International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 8, August - 2014

Power Electronics Application in Renewable Energy

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Abstract— **Over the last few decades there has been a considerable depletion of non-renewable energy resources and it has produced green house gases. To reduce the impact on environment and meet the increasing power demand it is important to shift focus on renewable energy. Use of distributed generation in the grid has accelerated momentum. This paper focuses on the use of solar energy for meeting the power demands; also it emphasizes the role of power electronics for its stability. Its represents a overview of photovoltaic systems, its principle and its synchronizing power with the grid. A Matlab simulation in Simulink of a DC-DC Converter for stable output voltage from a solar panel is presented in the paper.**

Keywords— Buck boost converter, PV, Simulink.

I. Introduction

Last few decades saw increase in distributed generation where various forms of energy like solar, wind, geothermal were used. These sources of energy are used to transmit power only to short distances. They also create less impact on the environment and gives improved security of supply. This paper focuses on photovoltaic technology used in power generation. Photovoltaic cells consist usually of large solar farms which feed the power to the grid. Generation of power form photovoltaic cells is DC (Direct Current), which is then given to a DC-DC converter for a stable output voltage and then to the inverters which convert DC power to AC power and then feed it to the grid. Certain modern system employ MPPT (Maximum Power Point Tracking) unit which continuously monitors the voltage according to the motion of the sun.

DC-DC converter is the most important step in this process as it gives a constant output voltage for charging the batteries. DC-DC converter is a power electronic circuit employing high frequency switching of MOSFET's or IGBT. DC-DC converter can buck or boost the input voltage according to its circuit configuration which ultimately helps to achieve constant voltage during under-voltage or over voltage condition. The battery voltage declines as its stored energy is drained, switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. The cost of renewable energy technologies is on a falling trend and is expected to fall further as demand and production increases. Power electronics find applications in most RES technologies, solar and wind energy systems being the most important applications.

II. Power electronics for PV

The PV modules and the power electronics that convert the produced electric power by the PV modules are the basic parts of a PV installation. The PV modules comprise several solar cells which convert the energy of the sunlight directly into electricity, and are connected in a proper way (typically in series), to provide desired levels of DC current and voltage. They produce electricity due to a quantum mechanic process known as the "photovoltaic effect". There are many semiconductor materials suitable for solar cells manufacturing. The most commonly used are monocrystalline Si cells, polycrystalline Si cells and amorphous Si cells, although several other thin film technologies exist in the market. All PV modules have a typical current-voltage characteristic curve, used to make all necessary calculations. There are two types of PV systems: stand alone and grid connected. The first is used in remote locations, where the utility grid is not present. The grid connected systems inject power and energy directly to the utility grid. These systems have different structure and the inverters which are used have different methods to synchronize and produce clean AC power. Off-grid PV systems are used in cases, where the grid is not present and the use of batteries to store energy is required, in order to cover the demand during the night or whenever energy is needed. Blocking diodes are used to prevent the batteries to discharge on the modules during the night, while they also protect the batteries from short circuit. If more than one string is used, they also provide over-current protection of the strings in case of short circuits. Charge regulators control the charging of the batteries. In off-grid systems, there is the need to use dc voltage and current with stable characteristics, independent from irradiance fluctuations. Therefore, a DC – DC conversion topology is used. Switch mode DC – DC converters are used to match the dc output of a PV generator to a variable load. Three different topologies are mostly used; step down converters, step up converters and a combination of these two.

III. PRINCIPLE OF PHOTOELECTRIC EFFECT

There are few metals which emit electrons when exposed to sunlight. Electrons in this form are called as photoelectrons. In this principle mainly energy of light is transmitted to electrons so that they get detach from their orbit and later constitute a

ISSN: 2278-0181
Vol. 3 Issue 8, August - 2014

current when connected across a load. By changing amplitude and wavelength we can control the rate of emission. Electrons are only dislodged by the photoelectric effect if light reaches or exceeds a threshold frequency, below which no electrons can be emitted from the metal regardless of the amplitude and temporal length of exposure of light. Devices based on the photoelectric effect have several desirable properties, including producing a current that is directly proportional to light intensity and a very fast response time. In the photovoltaic effect, a voltage is generated when the electrons freed by the incident light are separated from the holes that are generated, producing a difference in electrical potential. This is typically done by using a *p-n* junction rather than a pure semiconductor. A *p-n* junction occurs at the juncture between *p*-type (positive) and *n*-type (negative) semiconductors. These opposite regions are created by the addition of different impurities to produce excess electrons (*n*-type) or excess holes (*p*-type). Illumination frees electrons and holes on opposite sides of the junction to produce a voltage across the junction that can propel current, thereby converting light into electrical power. Other photoelectric effects are caused by radiation at higher frequencies, such as X-rays and gamma rays. These higher-energy photons can even release electrons near the atomic nucleus, where they are tightly bound. When such an inner electron is ejected, a higher-energy outer electron quickly drops down to fill the vacancy.

