Implementation of Digital Signal Controller TMS320C28027 Based PWM for A Single Phase Bidirectional High Frequency Link Photovoltaic Inverter

Prashant V. Thakre[1,*], Saroj Rangnekar[2]

[1]Electronics & Telecommunication, SSBT's COET, Jalgaon, 425001, India (North Maharashtra University)
[2]Department of Energy, MANIT, Bhopal, 462051, India (MANIT,Bhopal)

Abstract   PV grid connected and stand alone systems are becoming more and more popular now a days.With proper tracking system an efficient inverter system can be developed for single phase as well as three phase.This research paper is basically based on the approach that by considering a conventional tracking system a single phase inverter circuit is implemented whose switching is done by using DSP TMS320C28027.

Keywords   photovoltaic panels, boost converter , bridge inverter, unipolar pwm switching, TMS320C28027

1. Introdction

Continuous efforts are being made to reduce green house emission by using alternative sources of energy. Due to which photovoltaic energy is gaining more attention in research field. One of the major area where it is gaining more importance is usage of this energy as an alternative for conventional electrical energy. For generating electrical energy it is necessary to use proper tracking system for harvesting the photovoltaic energy and then using an appropriate inverter for converting the stored DC signal into a proper AC signal with reduction in harmonics. For tracking system the most commonly used technique is MPPT algorithm where maximum power is extracted when the voltage and current is maximum for a photovoltaic panel[1]. Commonly used algorithms include Perturb and Observation method (P&O) and Incremental Conductance method (ICM) [2]. P&O method perturb the solar array voltage in one direction at each sampling period and tests the power change afterwards. The incremental conductance method calculates the derivative of power to get correct direction for perturbing the arrays reference variable[3].

For any type of inverter pulse width modulation is the most powerful technique which offers a convenient method for controlling the analog output generated through digital signal processor. With the availability of low cost high performance digital signal processors, it is easily possible to control the output of single phase photovoltaic inverter by adjusting or controlling the switching frequency or switching time of the power device with altering the PWM signal through digital signal processor. Controlling methods can be broadly classified as current control and voltage control. But both the methods ultimately controls the sinusoidal output generated through inverter circuit[4]. For obtaining a smooth sinusoidal signal with reduced harmonics contents, the duty cycle of the PWM signal is varied .The variation in duty cycle is achieved by implementing a closed loop system where the output current or output voltage is continuously monitored and controlled by digital signal processor according to which switching time of power device is adjusted. This results in a smooth sinusoidal signal with less harmonic contents[5].

This research paper presents a theoretical and experimental approach for implementation of digital signal processor in a single phase bidirectional high frequency link photovoltaic inverter. This proposed method offers an advantage of using a cheaper and effective digital signal processor TMS320C28027 from Texas Instrument for generating PWM signal for a photovoltaic single phase inverter. This method in addition also offers an advantage of doubling the switching frequency of the inverter voltage by using unipolar switching technique, due to which design of output filter becomes easier and also the cost and size is reduced. In addition to the above advantages, if a bidirectional high frequency link photovoltaic closed loop inverter is used, then it provides an additional feature of improving the output signal by reduction in harmonics.

2. Implementation of Tracking System

The most commonly used MPPT algorithm is Purterb and observe method which is more convenient to implement.

