Design and Implementation of PV Fed Two Stage DC/DC Converter for Home Applications

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Abstract

In this paper PV fed two stages DC-DC converter has been designed and implemented for home applications .In two stages first stage consists of step down converter and second stage consists of step up converter connecting in cascade manner and power is transfers through both the stages. Here boost stage for step-up the voltage given by buck converter which is step down stage and will give required voltage to operate the load. By using P&O based MPPT algorithm maximum power has been extracted from the PV system. The proposed model has been implemented by using MATLAB / Simulink and results are verified experimentally.

Keywords: Boost, Buck, DC-DC Converters, MPPT Controller, Photovoltaic, PV Module

1. Introduction

Power generations from the conventional sources are not sufficient to meet the present power demand. If thinking future demand existing conventional sources are may not full fill the requirement, hence alternate sources to meet the demand generation of power from the renewable sources. One among the available renewable sources of energy is solar energy, i.e., conversion of sun radiation into useful form of energy. Research on semiconductor technology and materials there is a possibility of efficient conversion of PV energy into electrical energy with the help of PV system¹⁻³.

PV system consists of array of PV cells, Converter unit and load. In order to extract maximum power depending on the ambient condition a maximum power point tracking is employed. A number of methods are available in literature like Perturb and Observe (P&O), Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit

Voltage, Fuzzy Control and Neural Network Control to track maximum power point of PV module⁴. For extraction of maximum energy from PV module most popular method hill climbing (or) P&O algorithm is used in this work^{5,6}. This model consists of photo-voltaic PV module, DC to DC Buck converter and Boost converter, MPPT Controller, Battery Storage, and Load. MPPT controller operates on adjusting the voltage and identifies maximum power point.

The first stage of the DC/ DC converter used in this work is buck converter which produce an output voltage lower than the supply voltage which the voltage is used to charge the battery and the other converter is Boost converter is used to step-up the voltage and will give output voltage to operate the load.Here the battery is interlinked between buck and boost converter to operate as when system is under normal-load i.e., less than fullload where the power used to charge by 30-40 % of input power entering battery and if the load requirement is more the battery will compensate power.

Paper is organized as follows secession II described the proposed model block diagram. Secession III explains the Modeling of PV module. In secession IV development of MPPT algorithm. Secession V explains about the DC-DC converters which are used in this proposed model. Secession VI contains design parameters of model. Secession VII is contains the Results and discussion followed by conclusion.

2. PV Fed Two Stage DC-DC Converter

PV fed two stage DC-DC converter block diagram is shown in Figure 1.



Figure 1. proposed of PV fed two stage DC-DC converter.

Here two stages of conversion is implemented one stage is to step-down and another is to step-up. In first stage step down stage to charge the lead-acid battery which is used to compensate the power when output load requires more power. In the second stage step-up stage to feed power to the load. Duty ratio of the DC/DC converter is changed with the help of PWM signal, the load impedance matches with the source impedance to transfer maximum power. This proposed model is used as a stand-alone system. This model is effectively used in the areas where out of the power grid like in tribal, hilly, and forest check-posts etc.

3. Modeling of Photo-voltaic System

Electrical equivalent model of PV cell is shown in Figure 2.It consists of current source parallel with diode, selfseries resistance due to interruption of flow of charge carriers inside cell and parallel resistance due to leakage carriers. When PV cell strikes with irradiance potential will develop, hence current will flow. If higher the irradiance more will be the current.



Figure 2. PV cell equivalent circuit.

Diode current equation itself is the PV cell current,

$$I_{d} = I_{o,cell} \left[exp\left(\frac{qV}{aKT}\right) - 1 \right]$$
⁽¹⁾

The basic equation from the system that mathematical the ideal PV cell is

$$I = I_{pv,cell} - I_d \tag{2}$$

$$I = I_{pv,cell} - I_{o,cell} \left[\exp\left(\frac{qV}{aKT}\right) - 1 \right]$$
(3)

where,

Ipv,cell Is current due to incident sunrays (A)

lo,cell Is reverse saturation current (A)

Q Is charge of electron $[1.60217646 \times 10^{-19}C]$

K is the Boltzmann constant $[1.3806503 \times 10^{-23} \text{ J/K}]$

T is the temperature of the p-n junction [K] and a is the diode ideality constant $(1 \le a \le 1.5)$

Characteristics equation at the terminals of the PV array is⁷⁻⁹ as

$$I = I_{pv} - I_o \left[\exp\left(\frac{V + R_s I}{V_t a}\right) - \mathbf{1} \right] - \frac{V + R_s}{R_p}$$
(4)

The V-I characteristic of the PV device depends on the internal characteristics of the device and on external influences like irradiation and temperature. It can be expressed in (5):

$$I_{pv} = (I_{pv,n} + K_I \Delta T) \left(\frac{G}{G_n}\right)$$
⁽⁵⁾

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where,

Ipv is the Radiation produced current at the normal condition (25C and 1000 W/m2) $\Delta T = T - T_n$

 $(T \text{ and } T_n \text{ the actual and normal temperatures } [K])$

G is the irradiation on the cell surface $[W/m^2]$, and G_n is the nominal irradiation $[W/m^2]$.

4. MPPT Control of Proposed Circuit

Normally efficiency of a PV cell is quite low and also when such cells are combined to form a panel then its efficiency further decreases. In order to increase the efficiency (η) of PV cell or PV panel has to be use maximum power transfer theorem. This theorem states that "the maximum power is transfer when the load resistance matches with the source resistance i.e. panel impedance. The MPPT method employed in this paper is P&O algorithm. Figure 3 is the flow chart that explains the implemented MPPT scheme.



