Performance Analysis of Photovoltaic PWM Inverter with Boost Converter for Different Carrier Frequencies Using MATLAB

Prashant. V. Thakre, V. M. Deshmkh, and Saroj Rangnekar

Abstract—**This paper presents the performance analysis of photovoltaic inverters with boost converter using MATLAB.A string of photovoltaic panels are coupled to a single phase inverter using a boost converter. Boost converter can step up the voltage without using a transformer. With the selection of switching frequency the bridge circuit used in inverter model can be allowed to generate a single phase ac signal. Thus by selecting different switching frequencies the nature of ac signal can improved.**

Index Terms— **Boost converter, bridge inverter, photovoltaic panels, unipolar pwm switching.**

I. Introduction

Inverters are power converters that convert dc to ac. In domestic solar energy systems, PV inverters are used to transfer dc power from PV panels to ac loads. With the growing energy demand, increasing global environmental issues, and depleting energy resources (coal, oil and gas), the need to develop and utilize new sources of energy seems inevitable. For these reasons, renewable energy resources such as solar, wind, biomass and geothermal, appear as important alternative energy options. Solar energy, one of the few clean and abundant renewable energy resources, has come into the limelight in recent years India today stands among the top five countries in the world in terms of renewable energy capacity. We have an installed base of over 15 GW, which is around 9% of India's total power generation capacity and contributes over 3% in the electricity mix. While the significance of renewable energy from the twin perspectives of energy security and environmental sustainability is usually well appreciated, what is often overlooked, or less appreciated, is the capacity to usher in energy access for all, including the most disadvantaged and the remotest of our habitations. In its decentralized or stand alone avatar, renewable energy is the most appropriate, scalable, and optimal solution for providing power to thousands of remote and hilly villages and hamlets. Even

today, millions of decentralized energy systems, solar lighting systems, irrigation pumps, aero-generators, biogas plants, solar cookers, biomass gas fires, and improved cook stoves, are being used in the remotest, inaccessible corners of the country. Providing energy access to be most disadvantaged and remote communities can become one the biggest drivers of inclusive growth [1].To harness the solar energy, various energy conversion technologies are required. Photovoltaic (PV) panels, or commonly known as solar panels, are devices used to convert sunlight into electricity. The acronym PV stands for photo (light) and voltaic (electricity), whereby sunlight photons free electrons from the atoms of the panels and creates a voltage difference [2].

Since the PV panels convert sunlight into electricity in the form of direct current (dc), while most electrical devices for residential applications require alternating current (ac), dc-ac power conversion is needed. This can be realized by power converter known as inverter. In solar energy systems, PV inverter is the power converter used specifically to convert the dc power obtained from PV panels into ac power. From the economic point of view, although the cost of PV power is relatively high as compared to other renewable energy sources such as wind and biomass, it has decreased from more than \$50/W in the early 1980s to about \$2/W today [1]. This can be attributed to the economics of scale and subsidies from the government of India [2]. The future plan from utility providers to "purchase" electricity ("buy back" policy) generated by users, for example the Net Metering System [2], has further encouraged the development of grid-connected PV systems. Besides, the PV panels can be designed as part of the roof structure, replacing the conventional ceramic or concrete-based roof tiles. In view of these advantages, PV is envisaged as a viable economics proposition of the future in India. As the solar energy for domestic application is gaining considerable interest, there have been numerous PV inverter topologies proposed in the literature [3]-[13].

Basically, there are two types of PV inverters, namely the stand-alone PV inverter and the grid-connected PV inverter. In the stand-alone mode, the inverter operates independently of the grid, and is normally equipped with batteries for energy storage. On the other hand, the grid-connected PV inverter operates in parallel with the grid without battery storage. If one were to consider the application of PV for domestic, it is desired that the inverter be able to operate in both operation modes.

System Composition

The system explained in this paper is a standalone system categorized into three individual system:-

1) Generating a dc signal using photovoltaic system
2) Step up of generated dc signal using boost converter.
3) Conversion of dc signal to ac signal using single phase bridge inverter.

The Fig. 1.1 shows a simulink model of PV array

Manuscript received April 5 2012; revised May 3, 2012. This work was supported in part by the Department of Energy, MANIT, Bhopal, India.