IV. DC-DC CONVERTER

Several methods exist to achieve DC-DC voltage conversion. Each of these methods has its specific benefits and disadvantages, depending on a number of operating conditions and specifications. DC-DC converter can perform buck, boost or buck-boost operation according to the design of the circuit. Buck and Boost are basic topologies and the rest of the topologies are derived from these two topologies. Buck-Boost topology gives the liberty to step up and step down the voltage at will. The simulation is done in Matlab Simulink, where figure 2 represents the model of a typical Buck-Boost converter. The circuit consists of DC input (In this case from the solar panel), diode, capacitor, inductor and an IGBT switch. The average output voltage can be controlled by controlling the switching frequency of the switch and adjusting the ON duration of the switch. In practical circuits, loads will be inductive and switch will have to absorb the inductive energy and therefore it may be destroyed. The problem is overcome by using a diode; also using a low pass filter of inductor and capacitor the output voltage fluctuations are diminished. The value of output capacitor is assumed to be very large for generating a constant instantaneous output voltage. The average inductor current is equal to average output current since the average capacitor current is zero. During the time when the switch is on the diode is reversed biased and the input provides energy to the load as well as to the inductor. During the time interval when the switch is off, the inductor current flows through diode, transferring all the stored energy to the load.

A important term relating input voltage with the output voltage is the duty ratio. Duty ratio is defined as the on time of the switch to the total switching time.

$$D = T_{on} / T \qquad (1)$$

$$V_0 = D*V_d / (1-D) \qquad (2)$$

T_{on} represents the on time of the switch, whereas T is the total time of one switching cycle. Equation 1 shows the relation of duty ratio with T_{on} and T. The equation 2 shows the relation of output voltage relating with duty ratio and input voltage. In buck mode the output voltage is less than the input voltage, this mode is applied when panel voltage at input side increases and we require a steady constant output voltage. A boost mode will produce the output voltage larger than the input voltage. This is applied generally when solar panel voltage drops. The Buck-book topologies DC-DC Converters are used in many applications like UPS, Spacecraft, and Power-Factor improvement. These topologies are acting like DC transformers and in future will find wide application in PV modules. For the Buck-Boost Converter the input is the voltage from PV modules and as the input fluctuates the duty cycle will get adjusted to give a desired constant output voltage. The practical results of input and output voltage with corresponding circuit parameters are represented above. The output voltage is a function of duty cycle and input voltage. The main aim of any DC-DC converter is the have a desired constant output voltage.

The IGBTs and MOSFETs with high pulsing frequencies provide improved power quality in compliance with the regulations of the utility grid. The high frequency used has led to the use of high frequency transformers with lower weight. This fact reduced the total weight of the inverters significantly (up to 20%). The lower the weight is, the easier the installation and the lower the transportation costs are. In grid-connected applications the energy is provided directly to the grid and the necessary parts are the PV modules and the inverters. This reduces the cost of the system and it also reduces the necessary maintenance, as the batteries are the most maintenance-demanding components. The inverters for grid connected applications may have different topology and operation than off-grid ones. They have to produce excellent quality sine wave output, follow the frequency and voltage of the grid and extract maximum power from the PV modules through the MPPT. The grid inverter always monitors the grid and the output voltage and frequency must be controlled. The most common modulation is the PWM modulation and operates at a range of 2 to 20 KHz. Grid connected inverters are classified as voltage source inverters (VSI) and current source inverters (CSI). However, in PV applications VSI inverters are used. The MPPT (Maximum Power Point Tracking) is often performed via a high frequency DC to DC converter. Its input is the output of the solar panels strings. It converts the DC input to high frequency AC, and then back to a different DC voltage and current in order to match the panel voltage to that of the batteries. MPPTs operate at very high (audio range) Frequencies, usually in the 20-80 kHz range. The advantage of high frequency circuits is that they can be designed with high efficiency and small volume transformers and other components.

