International Journal of Applied Power Engineering (IJAPE)
Vol. 1, No. 2, August 2012, pp. 87~92
ISSN: 2252-8792

Design and Development of Power Electronic Controller for Grid-Connected PV Array

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Article Info

Article history:

Received May 20, 2012
Revised Aug 20, 2012
Accepted Aug 26, 2012

Keyword:

Boost converter
Line commutated inverter
Maximum power point tracking
PI controller

ABSTRACT

Design and simulation of a simple power electronic interface for grid-connected PV array has been proposed using boost converter and line-commutated inverter with maximum power point tracking (MPPT) controller. The output of PV array varies with irradiation, and hence the duty cycle of the PI controller is adjusted automatically to supply a constant DC voltage to the inverter circuit, the output of which is directly connected to the grid. The MPPT controller extracts maximum power from the solar array and feeds it to the single-phase utility grid. The proposed scheme has been modeled in the MATLAB 7.1 software and the complete system has been simulated for open loop and closed loop configurations. The active power fed to the grid is taken for different firing angles in open loop mode and the firing angle for maximum power has been determined. This is compared with the firing angle obtained from the closed loop mode and found that both results agree with each other.

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1. INTRODUCTION

The rapid trend of industrialization of nations and increased interest in environmental issues has led recently to consideration of the use of renewable forms such as solar energy. Photovoltaic (PV) generation is gaining increased importance as a renewable source due to its advantages such as the absence of fuel cost, little maintenance, no noise and wear due to absence of moving parts etc. Photovoltaic sources are used today in many applications such as battery charging, water pumping, home power supply, swimming pool heating systems, satellite power systems etc. They have the advantage of being maintenance and pollution free but their installation cost is high and in most applications, they require a power conditioner for load interface. Since PV modules still have relatively low conversion efficiency, the overall system cost can be reduced using high efficiency power conditioners which, in addition are designed to extract the maximum possible power from the PV module. A controlled power interface between solar cells and grid is required to vary the power fed to the grid [4] as per the load conditions. But in India, the rural areas suffer from the scarcity of electrical power throughout the day. This paper discusses one such scheme wherein a controller consisting of a boost converter and a line commutated inverter has been used to interface the PV array to grid with provision to track maximum power from the solar array. Hence a control circuit is needed for maximum power transfer from the solar cells to the grid all the time [3], [7].

2. PROPOSED SCHEME

The block diagram schematic of the proposed scheme is shown in Figure 1. It consists of an array of solar panels interfaced to the utility grid through a boost converter and single phase SCR bridge circuit. The

DC voltage from the PV array is sensed and given to the boost converter which steps up the voltage to the required DC level. The duty cycle of the boost converter is controlled through a PI controller in the feedback for giving constant output voltage. The raised DC voltage from the boost converter is converted to AC using SCR bridge circuit to interface with the grid.

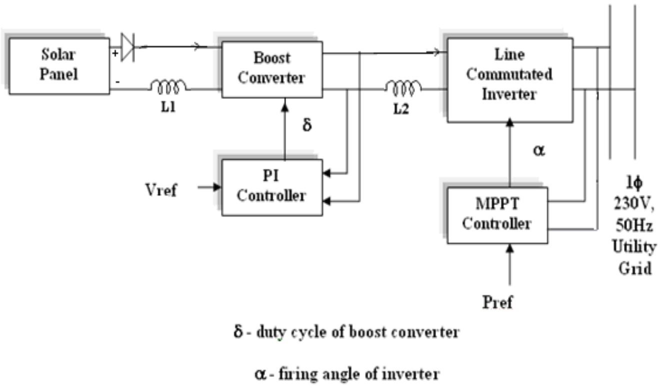

Figure 1. The block diagram schematic of the proposed scheme

The SCR bridge circuit is operated as line commutated inverter by keeping the firing angle above 90°. One input to the PI controller is from the actual output voltage from the boost converter and the reference voltage (260V) is given as another input. Based on this reference voltage the modulation of duty cycle is carried out. The inverter is provided with controller for feeding maximum power to the grid all the time. The actual power P_o and the reference power P_{ref} are compared and the difference between these two powers is given as input to the controller. The output of the controller modifies the firing angle to minimize the error. The PV array in the proposed scheme consists of two solar panels of 80W, 21V, 5A each, connected in series. A single-phase utility grid of 230V, 50Hz is considered, to which the output of the inverter is connected.

2.1. Boost converter

The boost converter shown in Figure 2. is used to step-up the voltage obtained from the PV panel to equal the reference voltage (260V). The output voltage of the boost converter is given by

$$V_o = V_d \frac{1}{(1-\delta)} \tag{1}$$

where δ = duty cycle of the boost converter and V_d = input DC supply.