P&O method is based on the calculation of PV array output power and the power change by sensing both photovoltaic voltage and current. The tracker operates periodically by comparing the actual detected value of the power with the previous value to determine the change in solar voltage. To achieve such type of perturbations a stepper motor can be implemented which moves as per the step size generated after comparing the present value with previous value. The P&O method can be explained with the algorithm shown in fig.1.1.
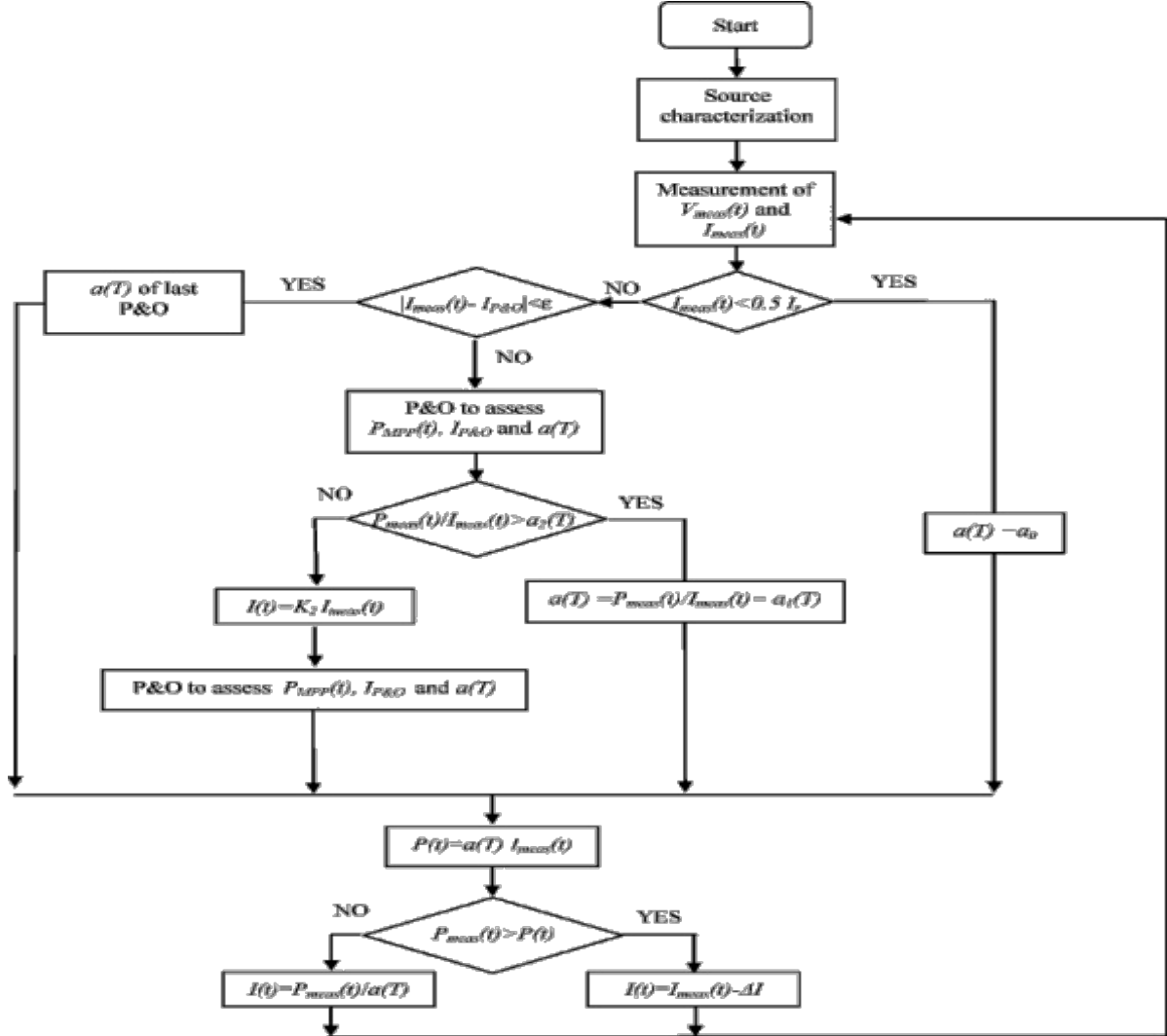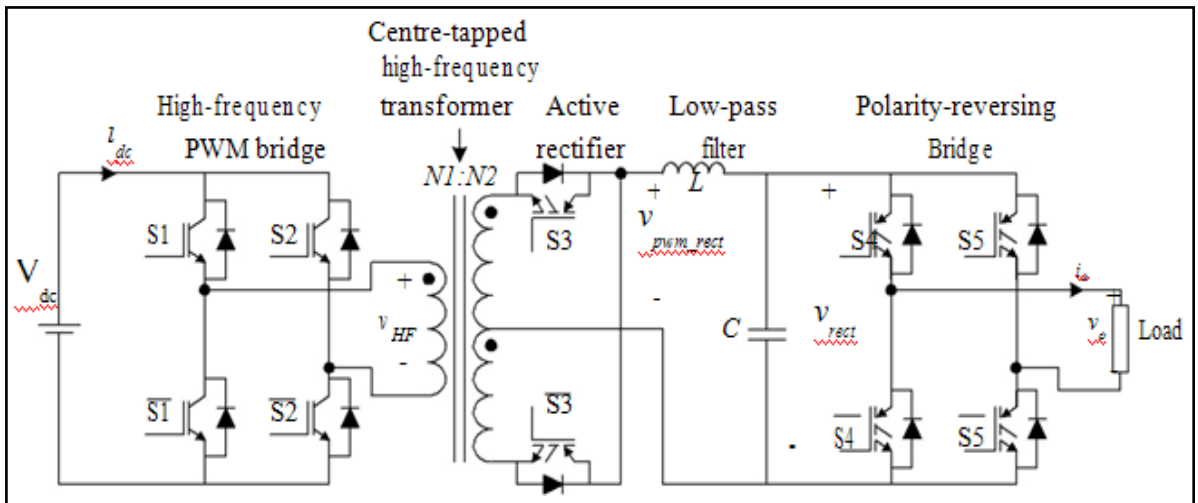

Figure 1.1.

Figure 1.2.

3. Modeling of Closed Loop Inverter

To design a closed-loop controller for the BHFL inverter, a dynamic model of the BHFL inverter is first derived. State-space technique is used to model the inverter.