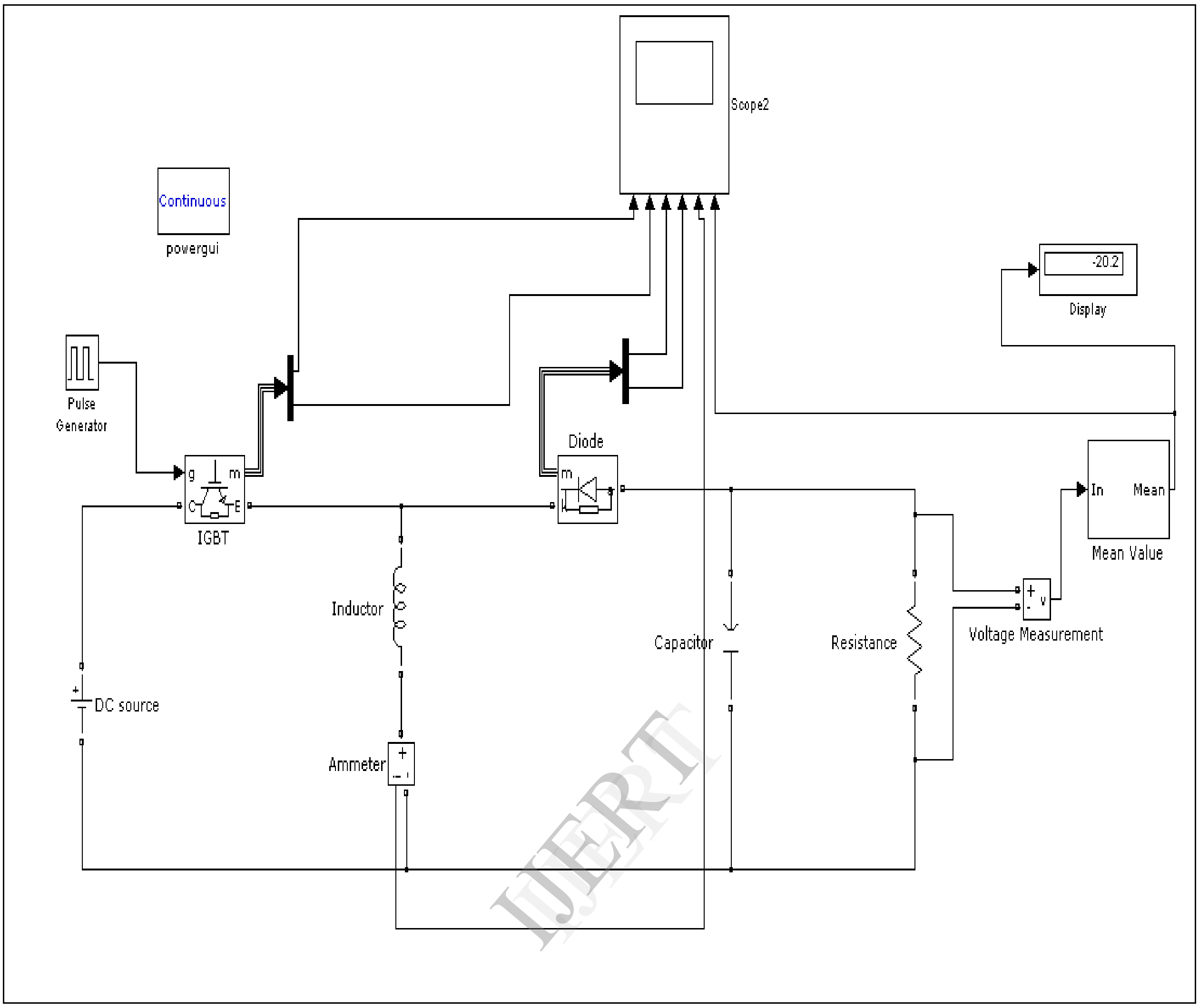

Fig.1. Simulation of Buck-Boost Converter.

V. BUCK-BOOST CONVERTER SIMULATION

The above diagram shows simulation of a buck-boost converter done in MATLAB Simulink where the various values of components and practical results are represented below:

TABLE I
BOOST CONVERTER:

DC Voltage	15V
Inductance	0.09mH
Capacitance	0.2mF
Resistance	10ohms
Duty cycle	60%
Switching Frequency	25khz
Switch	IGBT
Output Voltage	-20.2V

Due to the boost operation of the circuit the output voltage is more than the input voltage which depends on the duty cycle, waveforms of buck operation is show below.

TABLE II
BUCK CONVERTER:

DC Voltage	15 V
Inductance	0.09mH
Capacitance	0.2mF
Resistance	10ohms
Duty Cycle	40%
Switching Frequency	25khz
Output Voltage	-8.533V

The results tabulated shows that if input is same we can get different outputs as we desire. Simulation results clearly show that none of the circuit parameters are changed for achieving buck or boost operation except varying the duty ratio. The output voltage in boost operation is having a negative polarity due to the inverted position of the output capacitor. In pratical situations input keeping on varying as is the case with solar panel and just by changing the duty cycle we are able to get a constant output voltage. Equation 2 stated above will help us in achieving the constant output voltage with changing input voltage. The variation of the duty ratio can be between 0 to 1. In this range it performs buck or boost operation according to the circuit parameters. Cuk and flyback are other forms of converter which can also be used according to the application.