By varying the duty cycle, the output voltage can be varied above V_d. The introduction of the boost converter eliminates the step-up transformer between the inverter and the grid thereby reducing the cost of the system and also eliminating the losses produced by the transformer leakage inductance.[5]

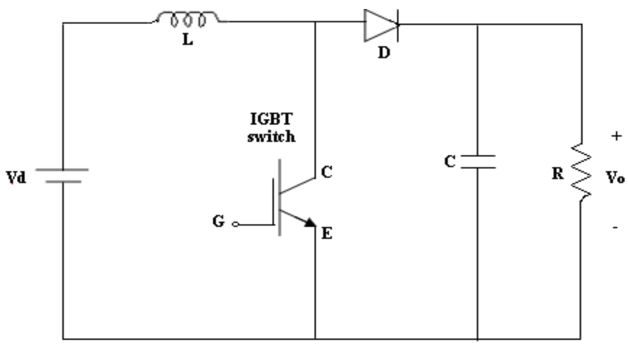

Figure 2. Circuit of the boost converter

2.2. Controller for boost converter

For getting the constant output voltage (260V) from the boost converter, the duty cycle of the converter is automatically adjusted using PI controller in the closed loop.The actual output voltage from the converter V_{act} is compared with the reference voltage V_{ref}. The error voltage V_{error} is used for the variation of the duty cycle δ of the converter.The error voltage is given to the PI controller. The PI controller output V_0 is compared with the sawtooth wave (500KHz) in a comparator which gives the gate pulses for the converter. The PI controller output is given by

$$V_0 = \left[K_P + \frac{K_I}{S}\right](V_{ref} - V_{act}) \tag{2}$$

where K_p and K_i are proportional and integral gains respectively.

In the proposed scheme, the proportional and integral controller gains ($K_P = 0.25$ and $K_I = 1$) have been chosen by trial and error method for getting the output voltage of 260V from the boost converter.

2.3. Analysis of Line Commutated Inverter

A single-phase fully controlled bridge converter shown in Figure 3. can be operated in two modes namely rectifier and inverter modes. When the firing angle α is between 0° and 90°, the converter is said to be in rectification mode and when the firing angle α is between 90° and 180°, it is said to be in inversion mode. In the proposed scheme, the converter operates as an inverter. The thyristors T_1 and T_2 are fired at firing delay angle of α° and the thyristors T_3 and T_4 are fired at (α+180)°. The direction of power flow can be reversed by reversal of the DC voltage, the current direction being unchanged. The delay angle α must be greater than 90°. In the present case, no extra effort is required to synchronize the inverter output frequency with that of the grid supply[2]. This of course is possible only with SCR converters. The average output voltage E_{dc} is hence given by,

$$E_{dc} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} E_m \sin\theta \, d\theta = \frac{2}{\pi} E_m \cos\alpha \tag{3}$$

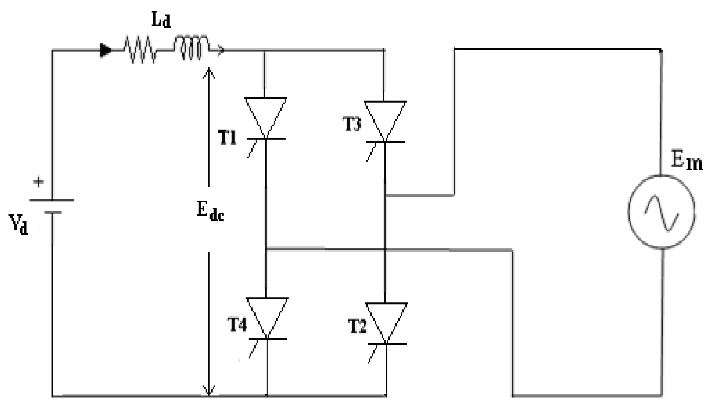

Figure 3. Circuit of the single-phase fully controlled bridge converter

2.4 Controller for Maximum Power Tracking

For extracting maximum power from the solar array, the firing angle of the inverter is adjusted in closed loop.The reference power from the solar array P_{ref} is given by[1]

$$P_{ref} = V_{mp} \times I_{mp} \text{ W} \tag{4}$$

Here $$V_{mp} = K_1 \times V_{oc} \tag{5}$$

$$I_{mp} = K_2 \times I_{sc} \tag{6}$$

where V_{oc} is the open-circuit voltage and I_{sc} is the short-circuit current of the PV array. K_1 and K_2 are constants taken as 0.76 and 0.8 respectively.

The actual grid power P_{grid} is compared with the reference power and any mismatch is used to change the firing angle α of the inverter as follows:

$$\alpha = (P_{ref} - P_{grid})[K_P+K_I/S] \quad (7)$$

The optimum values for K_P and K_I have been arrived by trial and error method. In the proposed scheme, the P and I controller gains are chosen to be 0.3 and 7 respectively.

