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FPGA implementation of DPWM utility/DG interfaced solar (PV) power converter for green home power supply

SHIVA NAND SINGH and SNEHLATA MISHRA

In this paper, utility/DG interfaced DPWM solar (PV) power converter (SPC) has been proposed and developed to meet the growing green energy demand of household applications in a developing country like India. The use of new software based direct PWM strategy (DPWM) in the inverter circuit has resulted in to produce a very near sine-wave, most suitable for various home loads. Simulated results of proposed PWM output wave form and computation of its harmonics content in terms of THD value (upto 5% or even less) using MATLAB software has been reflected in the proposed scheme. The features like an intelligent control action to prevent battery from overcharge or undercharge, higher efficiency (> 90%), generation of grid quality green electricity, sustainability of solar renewable energy sources, cost effective hardware realization with FPGA based VLSI embedded system, shows the superiority of the proposed scheme over conventional power supply systems.

Key words: direct pulse width modulation (DPWM), total harmonic distortion (THD), field SMF: sealed maintenance, free programmable gate array (FPGA).

1. Introduction

A developing country like India is facing acute shortage of grid power specially in rural and suburban sectors due to various technical constraints and economic reasons. DG sets are being used to supplement the existing grid power sources. The use of DG set is not only polluting the environment due to noise pollution and emission of hazardous gasses like CO_2 etc but also becomes a costly affair, as it requires a huge consumption of diesel fuel and regular maintenance. The need has been felt to develop a technology to use non-conventional energy sources like solar, wind, biogas, fuel cell etc as alternative or supplementary source(s) to generate green power electricity [1,2, 3, 4].

In the proposed project study, a sustainable freely available solar energy source has been used and an integrated solar power converter (SPC) has been developed to work with or without grid/DG to deliver a PWM modulated sinusoidal ac power for home

The authors are with National Institute of Technology - Jamshedpur(India) 831014, e-mails: snsnitjsr@gmail.com, snehlatamsr12@gmail.com

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loads. The use of DPWM and its implementation by software based FPGA system add more flexibility in the optimal operation of system and easy transfer of technology in an embedded chip resulting in cost effectiveness. The operation of DG, used as a standby source in this scheme, has been minimized with the use of SPC by intelligent control and thus producing pollution free green power supply.

2. System configuration

The system configuration comprises of solar panel, bi-directional converter module, controller, energy storage device (i.e Battery B1/B2) etc as shown in Fig. 1 and 2. The converter works in two mode of its operation i.e inverter and rectifier.

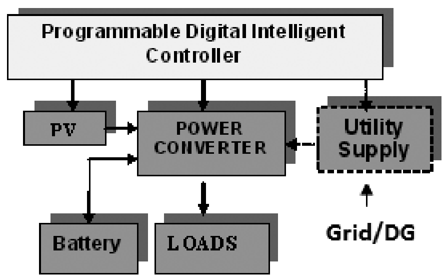

Figure 1. Block diagram of utility (grid/DG) integrated solar power converter model.

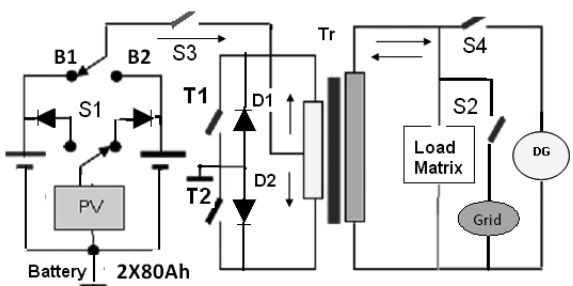

Figure 2. Circuit diagram of power module of solar bi-directional power converter.

The novel DPWM technique used with variable number of PWM pulses(i.e $N = 3 \dots 9$) in the inverter system produces approximated sine wave resulting in THD value ranging from 12% to 2%. The algorithm developed [1,9,10] for generation of PWM pulses approximating sinusoidal wave is expressed by the following equation:

$$\text{Pulse Width}(Pi) = K\left(\frac{180}{2N}\right)2\sin\frac{(2i-1)\pi}{2N} \tag{1}$$

where

$i = 1, 2, \ldots, N$ is the number of PWM pulses approximating sinusoidal modulated wave in each half cycle of AC wave form,

K is the voltage regulating factor (0 – 1).

The simulation of sinusoidal PWM representative waveform containing three PWM pulses (i.e $N = 3$) using MATLAB program is shown in Fig. 3 and Fig. 4.

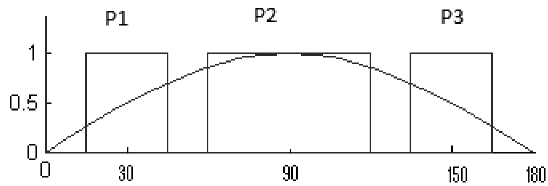

Figure 3. DPWM sinusoidal waveform for $N = 3$ $(P1, \ldots, P3)$ number of pulses.