Referring to Figure 1.2, it is assumed that the dc source voltage, V_{dc} is constant. The inverter switching frequency is considered to be much higher than the 50Hz sinusoidal modulating frequency. The high-frequency transformer is assumed to be operating in the linear area. As such, the high-frequency PWM bridge and the transformer can be modeled as constant gains. The polarity-reversing bridge is only operated at line-frequency (50Hz), thus its dynamics can be ignored. With these assumptions, the dynamics of the system can be simplified to a *LC* low-pass filter connected to the load. Figure 1.3 depicts the equivalent circuit of the BHFL inverter, where *u* is the system input (control variable), and *Z* denotes the output impedance of an unknown load. The Equivalent Series Resistance (ESR) of the filter inductor is denoted as r_L, and the ESR of the filter capacitor is denoted as r_c.
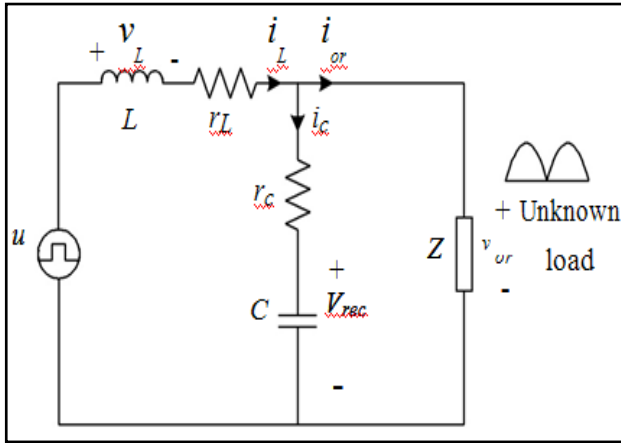

Figure 1.3.

By ignoring the polarity-reversing bridge, the rectified sinusoidal output voltage, v_{or} is obtained. Choosing the filter inductor current i_L and filter capacitor voltage v_{rect} as the state variables, the state-space representation and output equation of the system is given by

$$\frac{di_l}{dt} = -\frac{1}{L}(r_l + r_c)i_l - \frac{1}{L}V_{rect} + \frac{1}{L}v + \frac{r_c}{L}i_{or} \quad [1]$$

$$\frac{dv_{rect}}{dt} = \frac{1}{c}i_l - \frac{1}{c}i_{or} \quad [2]$$

Also

$$v_{or} = r_c i_l + v_{rect} - r_c i_{or} \quad [3]$$

Equation 1 & 2 can be represented in matrix form as

$$\begin{bmatrix} \frac{di_l}{dt} \\ \frac{dv_{rect}}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{L}(r_l + r_c) & -\frac{1}{L} \\ \frac{1}{c} & 0 \end{bmatrix} \begin{bmatrix} i_l \\ v_{rect} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} v + \begin{bmatrix} \frac{r_c}{L} \\ -1 \\ \frac{}{c} \end{bmatrix} i_{or} \ [4]$$

Also equation 3 can be expressed as

$$v_{or} = [r_c \quad 1] \begin{bmatrix} i_l \\ v_{rect} \end{bmatrix} + [-r_c]i_{or} \quad [5]$$

the values of r_l & r_c are assumed to be very small & can be neglected .Thus equation 4 & 5 becomes

$$\begin{bmatrix} \frac{di_l}{dt} \\ \frac{dv_{rect}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{c} & 0 \end{bmatrix} \begin{bmatrix} i_l \\ v_{rect} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} v + \begin{bmatrix} 0 \\ -1 \\ \frac{}{c} \end{bmatrix} i_{or} \quad [6]$$

$$v_{or} = [0 \quad 1] \begin{bmatrix} i_l \\ v_{rect} \end{bmatrix} \quad [7]$$

Based on the equation a dynamic model of the system is represented by block diagram as shown in Fig. 1.4
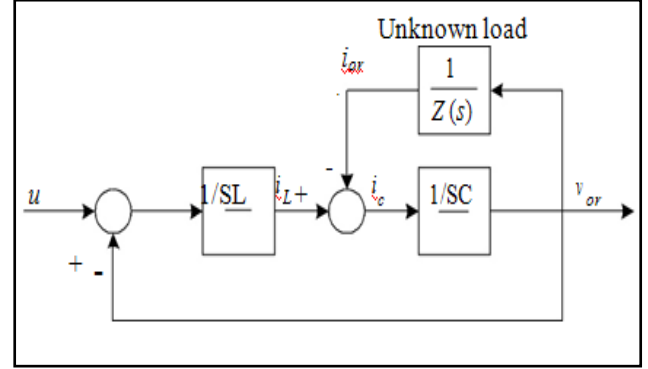

Figure 1.4.

Since the controller is to be implemented using a digital processor, the continuous time space equation are discretised. The discrete time state space equations with sampling period of T_s can be represented as

$$x(k + 1) = Ax(k) + Bu(k) + B_d i_{or}(k) \quad [8]$$

$$v_{or}(k) = Cx(k) \quad [9]$$

Where

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} = \begin{bmatrix} \cos(wT_s) & -\frac{1}{wL}\sin(wT_s) \\ \frac{1}{wc}\sin(wT_s) & \cos(wT_s) \end{bmatrix}$$

$$B = \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{wL}\sin(wT_s) \\ 1 - \cos(wT_s) \end{bmatrix}$$

$$B_d = \begin{bmatrix} B_{d_1} \\ B_{d_2} \end{bmatrix} = \begin{bmatrix} 1 - \cos(wT_s) \\ -\frac{1}{wC}\sin(wT_s) \end{bmatrix}$$

$$C = [0 \quad 1]$$

$x(k) = \begin{bmatrix} i_l(k) \\ V_{rect}(k) \end{bmatrix}$ is the state vector & $w = \frac{1}{\sqrt{LC}}$ is the cut off frequency of the low pass filter in radians/second.

