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MODELLING AND SIMULATION OF BOOST CONVERTER FOR SOLAR PV SYSTEM

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ABSTRACT: This paper represents the recent up surge in the demand of PV systems is due to the fact that they produce electric power without hampering the environment by directly converting the solar radiation into electric power. However the solar radiation never remains constant. It keeps on varying throughout the day. The need of the hour is to deliver a constant voltage to the grid irrespective of the variation in temperatures and solar insolation. In this paper we have designed a circuit such that it delivers constant and stepped up dc voltage to the load. We have studied the open loop characteristics of the PV array with variation in temperature and irradiation levels. Then we coupled the PV array with the boost converter in such a way that with variation in load, the varying input current and voltage to the converter follows the open circuit characteristic of the PV array closely. At various insolation levels, the load is varied and the corresponding variation in the input voltage and current to the boost converter is noted. It is noted that the changing input voltage and current follows the open circuit characteristics of the PV array closely. DC-DC converters are electronic devices used to change DC electrical power efficiently from one voltage level to another. Operation of the switching devices causes the inherently nonlinear characteristic of the DC-DC converters including one known as the Boost converter. Consequently, this converter requires a controller with a high degree of dynamic response. Proportional- Integral-Differential (PID) controllers have been usually applied to the converters because of their simplicity. However, the main drawback of PID controller is unable to adapt and approach the best performance when applied to non linear system.

I. INTRODUCTION

General Overview

The Conventional sources of energy are rapidly depleting. Moreover the cost of energy is rising and therefore photovoltaic system is a promising alternative. They are abundant, pollution free, distributed throughout the earth and recyclable. The hindrance factor is its high installation cost and low conversion efficiency. Therefore our aim is to increase the efficiency and power output of the system. It is also required that constant voltage be supplied to the load irrespective of the variation in solar irradiance and temperature. PV arrays consist of parallel and series combination of PV cells that are used to generate electrical power depending upon the atmospheric conditions (e.g. solar irradiation and temperature). So it is necessary to couple the PV array with a boost converter. Moreover our system is designed in such a way that with variation in load, the change in input voltage and power fed into the converter follows the open circuit characteristics of the PV array. Our system can be used to supply constant stepped up voltage to dc loads. The massy usage of the fossil fuels, such as the oil, the coal and the gas, result in serious greenhouse effect and pollute the atmosphere, which has great effect on the world. Meanwhile, there is a big contradiction between the fossil fuels supply and the global energy demand, which leads to a high oil price in the international market recently. The energy shortage and the atmosphere pollution have been the major limitations for the human development. How to find renewable energy is becoming more and more exigent. Photovoltaic (PV) sources are one of the significant players in the world’s energy portfolio and will become the biggest contributions to the electricity generation among all renewable energy candidates by year 2040 because it is truly a clean, emission-free renewable electrical generation technology with high reliability. The task of a maximum power point tracker (MPPT) in a photovoltaic (PV) energy conversion system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions. Since the solar array has a non-ideal voltage – current characteristic and the conditions such as insulation, ambient temperature, and wind that affect the output of the solar array are unpredictable, the tracker must contend with a nonlinear and time-varying system. Many tracking algorithms Simulation of Closed Loop Controlled Boost Converter for Solar Installation and techniques have been developed. The perturbed and observed method and the Incremental Conductance method, as well as variants of those techniques are the most widely used. The perturbed and Observe method is known for its simple implementation, but it deviates from and observe method oscillates close to a maximum power point (MPP) in the atmospheric conditions are constant or slowly changed. However when weather rapidly changes the perturb and observe method fails to track the maximum power point effectively. Other methods for solar array MPP tracking include short circuit current and the open circuit voltage of the PV module techniques. The MPP tracking method using the short circuit current of the PV module exploits the fact that the operating current at the MPP of the solar array is linearly proportional to its short circuit current. Thus, under rapidly changing atmospheric conditions. This method has a relatively fast response time for tracking the MPP. However, the control circuit is still somewhat complicated and both the conduction loss and the cost of the MPPT converter are still relatively high. Furthermore, the assumption that the operating current at the MPP of the PV module is linearly proportional to the short circuit current of the PV module is only an approximation. In reality, the application of this technique always results in PV module operation below the maximum power point. Open circuit voltage of the PV module employs the fact that the open circuit voltage of the solar array at the MPP is linearly proportional to its open circuit voltage. This technique has some limitations and disadvantages as the short circuit current of PV module method described above. Although the method is cost efficient, its application results in considerable errors in MPP tracking and consequent energy losses. Additionally, both the open circuit voltage and the short circuit current of PV module techniques fail to track the MPP effectively if solar array cells are partially shaded or if some cells in the array are damaged. The limitations of the conventional boost converters are analyzed and the conceptual solution for high step-up conversion is proposed in this paper. Then the state-of-the-art topologies are covered and classified based on the circuit performance. The challenges in high step-up renewable energy applications are summarized to generate the next generation non-isolated high step-up DC/DC converters.

