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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 need 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 is 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 a photovoltaic system based battery charged.**

***Keywords*—photovoltaic, buck converter**

I. INTRODUCTION

Increasing electrical energy demand are propotional 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 avaibility, enviroment- 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 enviroment factor. MPPT using dc-dc converter do not require current measurement so that system becomes simpler [5]. Toobtainoptimumpowercan be doneby usingdc-dc converters as power electronic circuit. Dc-dc converterconnects thephotovoltaicoutputandload. Using abuck converterforphotovoltaicapplicationsproduceshighperformance, efficientandrobust [7].

There are threeconfigurationsdc-dc convertersthatcan beusedforMPPTisa buck converter, boost converterandbuck-boostconverter. Buckconverteris acircuit that generates anoutput voltagelower thanthe inputvoltage, while theboost converterwillgeneratetheoutput voltagegreater thanthe inputvoltage. Buckboost converteroutput voltagewillresult inlarger orsmallerthanthe inputvoltage. The magnitude oftheoutput voltagedc-dc converterdependson the amount ofduty cycle. Buckconverterhas abetter efficiencythanthe other configuration.

Inthis articlewill 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 onusage 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 kilo –watt. 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 conversionefficiency ofsolar cells areassociatedwith themaximum powerpoint(MPP) of PV systems [3]. PVpanelsworkonamaximumpointwhichwillresult inmaximumoutput power. MPPis strongly influencedbysolarirradiation, celljunctiontemperatureandload currentchangesverynon-linear. Solarirradiationandtemperaturechangeswillshift theMPPjunction ofPVsystem. So that the necessaryarrangementstodetermine theMPP. ThePVsystemwillcontinue to operatearoundthe MPPdespitechanges insolarirradiationandthe celljunctiontemperature. Determination ofMPPisalso called themaximum power pointtracking(MPPT). Withtheusing ofthisMPPT,PVsystemefficiencycan 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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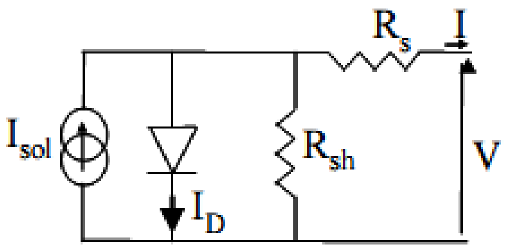
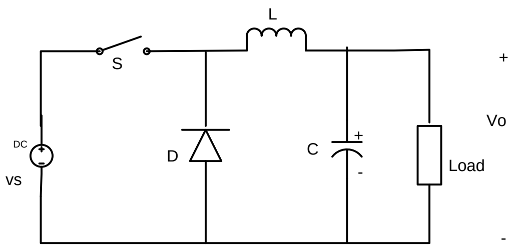


Fig 1. Equivalent Circuit of Solar Cell

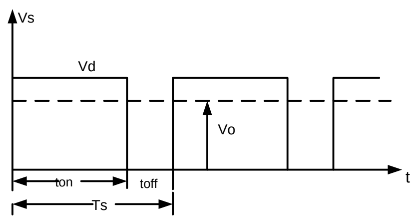
III. BUCK CONVERTER

A. Principle of Operation

Buckconverteris acircuitthat convertsthe DCvoltageintoanotherDC voltagewhose valueis smaller. Average outputvoltage ofthe buckconverteris smallerthanthe sourcevoltage. Buck convertercircuitis shownin Fig2. The working principle ofthe circuitdependsonthe condition ofthe switchSwhichhas atwocircumstances, when the switchSis closed(ON) oropen(off) whichswitchSis generallyapower electronics componentssuch asMOSFETs. Operatingmodebuck converterconsistsof two types ofcontinuousanddiscontinuous. Circuitoperatingmodesdependingon thecurrent through theinductor. Incontinuousmodethe inductor currentneverreacheszerowhile indiscontinuousmodewillreach a value ofzerofor a time.