From equation 8 and 9, the discrete time equation can be rewritten as:

$$u(k) = \frac{1}{B_1}i_L(k+1) - \frac{A_{11}}{B_1}i(k) - \frac{A_{12}}{B_1}V_{or}(k) - \frac{B_{d_1}}{B_1}i_{or}(k)[10]$$

$$i_L(k) = \frac{1}{A_{21}}V_{or}(k+1) - \frac{A_{22}}{A_{21}}V_{or}(k) - \frac{B_2}{A_{21}}v(k) - \frac{B_{d_2}}{A_{21}}i_{or}(k)[11]$$

From equation 10 and 11, it is observed that additional disturbance terms appear because of modal discretisation .As compared with continuous time modal shown in fig ---, there exist two disturbance instead of one,acting on inductor current and output voltage.

The current & voltage disturbances can be represented by the eqation,

$$i_d(k) = -\frac{A_{12}}{B_1}V_{or}(k) - \frac{B_{d_1}}{B_1}i_{or}(k) \quad [12]$$

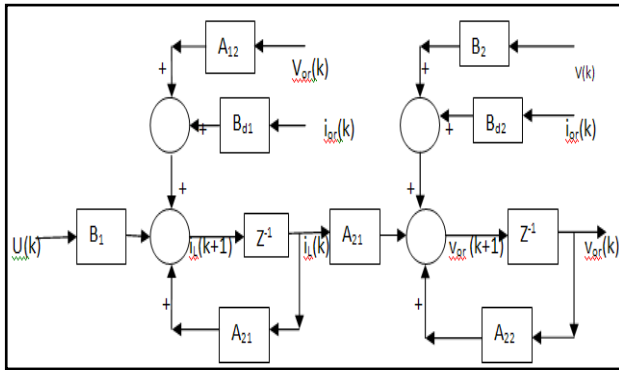$$V_d(k) = -\frac{B_2}{A_{21}}v(k) - \frac{B_{d_2}}{A_{21}}i_{or}(k) \quad [13]$$

Figure 1.5.

Based on the above equations the digital model can be represented by a block diagram as shown in figure 1.5 where

Z^{-1} is unit delay.

4. System Implementation

Generating DC signal using MPPT system:-

Based on the above theory a tracking system has been developed by using MATLAB/simulink as shown in figure 1.6