Urban Home System

Larger panels providing 200-400 volts are connected to an inverter to yield 120/240VAC at medium power levels (2-10kW). This system is connected to AC power lines through grid connection. The customer sells power to the power company during the day and buys power from the power company during the night. The grid-connected approach eliminates expensive and short- lived batteries. A couple of issues exist with this system. One, the inverter has potential as a single point of failure; and two, non-optimal power harvesting from the solar panels, especially in partial shading condition. Single Inverter with Multiple DC/DC Converters The use of DC/DC converters per string provides enhanced power harvesting from solar panels. The DC/DC converters may be separate modules or reside within the inverter module. This method is still susceptible to single- point-failure of the inverter, and involves the distribution of high voltage DC power – a potentially dangerous situation because direct current power fusing is difficult to achieve.

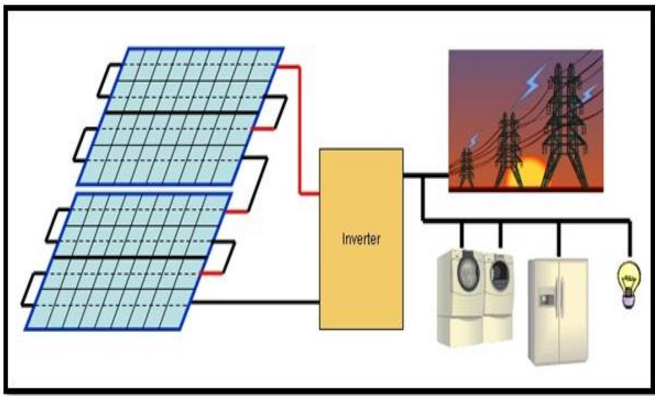

Figure1.1 Urban Home System

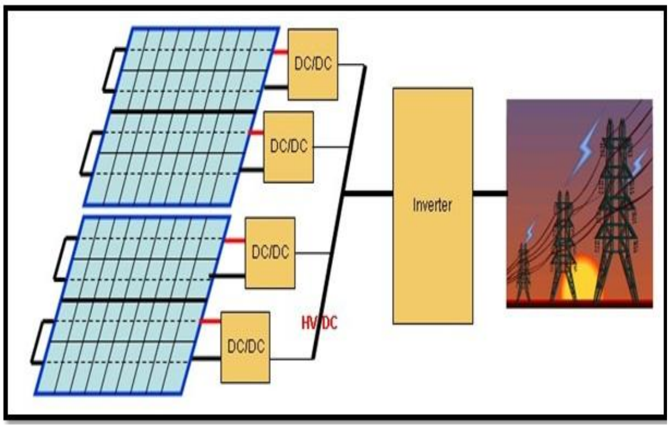

Figure1.2 Single Inverter with Multiple DC/DC

Panels providing 200-400voltsare connected to multiple inverters to yield120/240VAC at medium power levels (2-10kW). The inverters are connected to the grid. Use of multiple inverters provides enhanced power harvesting from solar panels and also provides enhanced system reliability.

What is photo voltaic system?

