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Design of Buck Converter For Photovoltaic System Applications

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Abstract—As a tropical country, Indonesia has a huge potential of solar energy as an alternative energy to replace fossil energy is increasingly scarce and expensive. Utilization of solar energy needs photovoltaic that will convert solar energy into DC electricity. Advantages of photovoltaic are unlimited energy source, non-pollution, environmentally friendly and low maintenance costs, but PV has low efficiency. To improve efficiency is to operate the PV on maximum power point using maximum power point tracking (MPPT). DC-DC converter is the heart of the MPPT that will maintain a stable output voltage at the maximum voltage despite changes in temperature and solar irradiation. There are three configurations DC-DC converters that can be used for MPPT: a buck converter, boost converter and buck-boost converter. Buck converter has a better efficiency than other configurations. This paper will analyze, design and simulation of a buck converter circuit for charging batteries using photovoltaic. The design includes the determination of the parameters of the circuit components that accordance with the requirements of a photovoltaic system based battery charged.

Keywords—photovoltaic, buck converter

I. INTRODUCTION

Increasing electrical energy demand are proportional with the growth of population and economic. While availability of fossil energy more scarce and expensive. So we need diversification a renewable energy as an alternative energy. Solar energy is one of the great potential renewable energy in Indonesia. It has the advantages of unlimited availability, environment friendly and free pollution. To utilize solar energy requires photovoltaic that convert solar energy to DC electrical energy.

Photovoltaic characteristic depends on light intensity and temperature of junction. Output voltage and current generated is directly proportional with light intensity received [6]. Drawback of photovoltaic is low efficiency so necessary controlling to work in maximum power point (MPP). One of method to define MPP is using MPPT with DC-DC converter. MPPT has advantages is directly measurement of array voltage and thus require lower cost compared than method using solar irradiation measurement and environment factor. MPPT using DC-DC converter do not require current measurement so that system becomes simpler [5]. To obtain optimum power can be done by using DC-DC converters as power electronic circuit. DC-DC converter connects the photovoltaic output and load. Using buck converter for photovoltaic applications produces higher performance, efficient and robust [7].

There are three configurations DC-DC converters that can be used for MPPT: a buck converter, boost converter and buck-boost converter. Buck converter is a circuit that generates output voltage greater than the input voltage, while the boost converter will generate the output voltage greater than the input voltage. Buck-boost converter output voltage will result in larger or smaller than the input voltage. The magnitude of the output voltage will depend on the amount of duty cycle. Buck converter has higher efficiency than the other configuration.

In this article will be designed buck converter for photovoltaic applications. Photovoltaic power for 50WP and buck converters are used to connect between the photovoltaic and battery. The selection of components buck converter will be determined based on usage and simulated using Simulink MATLAB.

II. PHOTOVOLTAIC

Solar cells will convert solar energy into DC electricity directly. The PV system consists of several solar cells can be connected in series or parallel. The PV system has the advantage that it does not cause pollution, environmentally friendly, low maintenance costs and the availability of solar energy is unlimited and continuous. But the use of PV systems is still rarely used because it has the disadvantage of high cost of installation and low energy conversion efficiency is only about 20% [2]. Currently the cost of solar energy is estimated at double the cost of fossil energy (coal, oil, etc.). But for the
future, where fossil fuels are very thinned so that the energy costs will increase to equal the cost of solar energy. Until 2000, it was reported to the procurement of solar cell modules to power up to hundreds of kilowatt. The price of system of per watt of energy generated is about 4.5 U.S. dollars, and in 2005 the price of energy generation system modules with solar cells can be reduced to $1 per Watt. The longer inverstasi costs for solar energy is going to go down, so that the operation of the PV system is the most important thing to do is improve the efficiency of the system.

Energy conversion efficiency of solar cells are associated with the maximum powerpoint (MPP) of PV systems [3]. PV panels work on a maximum point which will result in maximum output power. MPPs strongly influenced by solar irradiation, cell junction temperature and load current changes every non-linear. Solar irradiation and temperature changes will shift the MPP junction of PV systems. So that the necessary arrangement to determine the MPP. The PV system will continue to operate around the MPP despite changes in solar irradiation and the cell junction temperature. Determination of MPP is also called the maximum power point tracking (MPPT). With the use of MPPT, PV system efficiency can be improved.