Prashant. V. Thakre and Vijay. M. Deshmukh are with the SSBT College of Engineering and Technology, Bambhori, Jalgaon, Maharashtra, India, 425001 (e-mail: pvthakre2006@rediffmail.com, deshvm123@yahoo.co.in).

Saroj Rangnekar is with the Department of Energy, MANIT, Bhopal, India (e-mail: sarojrangnekar@gmail.com).

consisting of 6 pv modules in series. In this model, all module share the same current Ipv . It is assumed that all modules have same insolation of 1000 watt/m^2.The PV module parameters are the short circuit current Isc, open circuit voltage Voc, rated current i.e. PV current at maximum power point and ratedvoltage under standard test condition.

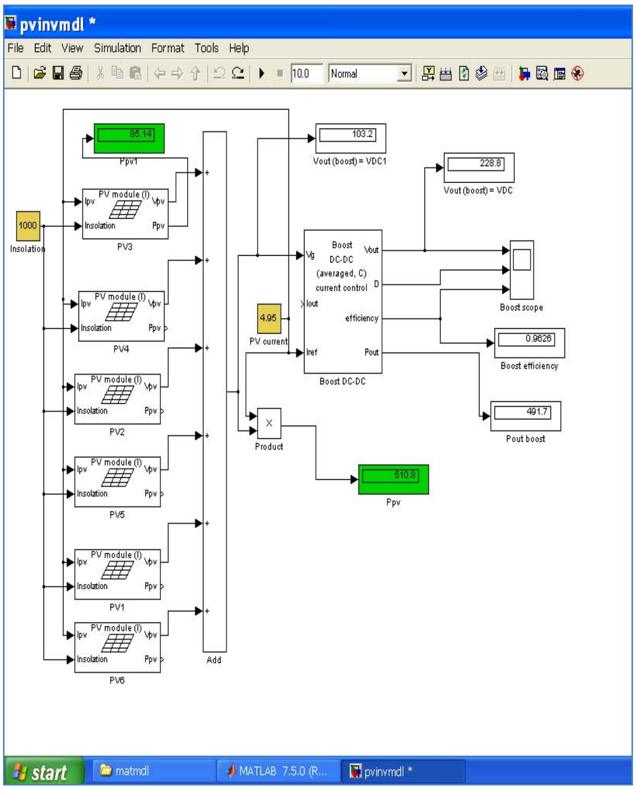


Fig. 1.1. PV model generating dc signal

II. Boost Converter

In boost converter the output voltage is greater than input voltage [3]. In this model a power MOSFET is considered in boost converter as shown in Fig. 1.2

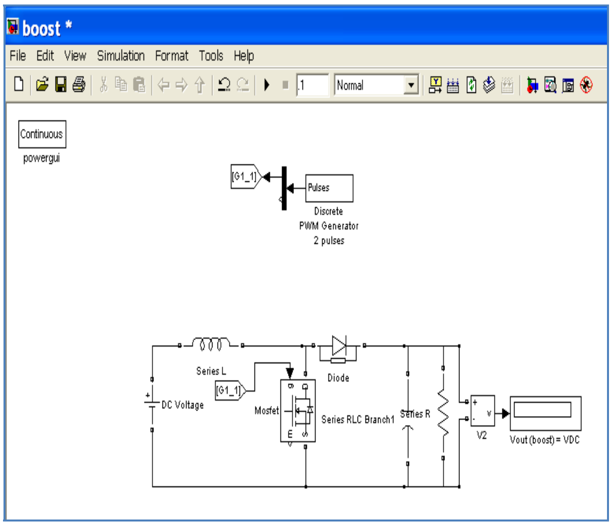


Fig. 1.2. Simulink model for boost converter

The circuit operation can be divided into two modes:-
Mode 1 - When transistor M_1 is switched ON at t=0,
Mode2 - When transistor M_1 is switched OFF at t=t_1.When transistor M_1 is switched ON, the input current rises and flows through inductor L and transistor M_1 as shown in Fig. 1.3