Photovoltaic (PV) power systems convert sunlight directly into electricity. A residential PV power system enables a homeowner to generate overall of their daily electrical energy demand on their own roof, exchanging day time excess power for future energy needs (i.e. night-time usage). The house remains connected to the electric utility at all times, so any power needed above what the solar system can produce is simply drawn from the utility. PV systems can also include battery backup or uninterruptible power supply (UPS) capability to operate selected circuits in the residence for hours or days during a utility outage. The purpose of this document is to provide tools and guidelines for the installer to help ensure that residential photovoltaic power systems are properly

II. SOLAR PV AND BATTERY OPERATING SYSTEM

Solar cell

There are several types of solar cells. However, more than 90 % of the solar cells currently made worldwide consist of wafer-based silicon cells. They are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. However, they indicate lower efficiencies than wafer-based silicon solar cells, which mean that more exposure surface and material for the installation is required for a similar performance. A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

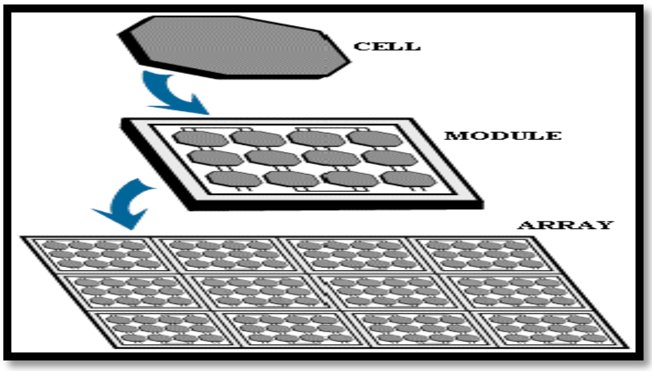

Fig-1.3 ELECTRICAL CONNECTION OF THE CELLS

There are two basic connection methods: series connection, in which the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, in which all the top contacts are connected together, as are all the bottom contacts. In both cases, this results in just two electrical connection points for the group of cells.

THE PHOTOVOLTAIC SYSTEM

A PV system consists of a number of interconnected components designed to accomplish a desired task, which may be to feed electricity into the main distribution grid, to pump water from a well, to power a small calculator or one of many more possible uses of solar-generated electricity. The design of the system depends on the task it must perform and the location and other site conditions under which it must operate. This section will consider the components of a PV system, variations in design according to the purpose of the system, system sizing and aspects of system operation and maintenance.

System design

There are two main system configurations – stand-alone and grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads. It may include a storage facility (e.g. battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can also be fed from the grid. It is also possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. These systems are then known as 'hybrid' systems. Hybrid systems can be used in both stand-alone and grid-connected applications but are more common in the former because, provided the power supplies have been chosen to be complementary, they allow reduction of the storage requirement without increased loss of load probability. Figures below illustrate the schematic diagrams of the three main system types.