Characteristics of highly non-linear photovoltaic systems are influenced by external factors. Solar irradiation, ambient temperature and wind speed are the main environmental factors affecting PV system. While the short circuit current (Isc), open circuit voltage (Voc), maximum voltage (Vmax) and current MPP is the main characteristic that shows the IV and PV curves [1]. According to El-Salhi & Bachtiri [4], solar cells are devices that are non-linear and can be expressed as a current source model as shown in Fig 1.

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### III. BUCK CONVERTER

#### A. Principle of Operation

Buck converter is a circuit that converts the DC voltage into another DC voltage whose values is smaller. Average output voltage of the buck converter is smaller than the source voltage. Buck converter circuit is shown in Fig 2. The working principle of the circuit depends on the condition of the switch S, which has two circumstances, when the switch S is closed (ON) or open (OFF) which switch S is generally a power electronics component such as MOSFETs. Operating mode of the buck converter consists of two types of continuous and discontinuous.

Circuit operation depends on the current through the inductor. In continuous mode, the inductor current never reaches zero, while in discontinuous mode, it will reach a value of zero for a time.

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**Fig 1. Equivalent Circuit of Solar Cell**

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**Fig 2. Circuit Diagram and Average Output Voltage of Buck Converter**

In most applications, buck converters use continuous mode so that the inductor current never reaches zero at full load conditions. By using the continuous mode, the overall performance of the circuit will be better than in the discontinuous mode, otherwise it will produce a maximum output power. But in the maximum load current smaller, using discontinuous mode is more profitable because the size of the inductor used is smaller so that the size of the converter becomes smaller. Increasing resistive load in continuous mode buck converter circuit will cause it to work in discontinuous mode. The working principle of continuous mode buck converter can be divided into two parts. Fig 3 shows diagram block for system photovoltaic using buck converter.

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**Fig 3. Diagram Block of Photovoltaic System**

**Mode 1. Switch S is ON.**

At the time of the switch in closed condition, diode will be reverse biased and current flows in the inductor L, capacitor...
C and load R. The current through inductor will increase while capacitor current have the opposite directions and depending inductor and load current. When inductor current increase, the stored energy will increase too. By using voltage kirkhoff law, inductor voltage can be determined by
\[ V_L = V_s - V_o \] (1)
and
\[ L \frac{di}{dt} = V_s - V_o \] (2)

With finishing eq. [2] will be obtained
\[ I_{LOFF} = \left( \frac{V_s - V_o}{L} \right) t_{ON} \] (3)
where \( V_s, V_o, L, I_{LOFF} \) and \( t_{ON} \) are source voltage, output voltage, inductor voltage, inductor current at switch-on condition and time on.

**Mode 2 : Switch S, OFF**

Atswitchoff, thediodeconducts, the loadis disconnectedto thesource. Inductors that store energywill to flow the current intothe capacitorand the load. Capacitor current willflow in the opposite direction with the inductor, so
\[ V_L = -V_C = -V_o \] (4)
and
\[ L \frac{di}{dt} = -V_o \] (5)

Inductor current during switch off can be determined by
\[ I_{LOFF} = \left( \frac{V_o}{L} \right) t_{OFF} \] (6)
where \( V_c \) is voltage of capacitor and \( t_{OFF} \)is switch off period
\[ t_{OFF} = T - t_{ON} \] (7)

Based oneq. [3] and [6], the inductor current in one period of
\[ I_{LOFF} + I_{LOFF} = 0 \] (8)
\[ \left( \frac{V_s - V_o}{L} \right) t_{ON} + \left( \frac{-V_o}{L} \right) t_{OFF} \] (9)
\[ \left( \frac{V_s - V_o}{L} \right) t_{ON} + \left( \frac{-V_o}{L} \right) (T - t_{ON}) \] (10)

With finishing eq. [10] will be obtained
\[ V_o = V_s \frac{t_{ON}}{T} \] (11)
\[ V_o = V_s D; \quad 0 < D < 1 \] (12)

Where D is duty cycle.