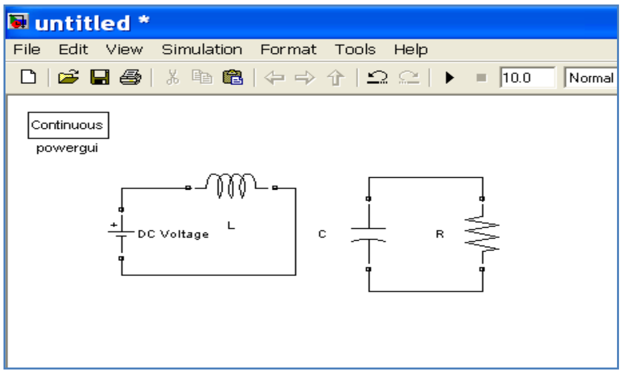


Fig. 1.3. Mode 1 with M1 on

When transistor M_1 is switched OFF, the current flows through L, C, Load and diode D as shown in Fig. 1.4

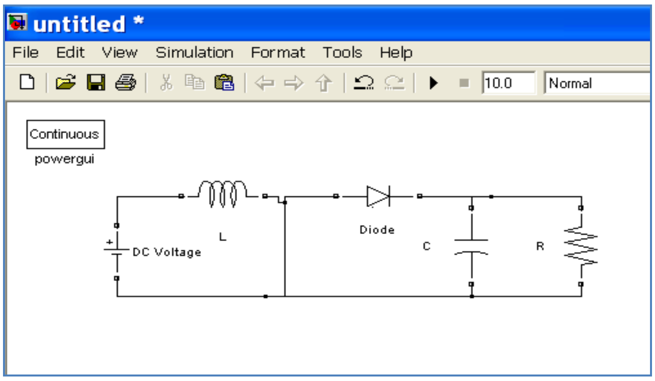


Fig. 1.4. Mode 2 with M1 off

Assuming that inductor current rises linearly from I_1 toI_2 in time t_1 then input voltage V_s is

$$Vs = L.\frac{(I_2 - I_1)}{t_1} = L\frac{\Delta I}{t_1}$$

$$t_1 = L.\frac{\Delta I}{V_s}$$

$$\Delta I = V_s.\frac{t_1}{L} \qquad (1)$$

If inductor current falls linearly from I_2 to I_1 in time t_2 then

$$V_s - V_a = L.\frac{(I_1 - I_2)}{t_2} = -L.\frac{(I_2 - I_1)}{t_2}$$

$$V_s - V_a = -L\frac{\Delta I}{t_2}$$

$$\Delta I = -\frac{(V_s - V_a)}{L}.t_2 \qquad (2)$$

where ΔI is peak to peak ripple current of inductor L and *Va* is average output voltage.
Equating 1 and 2

$$Vs.\frac{t_1}{L} = \frac{(V_a - V_s)}{L}t_2$$

Substituting t_1=*KT* and t_2 =*T* (1-*K*) and solving the equation we get

$$\frac{V_s}{V_a} = (1-K)$$

Assuming lossless circuit i.e $V_a I_a = V_s \cdot \frac{I_a}{(1-K)}$, the average input current is given by

$$I_s = \frac{I_a}{(1-K)}$$

For frequency put $K = \frac{t_1}{T}$

$$t_1 = \frac{(V_a - V_s)}{V_a \cdot f}$$

Thus switching period T can be calculated as

$$T = \frac{1}{f} = t_1 + t_2$$

$$= \Delta I.\frac{L}{V_s} + \frac{L\Delta I}{(V_a - V_s)}$$

$$= \frac{\Delta I.L(V_a - V_s) + \Delta I.L.V_s}{V_s(V_a - V_s)}$$

$$T = \frac{1}{f} = \Delta I.L.\frac{V_a}{V_s(V_a - V_s)}$$

Thus peak to peak ripple current is given by

$$\Delta I = \frac{V_s(V_a - V_s)}{f.L.V_a} = \frac{V_s K}{f.L}$$

When transistor is ON the capacitor supplies load current for $t=t_1$.Thus the average capacitor current during time t_1 is $I_c=I_a$ and peak to peak ripple voltage of capacitor is

$$\Delta V_c = v_c - v_c(t=0)$$

$$= \frac{1}{c}\int_0^{t_1} I_c.dt$$

$$= \frac{1}{c}\int_0^{t_1} I_a.dt = \frac{1}{c}.I_a.t_1$$

$$\Delta V_c = I_a.\frac{t_1}{c}$$

But

$$t_1 = \frac{(V_a - V_s)}{V_a \cdot f}$$

$$\Delta V_c = \frac{I_a(V_a - V_s)}{V_a.f.c}$$

$$\Delta V_c = I_a.\frac{K}{f.c}$$

If I_1 is average inductor current,the inductor ripple current is $\Delta I=2I_1$.