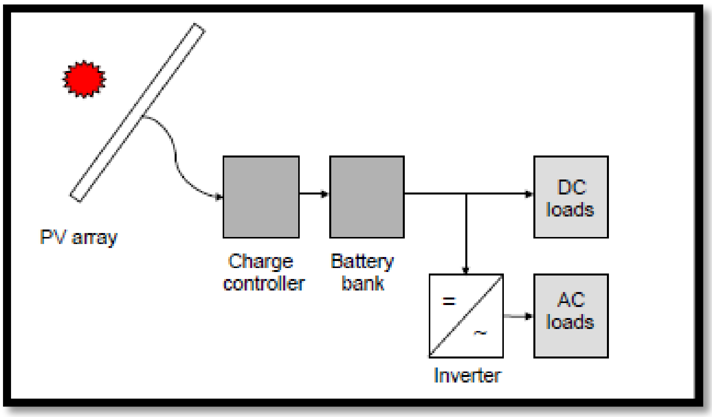

Fig-1.4 Schematic diagram of a stand-alone photovoltaic system

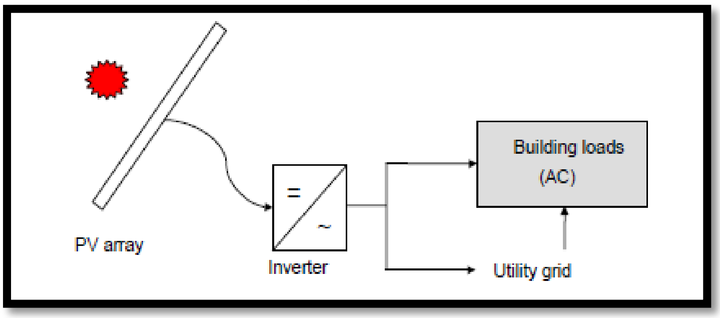

Fig-1.5 Schematic diagram of grid-connected photovoltaic system

CONVERTERS

DC-DC converters

Now days, as our life is getting more advances in technology, most of the technologies use power electronics to function. Also-called boost converter is including as one of the power electronic device. Due to the growing importance of the boost converter in technology, a detail study of boost converter is necessary to make an improvement for future technology. A good boost converter can make the technology more efficient in usage.

The key in controlling a DC-DC boost converter is the switching process that needs to be monitor frequently and perfectly. To gain a good output result, the switching process must be in a high switching frequency. Due to high switching frequency, it is hard to see the switching process, hence it need to be controlled by some appropriate controller such proportional integral derivative (PID) controller, hysteresis controller and others controller. This paper introduces three methods of controller to control the DC-DC boost converter, i.e., proportional integral derivative (PID) controller.

DC-DC converter can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about100 times longer than the transistor switching time to maximize efficiency. This limitation is due to the switching loss in the transistor. The transistor switching loss increases with the switching frequency and thereby, the efficiency decreases. The core loss of the inductors limits the high frequency operation. Control voltage Vc is obtained by comparing the output voltage with its desired value. Then the output voltage can be compared with its desired value to obtain the control voltage Vcr. The PWM control signal for the dc converter is generated by comparing Vcr with a saw tooth voltage Vr.[8]. There are four topologies for the switching regulators: buck converter, boost converter, buck-boost converter, cứk converter. However this paper work deals with the boost regulator and further discussions will be concentrated towards this one.

Boost Converter and its Operation

The figure belows hows a stepup or PWM boost converter. It consists of a dc input voltage source Vg, boost inductor L, controlled switch S, diode D, filter capacitor C, and the load resistance R. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

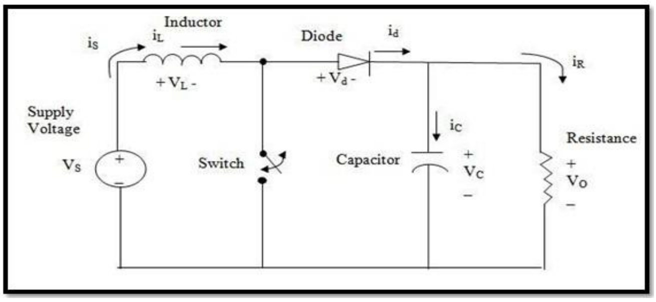

Figure: 2.1 Steady State Analysis of the Boost Converter

(a) OFF STATE: In the OFF state, the circuit becomes as shown in the fig

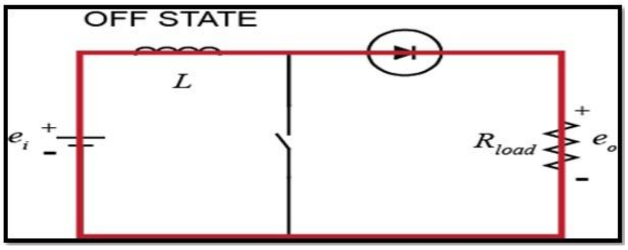

Figure2.2 The OFF state diagram of the boost Converter

When the switch is off, the sum total of inductor voltage and input voltage appear as the load voltage.

