Design of Buck Converter and PV Module for Solar Powered Sailing Boat

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Abstract: The main intention of this work is to minimize the operating cost and increase the power generation of solar photovoltaic (PV) power-driven sailing boat with buck converter. The design of dc-dc converter for solar powered sailing boat is presented here. The entire PV source output power is taken and given to the solar boat through buck converter. The entire output power from the PV source which is given to the dc load is enough to drive a boat. The Buck converter model and solar PV module has been designed and simulated with the use of Matlab Simulink and compared with theoretical predictions.

Keywords: Buck Converter, Photovoltaic, Solar Sailing Boat

1.0 Introduction

Nowadays the generation of pollution free, Eco friendly green energy is essential. The water way transport is the most essential life sustenance transports of the current society. The most of the environmental problems in all large cities are created due to the energy comes from fossil fuels. The proper usage of renewable energy is the only solution for these problems. The usage of solar power sailing boat can reduces the environmental problems. In this work the solar energy is converted into dc power by Photo Voltaic Converters (PVCs) and is given to the dc load [1]. The major renewable electricity is generated from photovoltaic power systems which produces no greenhouse gas emission and not consumes any fossil fuel [2], [3]. The energy generated in photovoltaic generator (PVG) is used to drive the boat directly or that can be stored in a battery. Inverters and choppers are used to step-up or step-down the voltage from the photo voltaic generator depending upon the load requirements. PVG produces good efficiency in case of rainy day also and it can continuously convert solar energy [4], [5]. The buck converter is used to utilize entire power from the PV module and given into the DC load [6], [7].

2.0 The Proposed Method

2.1. Photo Voltaic System

The efficiency of the photo voltaic system can be improved by finding the most compatible DC/DC converter for particular application. The figure 1 shows the block diagram of PV system and it consists of photovoltaic panel, dc–dc buck converter and sailing boat dc motor. The dc –dc power converter is used to give the PV system output to the dc motor used in boat [8].
2.2. Photo Volataic Powered Sailing Boat

The circuit diagram for proposed buck converter based solar powered sailing boat is shown in figure 2. The solar energy is converted to electrical energy by using photo voltaic system [9]. PV system converts energy from solar into direct voltage and current and the output from PV system is feed into the chopper. Output of the chopper is given to the DC motor which is used to drive the sailing boat [10]. The dc power produced in the PV system is depends on the intensity of sun light. Through a coupler the dc motor used in the sailing boat is connected to propeller. The other side of motor shaft is connected to diesel engine by another clutch coupler and which can be used as prime mover. Whenever solar PV is not produce required power then the diesel engine can be used as backup protection. The weight and cost of PV panels can be achieved by cover design with fluorides [11]. The total weight of the boat and power usage is reduces by using this PV module [12].

3. Buck Converter

3.1. DC to DC Buck Converter

Buck converter used in this work is step down dc-dc converter with LC filter. Single stage LC filter with single inductor and capacitor is used in this proposed work [13]. Figure 3 shows the waveform of buck converter and assuming that the inductor current is positive always. In continuous conduction mode the inductor current is not zero for entire period of time and the diode is reverse biased during state. Diode conducts to maintain an uninterrupted current in the inductor during switch is in off position and buck converter efficiency is high. The output voltage of the buck converter is 110V.

\[ e_L = L \frac{di}{dt} \]
Let us assume, in time \( t_1 \), the inductor current increases linearly from \( I_1 \) to \( I_2 \).

\[
V_s-V_0 = \frac{\Delta I}{t_1} = L \frac{I_2 - I_1}{t_1} \tag{2}
\]

\[
t_1 = \frac{\Delta L}{V_s-V_0} \tag{3}
\]

In time \( t_2 \), the inductor current decreases linearly from \( I_2 \) to \( I_1 \).

\[
-V_0 = L \frac{\Delta I}{t_2} \tag{4}
\]

\[
t_2 = L \frac{\Delta I}{I_2-I_1} \tag{5}
\]

Where \( \Delta I = I_2 - I_1 \) is the ripple current in peak to peak of the inductor \( L \).

\[
\Delta I = \frac{(V_s-V_0)t_1}{L} = \frac{\rho_{ch} t_2}{L} \tag{6}
\]

Substitute \( t_1 = DT \) and \( t_2 = (1-D)T \) then the average output is

\[
V_o = V_s \frac{t_1}{T} = DV_s \tag{7}
\]

\( T \) is the switch period and it can be expressed as

\[
T = \frac{1}{f} = t_1 + t_2 = \frac{\Delta L}{V_s-V_0} + L \frac{\Delta I}{I_2-I_1} = \frac{\Delta L V_s}{(V_s-V_0)V_o} \tag{8}
\]

Peak to Peak ripple current is

\[
\Delta I = \frac{(V_s-V_0)\rho_{ch}}{fL} \tag{9}
\]

\[
\Delta I = \frac{(1-D)DV_s}{fL} \tag{10}
\]

Ripple voltage of the capacitor is

\[
\Delta V_c = \frac{(1-D)DV_s}{BLCf^2} \tag{11}
\]

![Figure 3. Waveform of Buck Converter](image)

### 3.2. Design of PV and Converter Model

PV powered sailing boat is run by 1.5 HP dc motor. Let us consider, the boat consist of four passenger with the weight 350 kg. The efficiency of the converter is considered as 95%, chopper input = \((1.5 \times 746) / 0.95 = 1.178 \) KW, one solar panel produces 300 watts. Number of panel = \(( 1.5 \times 746 ) / (0.85\times300) = 3.9\) approximately 4.

#### 3.2.1. Buck Converter Modeling

The output of the PV Module is given to buck converter and then buck converter is used to step down the Voc value to 110 Volt. The buck converter parameters are selected as follows: \( F_s=100 \) kHz, Input
voltage $V_{in} = 35.86 \times 4 = 143$ volt and output voltage $V_o = 110$ volt. Output load current $I_o = 8.25$ A. The duty cycle is calculated from the above data is $D = 76\%$, current ripple $\Delta I_L = 3.25$ ampere, inductor value $L = 8 \times 10^{-3}$ Henry and capacitor value $C = 0.70$ uF.

3.2.2. PV Modeling with Buck Converter

The output of the PV panel is given to input to the chopper. The figure 5 shows PV model with buck converter when output from PV panel is given to the input of buck converter by matlab simulink.

4. Results and Discussion

The total output power of the PV module is 1178 watts with four series connection of PV module. The maximum voltage and current generated in each PV module is 35.79 Volts and 8.23 Ampere. The PV array output voltage is 143.21 Volts. The voltage and current value is approximately 143 V and 8.2 A
according to the simulation graph and the experimental values are almost equal to the theoretical values.

**Figure 6. Simulation Result of Buck Converter**

The Output voltage from Photo Voltaic system is 144.28 Volts after adding both buck converter and PV module using Matlab Simulink and that is the input voltage given to the buck converter. Finally, the output voltage of buck converter is 110.38 Volts.

**Figure 7. PV with Buck Converter Simulation Results**

5. **Conclusions**
Buck converter controlled solar powered sailing boat is proposed in this work. The PV module and buck converter model has completed using Matlab Simulink software. The efficiency of the solar sailing boat with buck converter is tested. This sailing boat is completely pollution free and environmental friendly. The solar panels are installed on unused portion of the boat and there is no extra space requirement. Due to the availability of sunlight there is no fuel cost during day time and it has diesel engine backup protection. This solar powered sailing boat is most economical than the diesel engine boat.

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