3. SIMULATION RESULTS

The complete model of the proposed scheme is modeled in MATLAB 7.1/simulink software. It consists of blocks of solar array, boost converter, line commutated inverter, utility grid and closed loop controllers.The DC link inductance together with boost converter acts as load on the line commutated inverter. **Dr.S.Arul Daniel** and **Dr.N.Ammasai Gounden** [6] have proposed a simulink model for the solar array. This model has been used in the proposed scheme. The parameters of solar array are V_{oc} = 21.2V and I_{sc} = 5.17A; inductance L_1 = 3.4mH; for the boost converter; L = 1mH, C = 1000μF, R = 50Ω; for DC link inductance R_2 = 0.2Ω, L_2 = 20mH;

The SCRs in the inverter are triggered in open loop mode for different firing angles and the readings of active power fed to the grid, DC link voltage, DC link current and grid current were noted. From these readings, the firing angle corresponding to the maximum power is determined. This is compared with the closed loop readings and the results are furnished in Table 1. It is seen that both results agree with each other.

Table 1. Comparison of open loop and closed loop results

Parameters	Open loop	Closed loop
Firing angle at which maximum power occurs, α	160°	160.2°
Direct voltage, V_{dc} (in V)	-108	-119
Direct current, I_{dc} (in A)	0.9	1
Grid current, I_{grid} (in A)	1	0.4
Active power fed to grid, P_{grid} (in W)	-70.5	-72.62

The grid voltage and grid current waveforms are shown in Figure 4. The waveforms of DC link voltage and the DC link current are shown in Figure 5. The waveform for the power fed to the grid is shown in Figure 6.

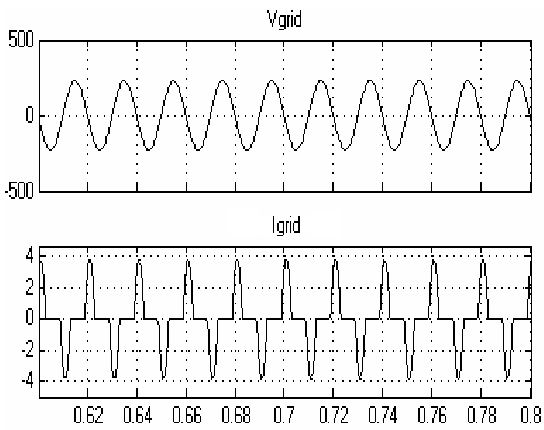

Figure 4. Grid voltage and grid current

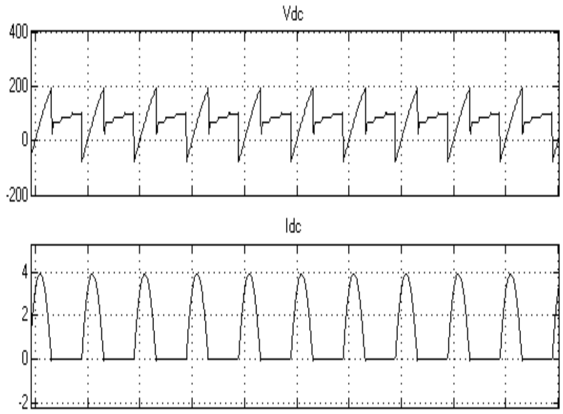

Figure 5. DC link voltage and DC link current

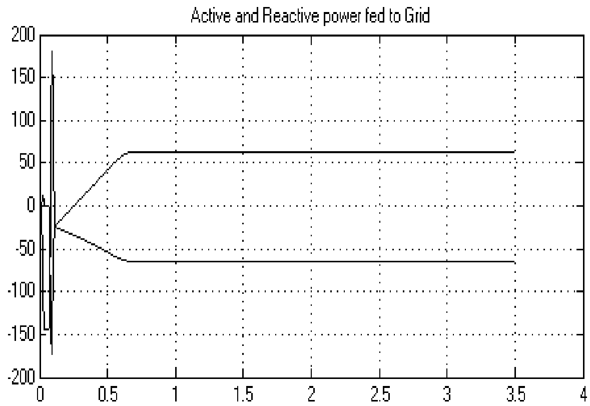

Figure 6. Active and Reactive power fed to the grid

4. CONCLUSION

A simple power electronic interface employing a boost converter and line commutated inverter has been developed for interfacing PV array with the single-phase utility grid. The simulation studies have been carried out to get the parameters such as active and reactive powers, DC link voltage and current and the firing angle corresponding to the maximum power. Due to losses in the inductor, the output power fed to the grid is somewhat less. This can be increased by selecting the inductor with low losses.

Nomenclature

E_{dc} DC link voltage (V)
I_{dc} DC link current (A)
K_p Proportional gain
K_I Integral gain
L_1 Inductance (H)
L_2 DC link inductance (H)
V_d Input voltage to the boost converter (V)
V_o Output voltage from the boost converter (V)
α Firing delay angle for SCRs (deg)
δ Duty cycle of the boost converter

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T.Shanthi received her bachelor’s degree from Institute of Road and Transport Technology, Erode, Tamilnadu, India in Electrical and Electronics Engineering during 1999. She received her Master’s degree from National Institue of Technology, Tiruchirappalli, India during 2007. She is currently working as Assistant Professor at the department of Electrical and Electronics Engineering in Kumaraguru College of Technology, Coimbatore, India.