The figure shows a simulink model of a PV array consisting of 6 PV modules in series.In this model all module share equal current I_{pv} .It is assumed that all modules have same insolation of 1000 watt/m^2.The pv module parameters are the short circuit current I_{sc} and open circuit voltage V_{oc} as well as rated current at maximum power point and rated voltage at standard test condition.
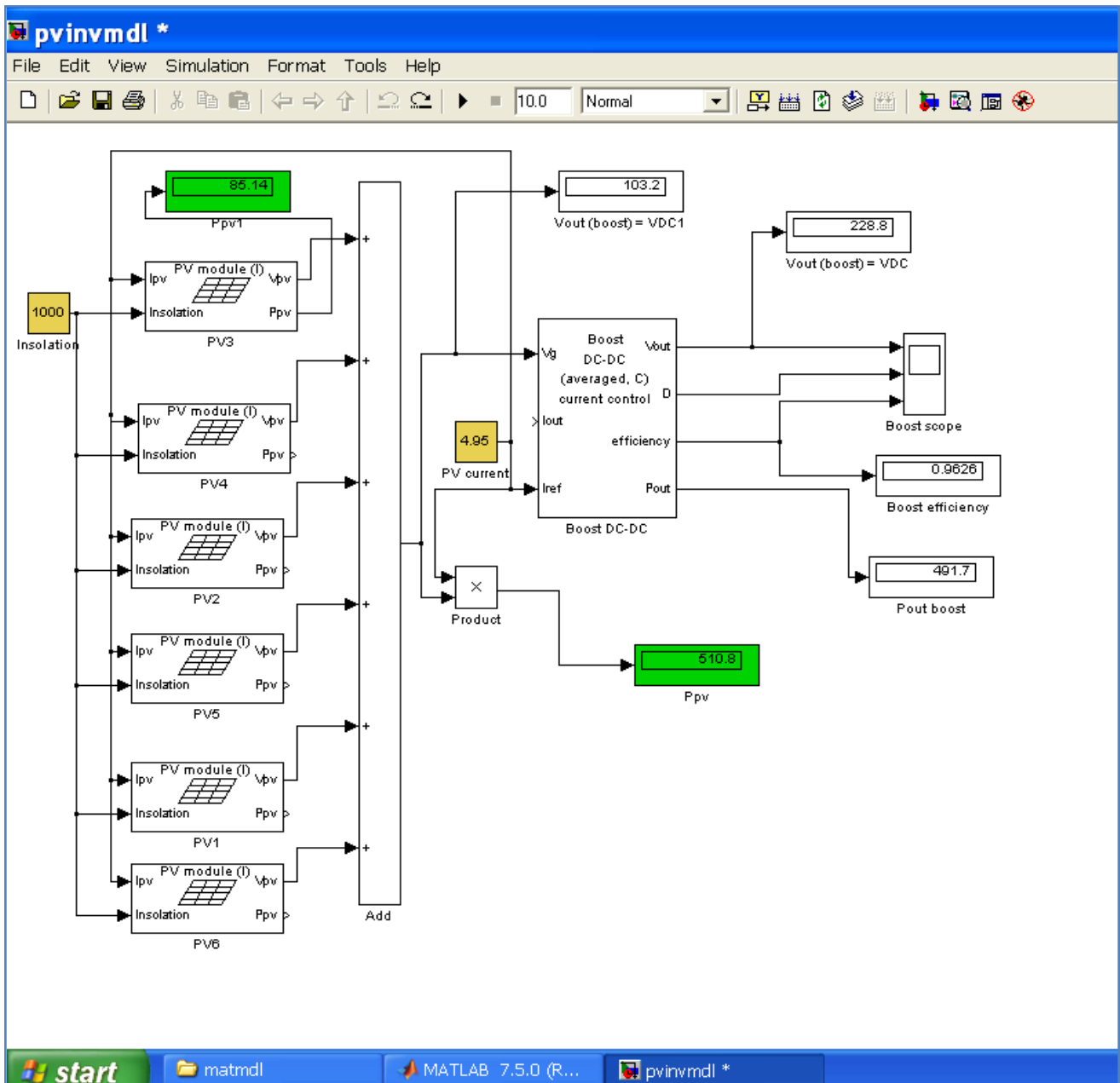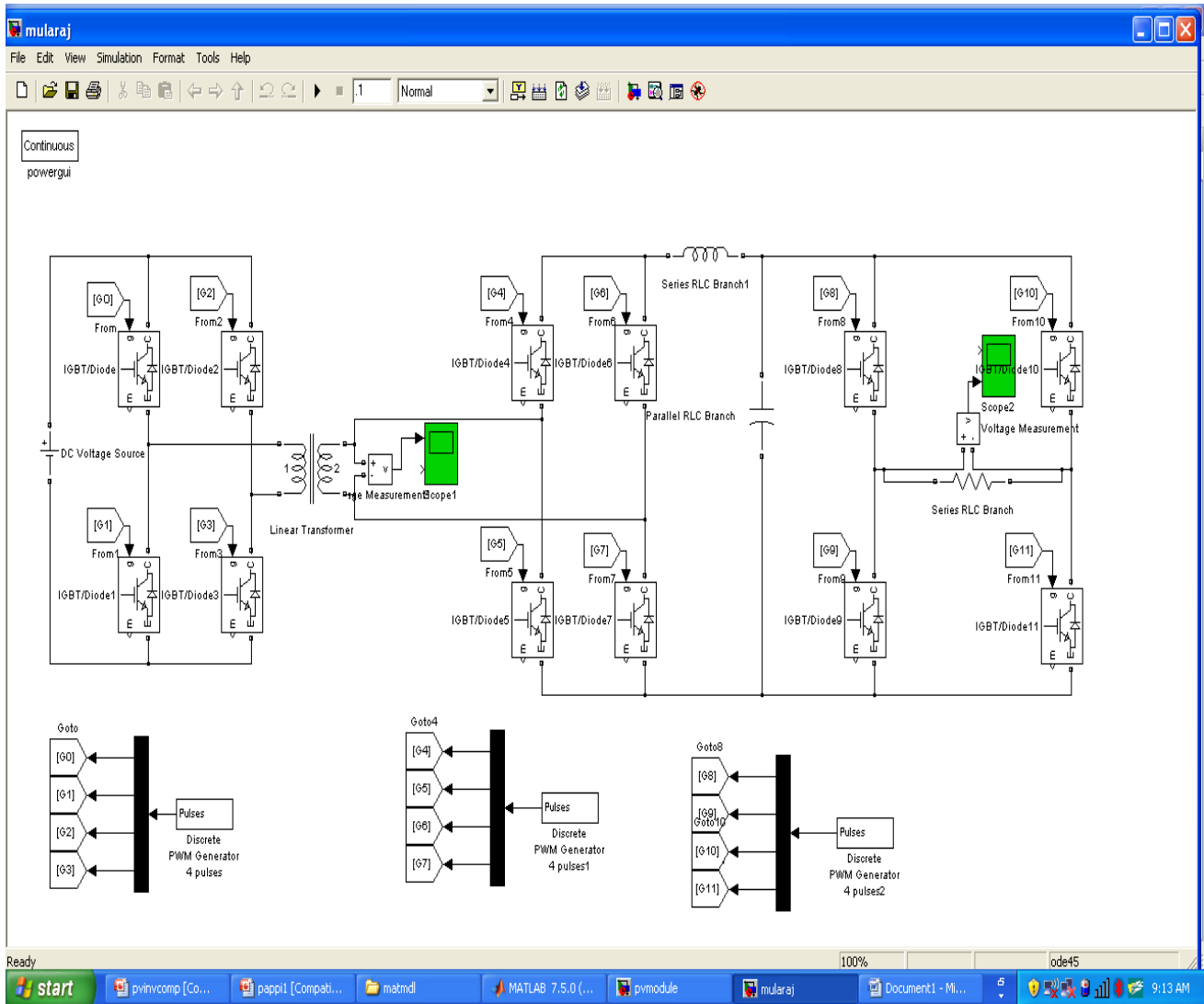