(b) ONSTATE: In the ON state, the circuit diagram is as shown below in

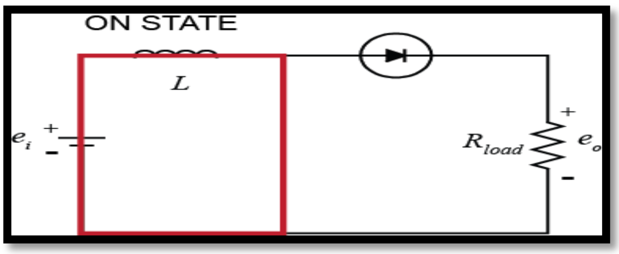

Figure2.3The ON state diagram of the boost converter

When the switch is ON, the inductor is charged from the input voltage source Vg and the capacitor discharges across the load. The duty cycle

$$D=\frac{T_{on}}{T} \text{ where } T=\frac{1}{f}$$

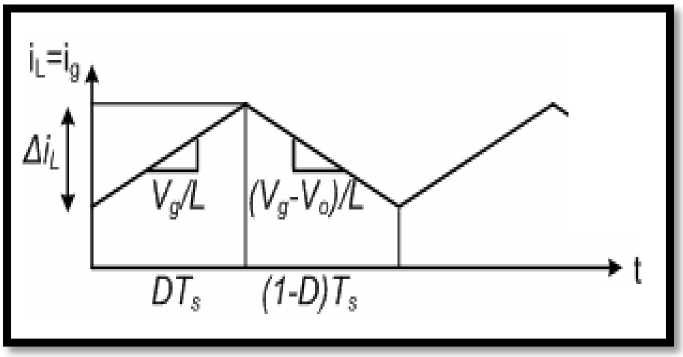

Figure 2.4 Inductor voltage waveform

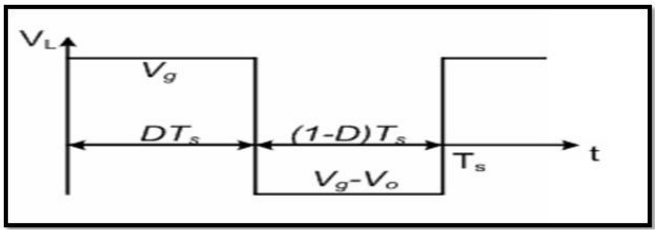

Figure2.5 Inductor current waveform

From The Inductor voltage balance equation, we have

$V_g(DT_s)+(V_s-V_o)(1-D)T_s=0$

$\Rightarrow V_g(DT_s)-V_g(DT_s)-V_gT_s+V_0DT_s-V_0T_s=0$

$\Rightarrow V_0=V_g/(1-D)$

$\Rightarrow$conversion ratio=V_0/V_g=$1/(1-D)$

From Inductor current ripple analysis, change in inductor current,

$\Delta I_L=(I_{max}-I_{min})$

$\Rightarrow \Delta I_L=\left(V_g/L*(DT_s)\right)$

$\Rightarrow \Delta I_L=\left(V_gD\right)/(f_sL)$

$\Rightarrow$L=$V_gD/f_s(\Delta I_L)$

The boost converter operates in CCM (continuous conducting mode) L>L_b where

$$L_b=\frac{(1-D)2DR}{2f}$$

3.3 Design of the Boost Converter

(1) CURRENT RIPPLE FACTOR (CRF):

According to IEC harmonics standard, CRP should be bounded within 30%.

i.e $\frac{\Delta I_1}{I_1} = 30\%$

(2) VOLTAGE RIPPLE FACTOR (VRF):
i.e. $\frac{\Delta V_0}{V_0}$
(3) SWITCHING FREQUENCY (fs):
Fs= 100 KHz
Given Data:
Input voltage, Vg=25V
Output voltage, Vo=300V
Output load current, Io=1A
Step 1: Calculation of Duty cycle (D):

$$\frac{V_0}{V_g} = \frac{1}{1-D}$$

$$\Rightarrow \frac{1}{1-D} = \frac{300}{25}$$

$$\Rightarrow D=11/12=.9166$$

Step 2: Calculation of Ripple Current:

$$I_L = 1\text{ A}$$

$$\Rightarrow \Delta I_L = (0.3 * 1)\text{A} = 0.3\text{ A}$$

Step 3: Calculation of Inductor value (L):

$$L = \left(\frac{Vg * D}{f * \Delta I_L}\right) = (25*.9166)/(0.3*10^5) = 7.63 * 10^{-4}\text{ H.}$$

Step 4: Calculation of capacitor value(C):