Thus

$$K.\frac{V_s}{f.l} = 2IL = 2I_a = \frac{2V_s}{(1-K)R}$$

The value of inductor is calculated as

$$L_c = L = \frac{K(1-K)R}{2f} \qquad (3)$$

If V_c is the average capacitor voltage, then capacitor ripple voltage $\Delta V_c=2V_a$

Thus

$$2V_a = I_a\frac{K}{f.c} = 2I_a R$$

The value of capacitor is calculated as

$$c = \frac{K}{2fR} \qquad (4)$$

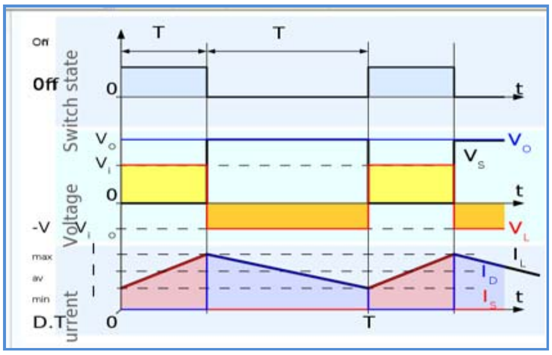


Fig. 1.5. Switching characteristics

III. Inverter Model

The inverter model used is a pulse width modulated inverter shown in Fig 1.6 .In this type of inverter,the input dc voltage is constant in magnitude whereas power device such as IGBT is used to rectify the line voltage[3] . Thus the inverter must control the magnitude and frequency of ac voltages. This is achieved by PWM inverters.The type of PWM switching used in this model is unipolar switching.

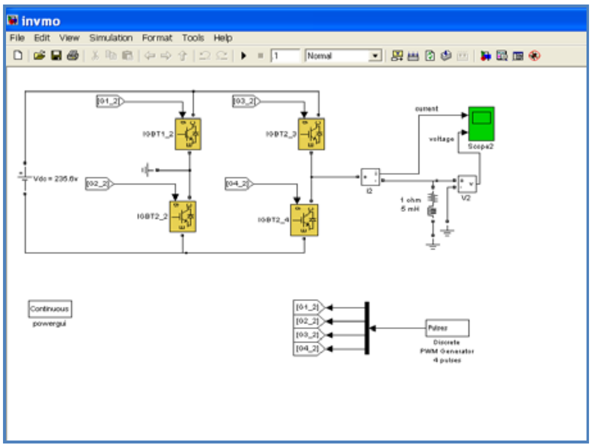


Fig. 1.6. Simulink inverter model

In PWM with unipolar switching, the two legs of full bridge inverter are not switch simultaneously [10]. The legs A and B are controlled separately by comparing the modulating signal (Vmod) with reference signal (Vref).

1) If Vmod > Vref then $G1$is ON and $Vo=Van$
2) If Vmod < Vref then $G2$ is ON and Vo=0
3) If –Vmod > Vref then $G3$ is ON and $Vo=Vbn$
4) If –Vmod < Vref then $G4$ is ON and Vo=0

Vo = *Van* – *Vbn*

Thus *G*1and *G*4 is ON, *Van*=*Vd*, *Vbn*=0 then *Vo* = *Vd*

*G*2 and *G*3 is ON, *Van*=0, *Vbn*=*Vd* then *Vo*=-*Vd*

*G*1 and *G*3 is ON, *Van*=0, *Vbn*=0 then *Vo*=0

*G*2 and *G*4 is ON, *Van*=0, *Vbn*=0 then *Vo*=0

Thus when switching occurs , the output voltage changes between 0 and +Vd as well as 0 and –Vd voltage levels.This is called as unipolar switching.The unipolar switching has advantage of doubling the switching frequency which results in cancellation of harmonics.