Figure 3. MPPT Flow Chart for PV system.

5. DC-DC Converters

In this paper two converters are used in two stages buck converter used as a step down converter in first stage and boost converter in second stage as a step up converter.

Buck converter shown in Figure 4 which accepting a dc input and by using PWM technique controls the output. A diode along with an inductor and a capacitor produces the regulated dc output voltage which is lower than the input voltage.



Figure 4. Circuit diagram of Buck converter.

Boost converter shown in Figure 5 which accepting a dc input and by using PWM technique controls the output. A diode along with an inductor and a capacitor produces the regulated dc output voltage higher than the input voltage.



Figure 5. Circuit diagram of Buck converter.

6. Design Parameters

The proposed model design parameters are shown in following tables. The PV panel parameters are shown in Table1. Buck converter and boost converter design parameters are shown in Tables 2 and 3.

Table 1. PV panel parameters

Parameter	Value
I _{scn}	0.40 (A)
V _{ocn}	10.6 (V)
I	0.35(A)
V _{mp}	8.5 (V)
P _{max,e}	3 (W)
K _v	-0.123 V/K
K _i	3.18x10 ⁻³ A/K
N _s	36

Table 2.	Parameters	of buck	converter
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Parameter	Value
Inductor (L)	470µH
Capacitance (C1)	220µF
Frequency (F _{sw})	20KHz
Output Voltage (V _{out})	4-5 Volts
Load Voltage Ripple (ΔV)	1% of V_{out}
Output Current Ripple (ΔI)	10-30% of I_{out}
Output Current (I _{out})	0.5A
Equivalent series resistance (ESR)	$\Delta V/\Delta I=0.01\Omega$
DC Input Voltage (V _{in})	8.5-10.6Volts

Table 3.Parameters of	boost converter
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Parameter	Value
Inductor (L)	470μΗ
Capacitance (C1)	220µF
Frequency (F _{sw})	20KHz
Output Voltage (V _{out})	19.5-25 Volts
Load Voltage Ripple (ΔV)	1% of V_{out}
Output Current Ripple (ΔI)	10-30% of I_{out}
Output Current (I _{out})	0.1A
Equivalent series resistance (ESR)	$\Delta V / \Delta I = 0.01 \Omega$
DC Input Voltage (V _{in})	3.5-5.5 Volts

7. Results and Discussion

7.1 MATLAB/Simulink

The proposed model is simulated using MATLAB. The diode equivalent model of the PV model in simulink is shown in Figure 6.



Figure 6. Mathematical Model of Solar PV- panel in Simulink.

PV module operating direct load without converter is shown in Figure 7. And the respective power, voltage and current waveforms are shown in Figure 8.



Figure 7. PV-Panel simulation output operating load directly.



Figure 8. Output waveforms for Voltage, Current and Power.

The proposed converter simulink model is shown in Figure 9.Boost converter output voltage waveform is shown in Figure 10.Load current waveform is shown in Figure 11. Load power waveform is shown in Figure 12.Battery charging waveform is shown in Figure 13.



Figure 9. Complete Model Simulation circuit.



Figure 10. Boost converter output voltage waveform.



Figure 11. Load current waveform.



Figure 12. Load power waveform.



Figure 13. Battery charging voltage waveform.

Voltages waveforms of solar input, Buck converter and Boost Converter at 4W load is shown in Figure 14.

Current waveforms of Solar input, Buck converter and Boost Converter at 4W load is shown if Figure 15.

Power waveforms of solar input, Buck converter and Boost Converter at 4W load are shown in Figure 16.



Figure 14. Output Voltages of operating 4W Load.



Figure 15. Output Currents of operating 4W Load.



Figure 16. Output powers of operating 4W load.



Figure 17. Battery VOC characteristics operating 4W.

7.2 Hardware Results

The prototype model of the proposed system is shown in Figure 18. In this experimental setup LM2599 IC is used for Buck converter and XL6009 IC is used for Boost converter. These converters are designed with internal pulse generators. Load used here is toy motor with current rating of 0.01A and battery used here is rechargeable battery of 4V, 5Ah rating. Figure 19 shows the buck converter input voltage. Figure 20 shows the output voltage from boost converter. Figure 21 shows the battery voltage.



Figure 18. Prototype model of proposed system.



Figure 19. Buck converter input voltage.



Figure 20. Output voltage from boost converter.



Figure 21. Battery voltage.

8. Conclusion

This paper focus on a standalone system operated by combination of two different converters which one of converter is will operated by MPPT controller. One simple solar panel that has standard value of irradiation and temperature has been included in the simulation circuit. From all the cases, the best controller for MPPT is Perturb and observe controller, because we implementing in hardware so complexity is less by using P&O. This controller gives a better output value for buck converter. Hence this controller will give stable output to operate the load. Here So this project shows that without changing the rating of storage equipment we are implemented two stages of conversion. Here the load demand increases we increase the input PV-module rating but the storage is kept constant. If there is any fault occurs in the battery storage for higher rating equipment replacement we have to disconnect entire PV-system, but in this project it shows that in place of higher rating storage equipment by using smaller rating storage we can easily replace them and if storage demand increase we can connect them in parallel with the existing storage equipment. This type of model is used in areas like forest check-posts, toll gates and street lights and house in area where ac-transmission grid network is not available.

9. References

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