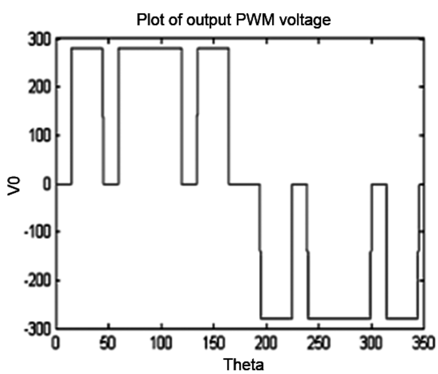

Figure 4. MATLAB produced simulated PWM AC waveform for $N = 3$.

3. Solar power converter module

The power converter module convert solar energy by PV module, stored in battery of 12 V DC to 220 V PWM AC output power to load. The power semiconductor devices like BJTs or MOSFETs, connected in a centre tap push-pull configured inverter unit, are made on and off alternatively for a duration of 10ms each in both the half cycle producing a PWM sine wave of 220V, 50Hz AC power as shown in Fig. 2. The battery of 12 V is normally charged from solar (PV) cell during day time (sun radiation/insolation period only) and store it in one of battery bank (i.e B1 or B2). The other battery (i.e B2 or B1) is used to deliver power to load(s) through DPDT switch S1 and ON/OFF switch S3. Thus sustainability in delivery of supply for 24×7 days [5] is maintained. This energy is utilized to meet the per day critical load power requirement of house and balance base/or peak loads are powered through grid/DG (standby) supply through S2 and S4 switches respectively. The battery also gets charged through D1 and D2 in its rectifier mode (while T1 and T2 remain off) from grid/DG when the voltage of battery fall below the cut-off discharge value i.e 10.4V and stops getting its charge beyond its upper cutoff limit i.e 13.4V. Thus the battery is protected from damage due to under charge or overcharge. During this period load power is also drawn from grid or in absence of grid from DG unit. The output PWM AC voltage 220V, 50Hz is obtained through step up transformer (Tr) by switching the transistors T1 and T2 on and off by PWM base drive pulses alternatively with positive as well as negative group of PWM base drive pulses in two of its control mode of operations.

Mode of push-pull operations are as follows:

1. T1 is on, T2 is off, output + VDC, +ve half PWM $(N = 3)$ AC sine wave (10 ms),
2. T2 is on, T1 is off, Ooutput - VDC, -ve half PWM $(N = 3)$ AC sine wave (10ms).

Figure 5. Prototype unit of solar power converter SPC LAB module.

4. Hardware implementation with FPGA embedded system

A prototype unit of 300W power converter (Fig. 5) with solar (PV) module (75Wp) and battery (2x80Ah = 150Ah) was developed and test has been performed on load(s) against energy requirement of 1200-1800Wh per day to validate the simulated result. The circuit implementation has been done through program developed in VHDL code. The simulation of coded programme is done with Xilinx inbuilt ISI simulator or model-Sim simulator. The simulated representative PWM pulses constituting AC wave on averaging with $N = 3$ PWM pulses (Fig. 6), its generation through Xilinx based FPGA hardware module spartan 3E (Fig. 7) and the corresponding load waveforms are shown in Fig. 8.

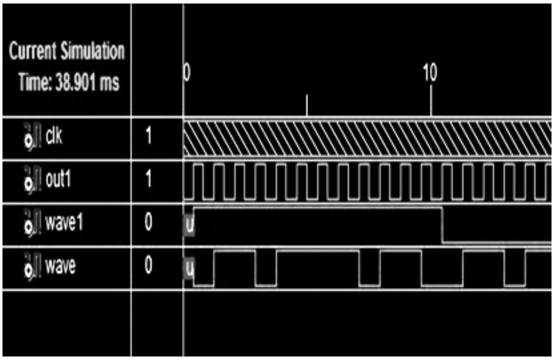

Figure 6. PWM Xilinx simulated waveform for $N = 3$.

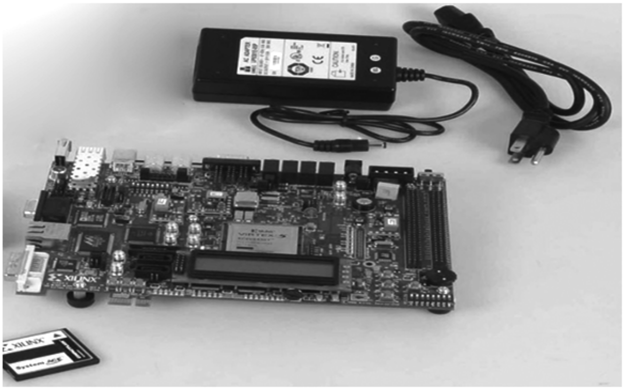

Figure 7. FPGA Spartan 3E board.