(a) Circuit Diagram



(b) Average Output Voltage

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

In most applications,buck converter use continuous modeso thatthe inductor currentnever reacheszeroatfullload conditions. By using thecontinuousmode,the overallperformance of thecircuit willbe betterthan in thediscontinuousmode, otherwise it willproduce amaximumoutput power. Butin themaximum load current smaller,usagediscontinuousmodeis more profitablebecausethe sizeofinductors that usedis smaller so thatthe size of theconverterbecomes smaller. Increasing resistive load in continuos mode buck convertercircuitwillcause it workindiscontinuousmode. The working principleof continuous modebuckconvertercan bedividedinto twoat thetimethe switchis closedandthe switchis open. Fig 3 shown diagram block for system photovoltaic using buck converter.

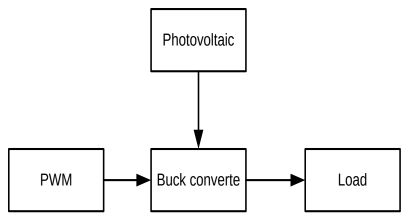


Fig 3. Diagram Block of Photovoltaic System

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 capasitor current have the opposite directions and depending inductor and load current. When inductor current increase, the stored energy will increase too. By using voltage khircoff law, inductor voltage can to be determined by

$$V_L = V_s - V_o \quad (1)$$

and

$$L\frac{di}{dt} = V_s - V_o \quad (2)$$

With finishing eq. [2] will be obtained

$$I_{LON} = \left(\frac{V_S - V_O}{L}\right) t_{ON} \quad (3)$$

where V_S, V_O, V_L, I_{LON} 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 capacitorandthe load. Capacitor current willflowin the opposite directionwith theinductor, so

$$V_L = - V_C = - V_o \quad (4)$$

and

$$L\frac{di}{dt} = - V_o \quad (5)$$

Inductor currentduring switch off can be determined by

$$I_{LOFF} = \left(\frac{-V_O}{L}\right) t_{OFF} \quad (6)$$

where Vc is voltage of capacitor and t_{OFF} is switch off period

$$t_{OFF} = T - t_{ON} \quad (7)$$

Based oneq. [3] and[6], the inductor current in one period of

$$I_{LOFF} + I_{LON} = 0 \quad (8)$$

$$\left(\frac{V_S - V_O}{L}\right) t_{ON} + \left(\frac{-V_O}{L}\right) t_{OFF} \quad (9)$$

$$\left(\frac{V_S - V_O}{L}\right) t_{ON} + \left(\frac{-V_O}{L}\right)(T - t_{ON}) \quad (10)$$

With finishing eq. [10] will be obtained

$$V_O = V_S \frac{t_{ON}}{T} \quad (11)$$

$$V_O = V_S D \qquad ; 0 < D < 1 \quad (12)$$

Where D is duty cycle.

B. Selection of Components

Buck converter circuit consists of inductor, capacitor, diode, switch and load. The selection ofappropriate componentsplay an important rolein the design ofthe circuitfor the system tooperateoptimally.

1) Switch

Some componentscanbe usedtopowerelectronicswitches, among others; BJTs, MOSFETs, IGBTandCOOLMOS. Transistorsare generallyusedforlow to mediumpower applications. While theMOSFETis avoltagecontrolledcomponents, are better suitedforlow power applicationsandhigh frequencyconverters, IGBTis moresuitable forhigh power applications [7]. For applicationsin50W PV,willbe usedMOSFET 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 $V_{DSS} >$ Vs = 20 Volt. For drain current I_D based on output power so that $I_D >$ D * Iout.

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 VDSS of 100 V and I_D of 15 A.

2) Inductor

Inductor valueused dependson theswitching frequencywillalsoaffectthe size of theinductor. The higher theswitching frequency, the value andsize of theinductorisusedalsowill be smaller. Forcontinuous operationtheinductor currentwillalways be greaterthanzeroso that theinductor valuecan be determinedby the equation

$$L = \frac{(1-D).V_O}{2.f.I_O} \quad (13)$$

Where f is switching frequency and I_O is output current.Inductorsareselected usingthe typetoroid, acomponentthat is suitable forhigh frequency applications.

3) Diode

With aswitching frequencyof200KHzthenrequire adiodewitha fastrecoverytimesousedSchottkydiodes. Diodereversevoltagemust beable toface the PVoutput voltage.