Figure 1.6.

Figure 1.7.

5. Generation of PWM Signal Using TMS320c28027

Generation of PWM signal is based on the performance of digital signal processor. For this, processor TMS320C28027 of Texas Instrument has been selected. It is a piccolo series processor which is coupled with highly integrated control peripherals in low pin count devices. It is a high efficiency processor with 32 bit CPU and having frequency of 60MHz, 50MHz and 40MHz respectively. It is also having ON-Chip flash, SARAM and OTP memory. It consists of analog comparators with 10 bit reference and can be routed directly to control PWM outputs.This processor is also cheaper and easy to implement.Generation of PWM signal is based on implementation of algorithm, preparing of source code in C or C++ and compiling,building and running the source code in code composer studio.

The version used for code composer studio is 3.1 and the PWM signal has been generated at 8 GPIO pins i.e from GPIO0 to GPIO7 by continuously comparing the output voltage or current received by inbuilt ADC. The PWM sig-nals generated from GPIO pins are applied to the IGBT's of inverter circuit through a driver circuit.

6. Modeling of BHFL Inverter Using MATLAB/Simlink

The inverter model used for simulation is a pulse width modulated inverter as shown in Fig.6. In such type of in-verter, the input DC voltage from a solar tracker or battery which is constant in magnitude, is applied to the inverter circuit. The inverter circuit consists of switching devices such as IGBT, MOSFET which rectifies the output voltage.

Thus the inverter must control the magnitude and fre-quency of the generated AC signal. This is achieved by using pwm technique. The type of switching used in model is unipolar switching. In pwm with unipolar switching, the two legs of full bridge inverter are not switched simultaneously. The two legs are controlled separately by comparing the modulating signal (Vmod) and carrier signal (Vref).

1. If Vmod > Vref then G1is 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 G1 and G4 is ON, Van=Vd,Vbn=0 then Vo = Vd
G2 and G3 is ON, Van=0, Vbn=Vd then Vo=-Vd
G1 and G3 is ON, Van=0, Vbn=0 then Vo=0
G2 and G4 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.

7. Simulation Result

The performance of photovoltaic inverter was tested using MATLAB and the output signal was observed with different carrier frequencies as shown in fig 1.8(a),(b) and (c).

7.1. Analysis of Photovoltaic Model

Insolation = 1000 w/m^2
Ratings of PV cell (with bypass diode)
Voc= 22.2 volts, Isc = 5.45Amp
Voltage at Pmax =17.2 volts, Current at Pmax = 4.95 Amp
Output dc voltage = 103.2 volts

7.2. Analysis of Boost Converter

Input dc voltage = 103.2 volts
Inductance (L) = 2mH
Load Resistance (Rl) =2K
Output dc Voltage = 235.6

7.3. Analysis of Inverter Model

PWM Generation: -
Sampling Time = 2μsec
Modulating Signal: - Modulation Index = 0.8
Frequency = 60 Hz
Input dc signal = 235.6

8. Output Signal

Carrier Frequency =1.5 KHz

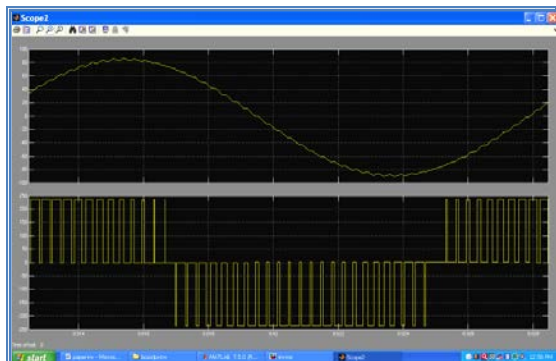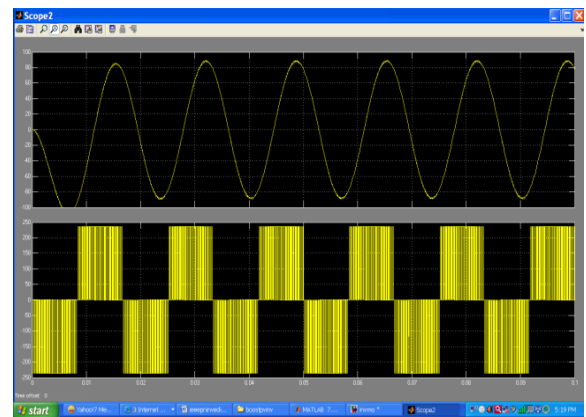**Figure 1.8(a)**.