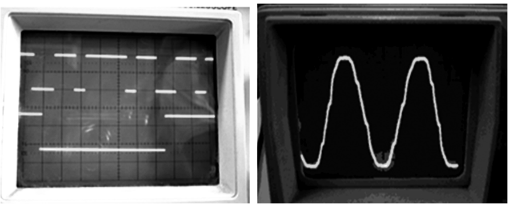

Figure 8. PWM control pulses generated by FPGA Board(left) and load waveform (220V, 50Hz) (right).

5. Performance of system parameters

The performance tests have been carried out on few system parameters such as efficiency and harmonics content in terms of THD value (%) for $N = 3$ (17%) to $N = 9$ (2%) as shown in Fig. 9 and Fig. 10, respectively. The use of DPWM strategy and elimination of lower order harmonics content in the output waveform, as analyzed by MATLAB program, shows grid quality power outlet by the system under study.

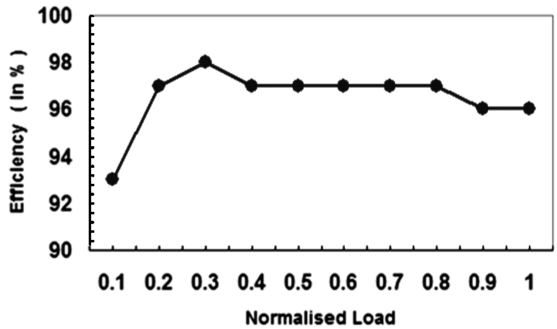

Figure 9. Efficiency of the inverter.

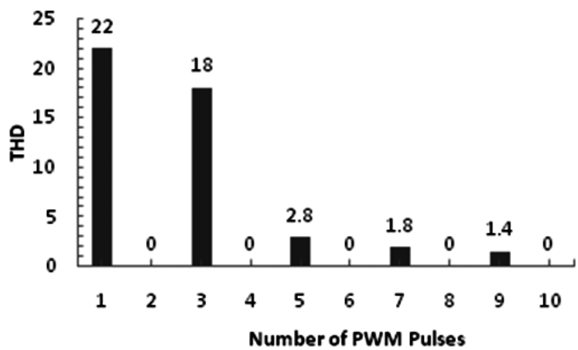

Figure 10. Harmonics content (THD) analysis of output PWM voltage waveform.

Table 1. Estimated cost of PV Power supply system (1200 -1800 Wh per day)

Accessories/Module	Rating	Approximate Cost (Rs)
Solar(PV) Panel	75Wp	7,500
Inverter	300W	2,000
Battery(SMF)	2×80Ah	10,000
	Total	19,500

6. Working economy

The approximate cost of solar generator for home power supply is estimated and shown in Table 1.

Table 2. Estimated cost of PV Power supply system (1200 -1800 Wh per day)

Month	Utilization of sources (Operational Time)			% saving by PV
	Grid	Dg	PV	
January	45%	5%	50%	50%
February	44%	4%	52%	52%
March	40%	6%	54%	54%
April	40%	10%	50%	50%
May	45%	5%	50%	50%
June	40%	9%	51%	51%
July	41%	7%	52%	52%
August	35%	5%	60%	60%
September	40%	5%	55%	55%
October	42%	6%	52%	52%
November	45%	5%	50%	50%
December	40%	6%	54%	54%

In our country, Ministry of Non Conventional Energy Sources (Government of India) is taking initiative through state renewable energy development authority to distribute solar PV panel at subsidized rate from time to time. These are made available from the Block Development Offices of each districts of state of the country or through NGOs [7].

7. Grid/DG power savings

A case study has been taken to compute the operational time of different sources of solar power converter (SPC) installed at a rural area located near Jamshedpur (India) city and the result has been reflected in Table 2. It depicts the daily average % of solar (PV) power sharing during the grid off period computed over a period of 12 months of one year. From Tab. 2, it is evident that due to high % of sharing by PV power, solar power converter has optimally limited the operational on time of DG set to a value not more than 6% on an average.

Figure 11. Power saving observation of SPC installed at a tailoring house located in rural sector of Jamshed-pur city.

8. Conclusion

A utility/DG integrated solar power converter has been developed for home load of 300W but due to flexibility it can be scaled to higher power requirement. The grid power integration with PV sources resulted in consistency in the availability of power. The DG operation has been minimized and thus attempt has been made to generate green power supply for household application. The PWM wave form generation using DPWM strategy and its implementation on an FPGA based VLSI embedded system chip will be a cost effective over other existing converter systems. The features like grid quality (i.e low THD value upto 5% or even less) PWM AC waveform, power saving due to minimization of DG operation, pollution free green power supply etc., show superiority of the system over other descript as well as microprocessor based conventional power supply systems. The system may find its application(s) in the following areas such as [6,8]:

- home power including hawkers/restaurant supply,
- hospital/medical home power supply,
- telecommunication Wi-Fi power supply,
- computer, laptop and UPS,
- industrial instrumentation and control systems, etc.

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