**B. Selection of Components**

Buck converter circuit consists of inductor, capacitor, diode, switch and load. The selection of appropriate components play an important role in the design of the circuit for the system to operate optimally.

1) Switch

Some components can be used topowerelectronicswitches, among others; BJTs, MOSFETs, IGBT and COOLMOS.

Transistors are generally used for low to medium power applications. While the MOSFETs avaltagecontrolled components, are better suited for low power applications and high frequency converters, IGBTs are more suitable for high power applications. For applications in 50W PV, will be used MOSFET aselectronicswitches.

To determine the type MOSFETs that used by determined how much voltage \( V_{DSS}, I_D \) and the maximum frequency that may be imposed on the MOSFET. \( V_{DSS} \) is the maximum voltage that will be imposed on MOSFET, due to MOSFET input come from photovoltaic output voltage of 20V so \( V_{DSS} > V_s = 20 \) Volt. For drain current \( I_D \) based on output power so that \( I_D > D \times I_{out} \).

With D is the duty cycle with a value between 0 and 1, while the desired Iout at 2 amperes, thus ID of 2 amperes. Based on the calculation above, the MOSFET type IRF540 chosen because it has a \( V_{DSS} \) of 100 V and \( I_D \) of 15 A.

2) Inductor

Inductor value used depend on the switching frequency will affect the size of the inductor. The higher the switching frequency, the value and size of the inductor will be smaller. For continuous operation, the inductor current will always be greater than the inductor value can be determined by the equation
\[ L = \frac{(1 - D) V_o}{2 f I_o} \] (13)
Where \( f \) is switching frequency and \( I_o \) is output current. Inductors are selected using the typetoroid, component that is suitable for high frequency applications.

3) Diode

With switching frequency of 200KHz then require adiode with fast recovertytimes used Schottkydiodes. Diodereverse voltage must be able to face the PV output voltage.

4) Capacitor

Capacitance value which used will be influenced by ripple output voltage. Capacitor value can be determined by
\[ C = \frac{(1 - D) V_o}{2 f^2 V_{ripple}} \] (14)
Where \( V_{ripple} \) is ripple output voltage.

**IV. SIMULATION**

To determine the characteristics of the buck converter circuit has been designed through simulation using Simulink/ Matlab. Circuit diagram of buck converter simulations shown in Fig.4. Based on the calculation of the value of inductor 0.2mH, capacitor 4.34μF, source voltage 20V and switching frequency 200KHz.
The simulation result of the buck converter at duty cycle 50% as shown in fig 5 and at duty cycle 80% in fig 6.

Fig 5. Simulation Result For Duty Cycle 50%

Fig 6. Simulation Result For Duty Cycle 80%

Fig 4. Simulation Buck Converter Circuit

Fig 7. Efficiency to Duty Cycle

Duty cycle changes will result in changes in voltage and output power. It also will affect the efficiency of the circuit. The relationship between the efficiency of the circuit with duty cycle is shown in Fig 7. The higher duty cycle will increase the efficiency of the circuit.

VI. CONCLUSION

Buck converter circuit design for photovoltaic applications have been described. The circuit works in continuous mode with switching frequency of 200 KHz. Determination of the components based on the needs of photovoltaic systems with duty cycle settings. The increasing efficiency is proportional to the circuit duty cycle.

V. RESULT AND DISCUSSION

Based on the simulation results obtained voltage and output current circuit. With duty cycle of 50% produces a voltage output at steady state conditions at 9.56V. Transient response of output current and voltage have maximum overshoot 31%. While the duty cycle of 80% produces the output voltage of 15.7V at conditions steady state and transient response has a maximum overshoot of 32.5%. By using the parameters of the components designed, the circuit operates in continuous current mode, change the operating mode depending on the value of inductance are used. The greater the inductance value is used then the circuit will operate in continuous mode.

Reference