Carrier Frequency =2.5 KHz
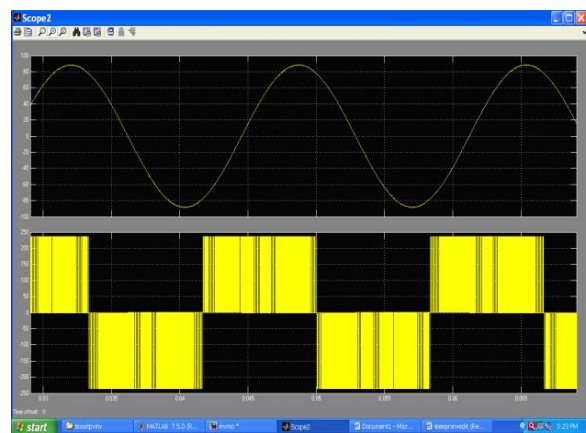

Figure 1.8(b).

Carrier Frequency=10 KHz

Figure 1.8(c).

9. Hardware Implementation

A photovoltaic bidirectional link inverter was implemented using a solar tracker .An inverter circuit with a filter, driver circuit with processor tms320c28027 was developed and tested with a conventional solar tracker.The specification of hardware is as follows:-
Specification of PV module
Model – SLP5-12, Rated Power :- 5watt
Rated Voltage: -17volt,Rated Current: -0.29 Amp
O.C voltage: - 21.6 volts,S.C current: - 0.34 Amp
Standered Test Condition – 1000watt/m^2
Battery specification
Microtek: - 12 volt, 7.2 Ah
Inverter circuit specification
IGBT Driver: - TLP 250
IGBT: - G4PC60U
Filter Circuit: - Inductor-10mH, Resistance – 22 ohms, Capacitor – 22 microfarad

A solar tracker as shown in Fig.1.9 was designed to charge a 12 volt, 7 amp battery. The solar tracker was able to track the sun from east to west based on the LDR circuit by rotating the PV module with 22.5 degree at every 3 hours to get maximum power.
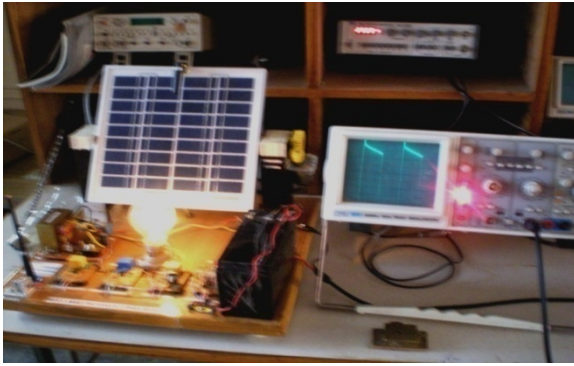
Figure 1.9.

A bidirectional high frequency link inverter was developed with the given specification in order to achieve relatively small size, light weight and high efficiency inverter circuit as shown in fig.1.10
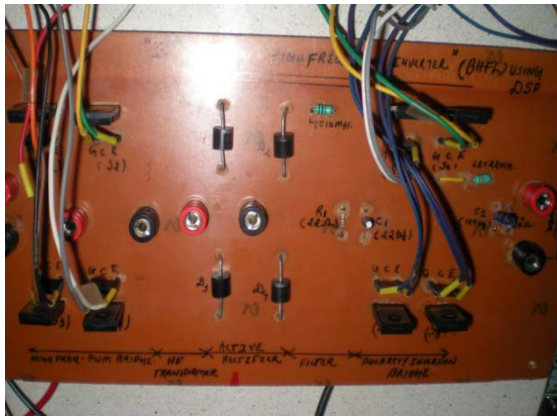

Figure 1.10.

For switching of the IGBT's a driver circuit based on TLP250 was used with processor TMS320C28027 as shown in Fig.1.11 and the output signal was observed.
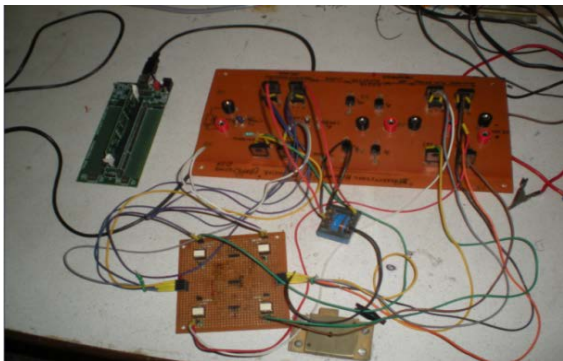

Figure 1.11.