4) Capacitor

Capacitance value which used will be influence to ripple output voltage. Capacitor value can be determined by

$$C = \frac{(1-D)V_O}{2f^2 L V_{ripple}} \quad (14)$$

Where V_{ripple} is ripple output voltage.

IV. SIMULATION

To determine thecharacteristics of thebuck convertercircuitthathas beendesignedthrough simulationusingSimulinkmatlab. Circuit diagram of buck converterforsimulationas shown inFig4. Based on thecalculation ofthe valueof inductor0.2mH, capacitor4.34µF, source voltage 20Vandswitching frequency200KHz.

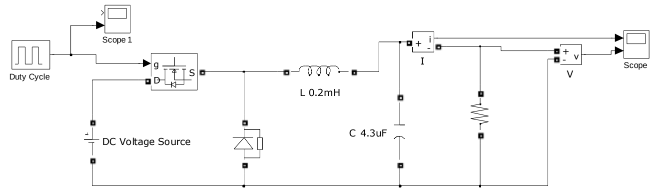


Fig 4. Simulation Buck Converter Circuit

The simulation result of the buck converter at duty cycle 50% as shown in fig 5 and at duty cycle 80% in fig 6.

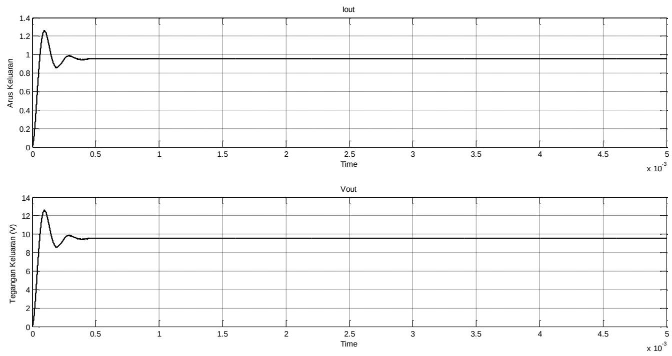


Fig 5. Simulation Result For Duty Cycle 50%

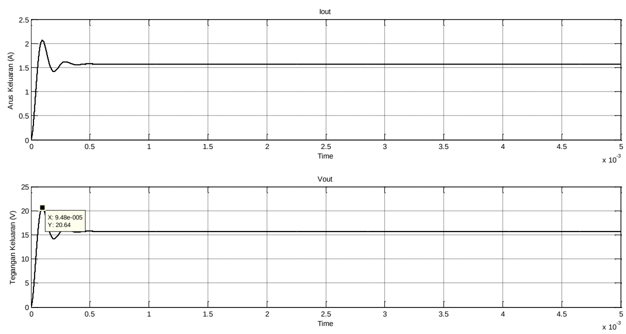


Fig 6. Simulation Result For Duty Cycle 80%

V. RESULT AND DISCUSSION

Based on the simulation results obtained voltage and output current circuit. With aduty 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 stady 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.

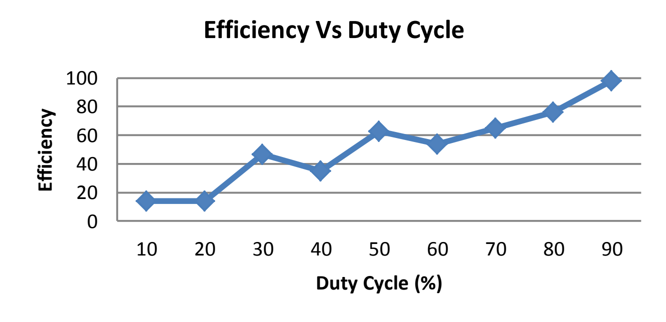


Fig 7. Efficiency to Duty Cycle

Duty cyclechangeswillresult inchanges involtageandoutput power. It alsowillaffect theefficiency ofthe circuit. The relationshipbetweenthe efficiency ofthe circuitwithduty cycleusedis shownin Fig7. The higher duty cycle will increase efficiency of circuit.

VI. CONCLUSION

Buck convertercircuit design for photovoltaic applications have been described. The circuit works incontinuous mode with aswitching frequency of 200 KHz. Determination of the componentsbased onthe needs of photovoltaic systems with duty cyclesettings. The increasing efficiencyis proportional to the circuitduty cycle.

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