IV. Result

1) Analysis of photovoltaic model

Insolation = 1000 w/m^2

Ratings of PV cell (with bypass diode)

Voc = 22.2 volts, *Isc* = 5.45 Amp

Voltage at *P*max =17.2 volts, Current at *P*max = 4.95 Amp

Output dc voltage = 103.2 volts

2) Analysis **of boost converter**

Input dc voltage = 103.2 volts

Inductance (*L*) = 2mH

Load Resistance (*R*l) =2K

Output dc Voltage = 235.6

3) Analysis of Inverter model

PWM Generation:-

Sampling Time = 2µsec

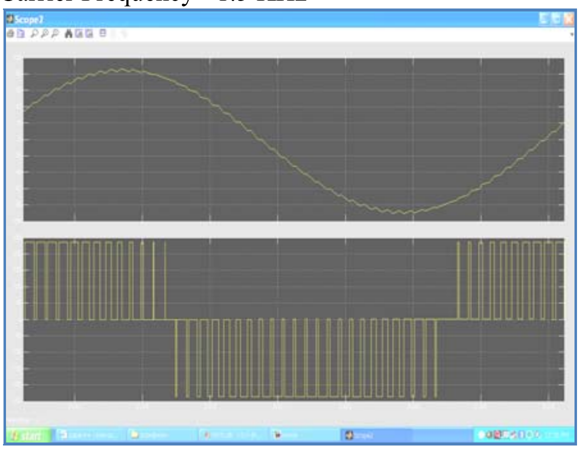
Modulating Signal:- Modulation Index = 0.8

Frequency = 60 Hz

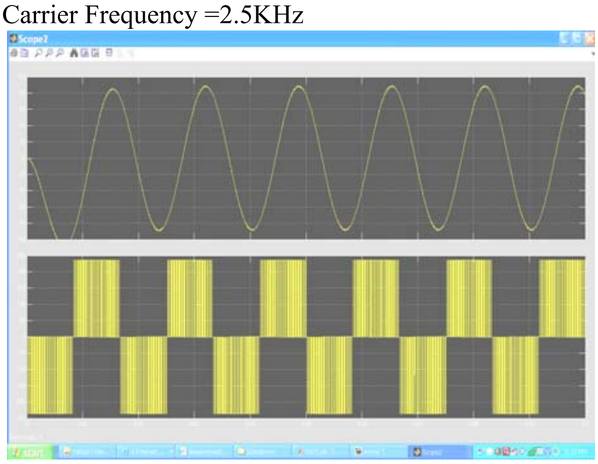
Input dc signal = 235.6

Output Signal:-

Carrier Frequency =1.5 KHz



Carrier Frequency =2.5KHz



Carrier Frequency=10KHz

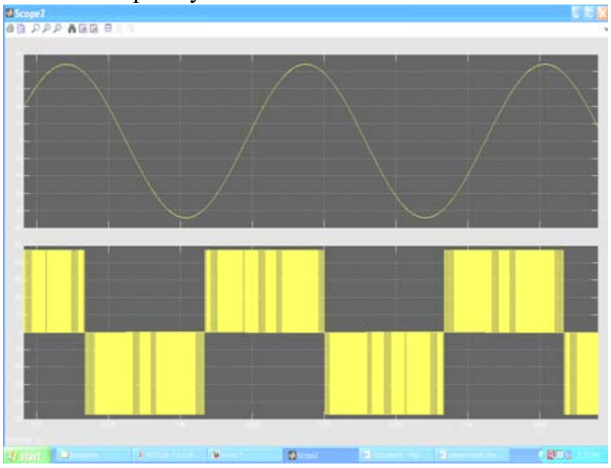


Fig. 1.7. Output ac signal

V. Conclusion

This paper designs a photovoltaic PWM inverter with boost converter. The boost converter is allowed to work in continuous mode and the switching sequence of IGBT inverter is decided by a PWM generator which uses a unipolar switching technique. It has been observed that by increasing the frequency the AC signal can be improved.Further advancement in this model can be done by generating the PWM signals using a DSP processor which gives more flexibility to the designed model.

References

[1] Yuchin qin, Ned Mohan, Rich West, and Rusell Bonn, "Status and needs of power electronics for photovoltaic inverters," *Sandia Report*, Sand pp. 2002-1535, June 002.

