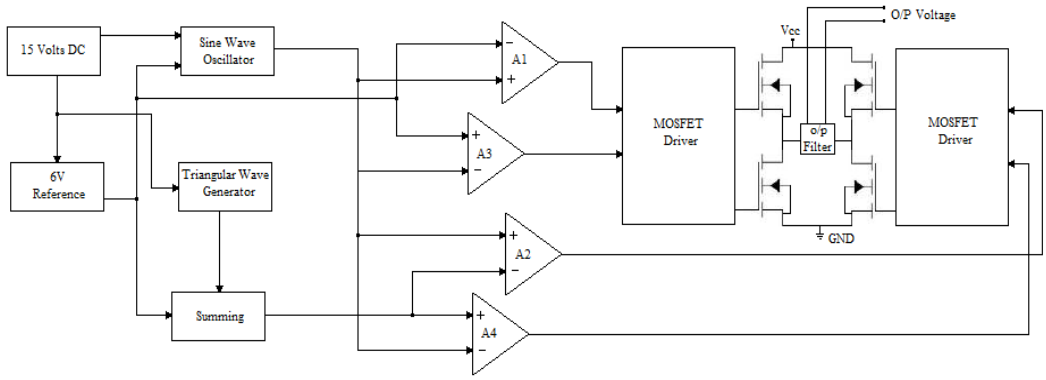

Fig.4. Block Diagram of Proposed H-Bridge Inverter System

When these blocks are implemented and interconnect with each other as per given in the H-Bridge inverter system they generate the PWM signal. The PWM signals are send to MOSFET drivers that generates desire voltage to drive four N Channel MOSFETs. The output of MOSFETs contain high ripple which can be filtered by a low pass LC filter.

C. Simulation Results of Proposed Chopper and Inverter

The simulation of proposed chopper is done on different conditions. Fig. 5 indicates graph of duty cycle D (x-axis) verses gain G (y-axis) with different turn ratio 'n'. The input voltage is changed from 15 volts to 35 volts which will maintain constant output voltage as source regulation is 1.5%. Similarly with 25volts input at different load level the output voltage is constant and load regulation of proposed chopper will be calculated at 2%.Fig. 6, 7, 8 and 9 indicates voltage across switch, voltage across magnetizing inductor, output voltage across load and output voltage of H-Bridge inverter respectively.