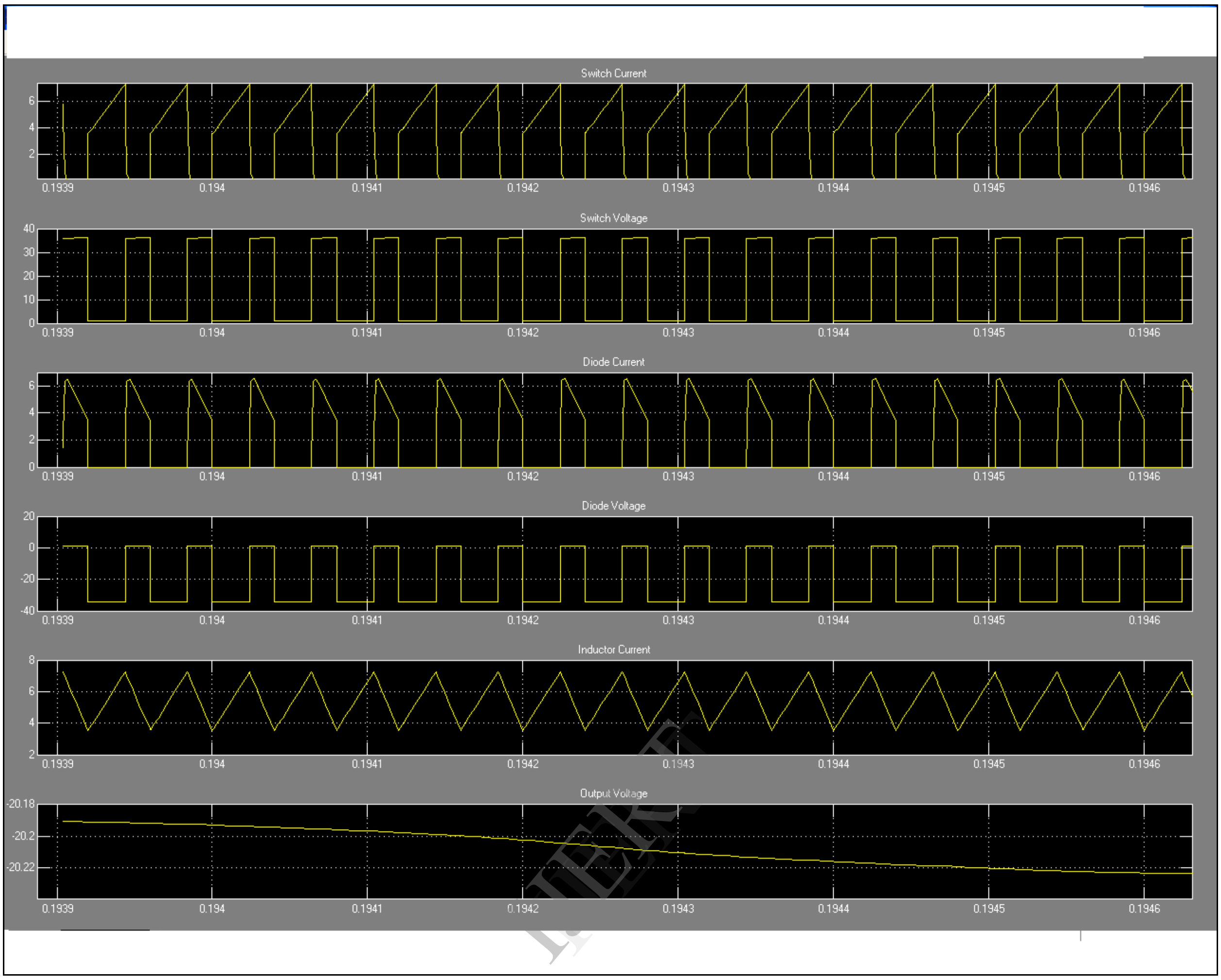

Fig.2. Waveforms of Buck-Boost Converter

The waveforms of switch current, switch voltage, diode current, diode voltage, inductor current, output voltage are plotted against time.

VI. CONCLUSION

The paper focuses on application areas of power electronics in PV systems. It then goes on to explain the principle of Photoelectric effect. Then explains the DC-DC converter circuit, its application in PV systems and the role it plays in achieving a constant output voltage. Later, simulink results shows that by varying the duty cycle one can buck or boost a particular input voltage giving constant output voltage. This DC-DC converter has lot of scope in PV systems in future. It calls for wider research in areas to improve power quality, reduce harmonics, increase inverter efficiency etc.

ACKNOWLEDGMENT

I would like to thank my college professors who gave good theoretical knowledge and taught me power electronics Matlab simulation in simulink. It is finally because of their guidance and encouragement I wrote this technical paper.

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