[2] *PV group white paper,' the solar PV Land Scape in India – An Industry Perspective*, April 2009

[3] Muhammad. H. Rashid, "Power Electronics- Circuits, Device and Applications," *Third Edition*-2005.

[4] Dezso Sera, Remus Teodorescu, and Tamas Kerekes, "Maximum Power Point Trackers Using a Photovoltaic Array Model with Graphical User Interface," *Institute of energy technology*.

[5] Tamás Kerekes, Dezső Séra, and Remus Teodorescu, "PV inverter control using a TMS320F2812 DSP," *Proceedings*, EDERS 2006, pp51-57.

[6] A. Yafaoui., B. Wu, and R. Cheung, "implementation of maximum power point tracking algo-rithm for residential photovoltaic sys-tems," *2nd Canadian Solar Buildings Conference Calgary,* June 10 – 14, 2007

[7] Giuseppe Fedele and Domenico Franscino, "Spectral analysis of a class of DC-AC PWM inverters by Kepteyn Series" *IEEE Transaction on power electronics*, vol. 25, no. 4, pg.839-849, April 2010.

[8] Hao Zhou, Chawan Tong, Meiqin Mao, and Chan Gao, "Devel-opment of single phase photovoltaic grid connected inverter based on DSP control," *2nd International Symphosium on power electronics for distributed generation system*, pp. no. 650-653, 2010.

[9] Bo Yang, Wuhua Li, Yi Zao, and Xiangning He, "Design and analy-sis of grid connected photovoltaic system," *IEEE transaction on power electronics*, vol. 25, no.4, pp. 992-1000, April 2010.

[10] Zhilei Yao, Lan Xio, and Yanggang Yan, "Seamless Transfer of single phase grid interactive inverters between grid connected and stand alone modes," *IEEE transaction on power electron-ics*, vol. 25, no. 6, pp.1597-1603, June2010.

[11] M. Chael, E. Ropp, and Sigifredo Gonzalez "Development of a MATLAB/simlink model of a single phase grid connected photovoltaic system," *IEEE transaction on Energy conversion*, vol 3, pp. 344-349, 2009.

[12] Hiren Patel and Vivek Agarwal, "A single stage single phase transformerless doubly gronded grid connected PV interface," *IEEE*

transaction on Energy Conversion, vol. 24, no.1, March 2009.
[13] Huan-Liang Tsei, Ci-Siang Tu, and Yi-Jiesu, "Development of generalized photovoltaic model using MATLAB/simulink," *proceedings of the world congress on engineering and com-puter science*,2008,WCECS, san Francisco, USA Oct 2008.
[14] D. Amorndecaphon and S.Prenurudeeppreechacharn, "An im-proved single phase inverter for small PV system using soft switching technique," proceeding of ECTI-CON, 2008.
[15] Feel-Soon Kang, Sung-Jun Park, and Chel-U Kim, "Multilevel PWM inverters suitable for the use of standalone photovol-taic power system," *IEEE transaction on energy conver-sion*, vol. 20. no. 4,Dec2005, pp. 906-915.
[16] Zhao Qinglin, Xu Yunhua, Jin Xiaoyi, and Wu Weiyang, "DSP based closed loop control of bidirectional high frequency link inverter with active clamp," *IAS, IEEE proceedings*, pp. 928-933, 2005.

Dr. Saroj Rangnekar is Professor in the Department of Energy, Energy Centre at Maulana Azad National Institute of Technology, Bhopal, India. She has 33 years of teaching and research experience and received three National awards. She has published 85 papers in various International and National journals, conference proceedings, and participated in International conferences in India, UK, USA and Switzerland.

Prashant.V.Thakre is a Ph.D. research scholar in the Department of Energy at Maulana Azad National Institute of Technology, Bhopal, India and working as Associate Professor in EandTC at SSBT's College of Engineering and Technology, Jalgaon. He has 16 years teaching experience and 08 publications in various National, International conferences and Journals. His research area is photovoltaic inverter.

Vijay M. Deshmukh is working as an Associate Professor in the department of EandTC in SSBT's College of Engg. and Technology, Jalgaon.He has 21 yrs of teaching experience. He has presented research papers in 3 international and 13 national conferences.