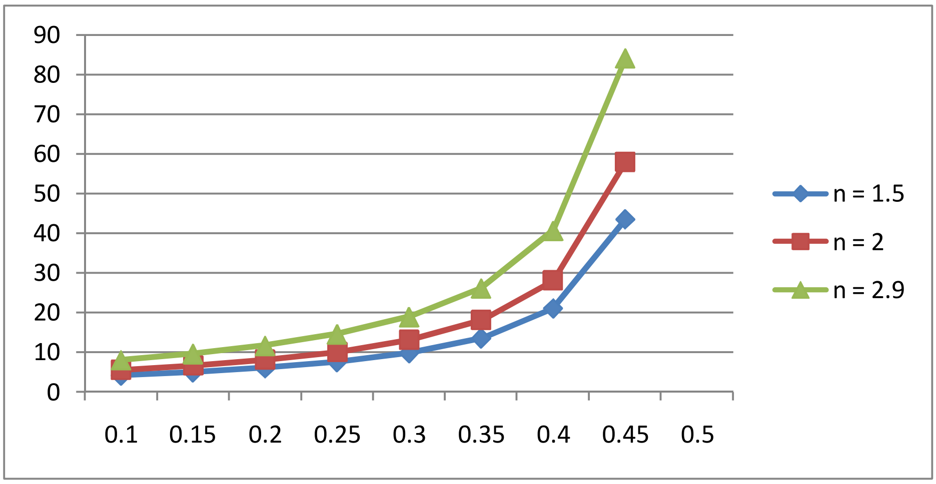

Fig.5.Graph of Simulated Results on Different Turn Ratio and Duty Cycle

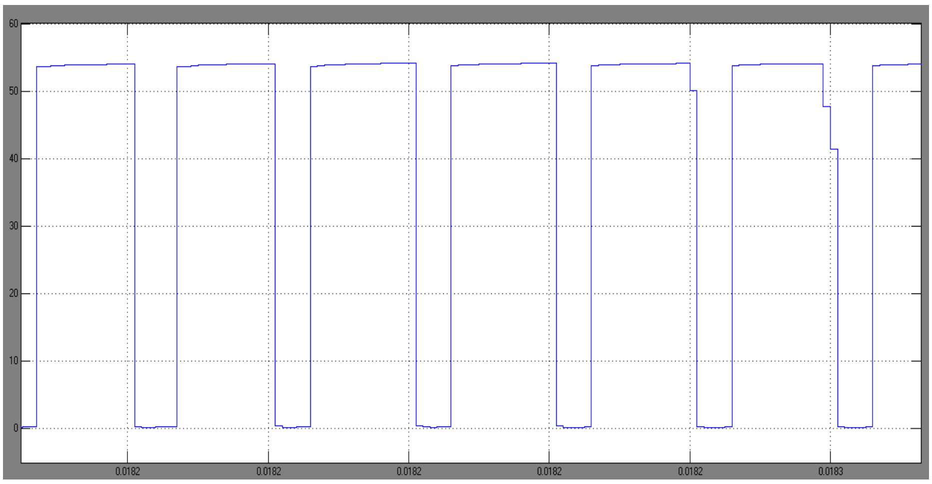

Fig.6. Simulated Voltage Waveform across Switch S

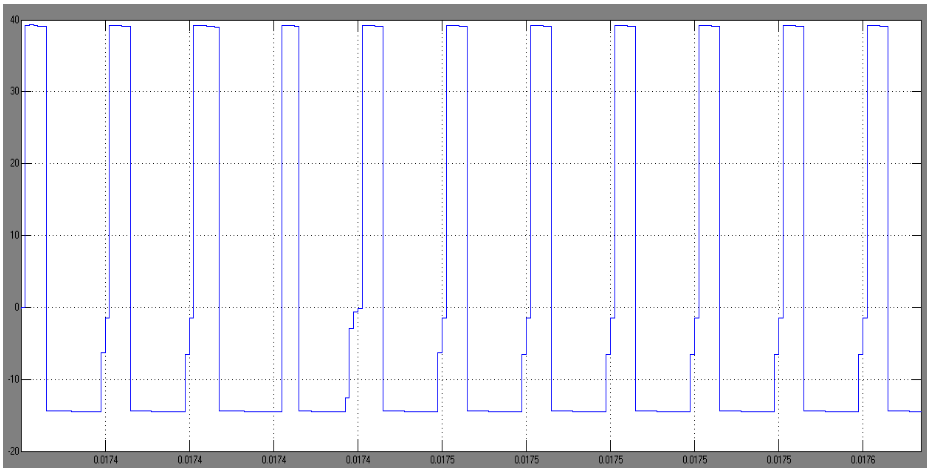

Fig.7. Simulated Voltage Waveform across Magnetizing Inductor L_m

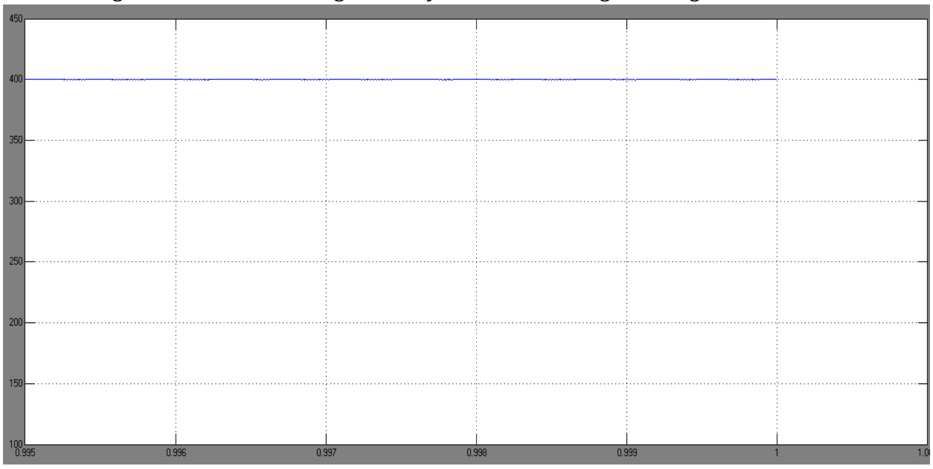

Fig.8. Simulated Output Voltage Waveform across Load R_L

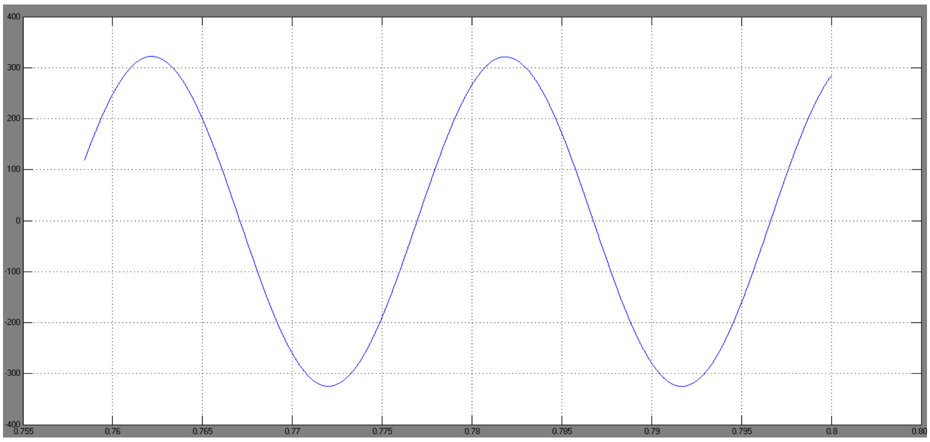

Fig.9. Output Waveform of H-Bridge Configuration with LC filter

D. COMPARATIVE STUDY BETWEEN CALCULATED AND SIMULATED VALUES

TABLE I

COMPARISON BETWEEN CALCULATED AND SIMULATED VALUE OF CHOPPER

PARAMETERS	MATHEMATICAL CALCULATION	THEORETICAL VALUES	PRACTICAL VALUES
Magnetizing Voltage during ON Time	$Vlm(on) = KVin\left[\frac{1-D}{1-2D}\right]$	40 V	39.6 V

Magnetizing Voltage during OFF Time	$Vlm(off) = -Vin\left[\frac{1-D}{1-2D}\right]\left[\frac{DK}{1-D}\right]$	−15.9 V	−14.7 V
Switching voltage during OFF Time	$Vds = \left[\frac{Vin}{1-2D}\right]$	56.8 V	56.4 V
Output Voltage	$Vo = 2nKVin\left[\frac{1+D}{1-2D}\right]$	400 V	400 V

The comparison is down with assumption $K = 1$.The small difference between theoretical values and practical values is present due to internal voltage drop of active devices and snubber circuit.

IV. CONCLUSIONS

The goal of this project can be achieved by proper boosting of input voltage from photovoltaic panel. The proposed chopper gives high efficiency at very low cost. The MATLAB simulation consists of a high step up chopper circuit which converts 20-30 volts DC to 400 volts DC with 300 watts power. The closed loop control circuit constantly maintains 400 volts output by adjusting the duty cycle. The different simulated voltage waveform is verified by mathematical model of chopper system with small tolerance due to uncalculated losses of devices. The H-Bridge circuit is used at the end of proposed chopper for converting400 volts of DC to 230 volts AC with frequency of 50 Hz and 300 watts power. The simulated output voltage waveform of inverter has been verified as per the requirement of system. The overall efficiency of system is high due to less number of components and simple circuit design. These features make it suitable for applications making use of PV panel and other systems which are having low output voltage.

ACKNOWLEDGMENT

I acknowledge with gratitude, my debt of thanks to Prof. Monika Bhagwat for his advice and encouragement for completing this project. I would also like to thanks to my family, mentors, colleagues and my friends for unending support to complete this task.

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