10. Output Signals Observed

PWM Signal: -

PWM signal for switching of IGBT was generated from a driver circuit consisting of IC TLP250. The input to driver circuit was given from the GPIO 1 to GPIO4 pins of processor TMS320C28027. The PWM signal through TMS320C28027 was generated by loading,debugging and building the program in code composer studio (version 3.1). The PWM signal generated is shown in fig.1.12.
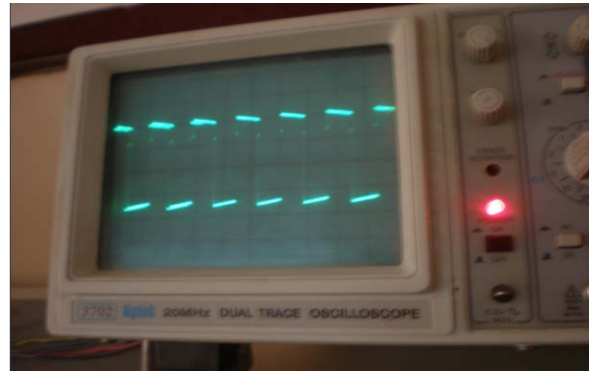

Figure 1.12.

Finally the generated PWM signals were applied to the IGBT's of the inverter circuit and the output AC signal was observed at the output of filter circuit. The fig.1.13 shows the generated AC signal.
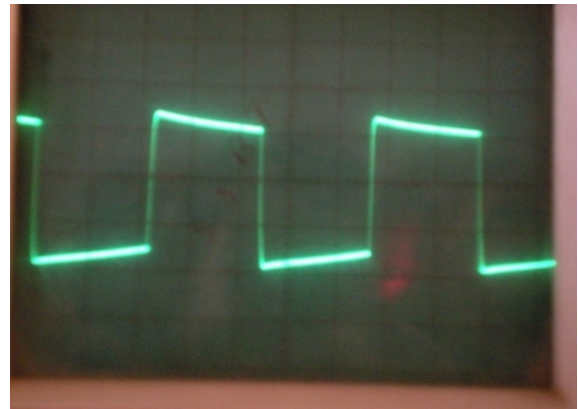

Figure 1.13.

11. Conclusions

This paper presents the simulation and hardware of a single phase photovoltaic BHFL inverter using TMS320C28027 control. It is observed in simulation that with the increase in frequencies the nature of the ac signal can be improved. Further, the implementation of TMS320C28027 processor makes the inverter more flexible due to its real time analysis. Also by considering a conventional photovoltaic tracking system maximum power can be extracted.

REFERENCES

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

[2] Tamás Kerekes, Dezső Séra, Remus Teodorescu 'PV inverter control using a TMS320F2812 DSP', Proceedings, EDERS2006, 51-57.

[3] A. Yafaoui., B. Wu and R. Cheung, **"IMPLEMENTATION OF MAXIMUM POWER POINT TRACKING ALGORITHM FOR RESIDENTIAL PHOTOVOLTAIC SYSTEMS"**, 2nd Canadian Solar Buildings Conference Calgary, June 10 – 14, 2007

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

[5] www.ti.com

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

[7] Bo Yang,Wuhua Li,Yi Zao,Xiangning He, "Design & analysis of grid connected photovoltaic system" IEEE transaction on power electronics,vol.25,no.4,April 2010,pg.992-1000.

[8] Zhilei Yao,Lan Xio,Yanggang Yan, "Seamless Transfer of single phase grid interactive inverters between grid connected & stand alone modes" IEEE transaction on power electronics,vol. 25,No. 6,June2010, pg.1597-1603.

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

[10] Hiren Patel, Vivek Agarwal, "A single stage single phase transformerless doubly gronded grid connected PV interface", IEEE transaction on Energy Conversion. Volume-24, no.1, march 2009.

[11] Huan-Liang Tsei,Ci-Siang Tu,Yi-Jiesu, "Development of generalized photovoltaic model using MATLAB/simulink", proceedings of the world congress on engineering & computer science,2008,WCECS,oct2008,san Francisco,USA.

[12] D.Amorndecaphon & S.Prenurudeeppreechacharn, "An improved single phase inverter for small PV system using soft switching technique,proceeding of ECTI-CON2008.

[13] Feel-Soon Kang,Sung-Jun Park,Chel-U Kim, "Multilevel PWM inverters suitable for the use of stand alone photovoltaic power system.",IEEE transaction on energy conversion,vol.20.no. 4,Dec2005,pg 906-915.

[14] Zhao Qinglin,Xu Yunhua,Jin Xiaoyi,Wu Weiyang, "DSP based closed loop control of bidirectional high frequency link inverter with active clamp",IAS 2005,IEEE proceedings,pg. -928-933.

[15] Ovidiu pop,Gabrel Chindris,Andri Dulf, "using DSP technology for true sine PWM inverters",27th International Spring Seminar on Electronics Technology,2004,IEEE,pg 141-146.

[16] T.J.Liang,J.F.Chen,C.A.Cheng, "Study and implementation of DSP based photovoltaic energy conversion system",IEEE proceedings ,PEDS2001,pg 807-810.

[17] Mohan, Undeland, Riobbins'Power Electronics-Converters, Applications & Designs' Media Enhanced Third Edition, Wiley-India Edition,2008