We have, $\frac{\Delta V_0}{V_0} = \frac{DTs}{R_0 C}$

$$R_0 = \frac{V_0}{I_0} = 300/1 = 300\Omega.$$

$$C = D/f * R_0 * (\Delta V_0/V) = (.9166)/(10^5)*(300)*(.05) = .611\ \mu\text{F}.$$

$$G(s) = \frac{V_o}{1-D} * \frac{1 - \frac{Ls}{(1-D)^2 * R}}{\frac{LCs^2}{(1-D)^2} + \frac{Ls}{(1-D)^2 R} + 1}$$

The transfer function of the boost converter used for the modeling is given by:
Putting the values of R, L, C, D, Vg in the above equation, the transfer equation that results is given by trial and error, we get the value of KP which gives desired results as 6.03.

$$G(s) = \frac{25*(300-(100.716*10^{-3}))}{((.139*10^{-6})*S^2)+0.763*(10^{-3})*S+2.08}$$

III. PID CONTROLLER

PID Controller

Most of the control techniques for DC motor controller in industrial applications are embedded with the Proportional-Integral-Derivative (PID) controller. PID control is one of the oldest techniques. It uses one of its families of controllers including P, PD, PI and PID controllers. There are two reasons why nowadays it is still the majority and important in industrial applications. First, its popularity stems from the fact that the control engineer essentially only has to determine the best setting for proportional, integral and derivative control action needed to achieve a desired closed-loop performance that obtained from the well-known Ziegler-Nichols tuning procedure. A proportional integral derivation controller (PIDController) is a generic control loop feedback mechanism widely used in industrial control system. A PID is most commonly used feedback controller. Over 90% of the controllers in operation today are PID controllers (or at least some form of PID controller like a P or PI controller). This approach is often viewed as simple, reliable, and easy to understand. Controllers respond to the error between a selected set point and the offset or error signal that is the difference between the measurement value and the set point. Optimum values can be computed based upon the natural frequency of a system. Too much feedback (positive feedback cause stability problems) causes increasing oscillation. With proportional (gain) only control the output increases or decreases to a new value that is proportional to the error. Higher gain makes the output change larger corresponding to the error. Integral can be added to the proportional action to ramp the output at a particular rate thus bring the error back toward zero. Derivative can be added as a momentary spike of corrective action that tails off. Derivative can be a bad thing with a noisy signal.

Typical steps for designing a PID controller are:

- Determine what characteristics of the system need to be improved.
- Use KP to decrease the rise time.
- Use KD to reduce the overshoot and settling time.
- Use KI to eliminate the steady-state error.

IV. PULSE WIDTH MODULATION

Pulse Width Modulation (PWM):

The Simulink model for the generation of the PWM signal is shown below:

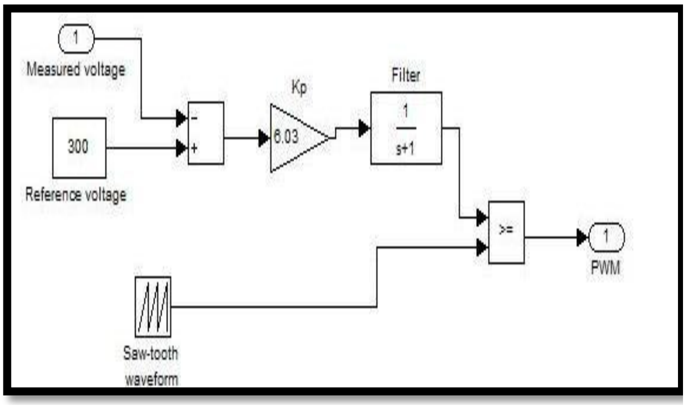

Figure 4.1 Simulink Model of PWM Signal Generation

The fundamental principle involved in making a boost converter is creating a square pulse to control the switching of the MOSFET. This square pulse is called the duty cycle and this duty cycle (D) controls the output voltage.

The transfer function is derived by the following set of equations. Figure 5.2 is the ideal gate voltage to be able to switch the MOSFET and create aboosted output voltage. The y-axis shows VGS (V) and the x-axis shows the time interval of the signal.

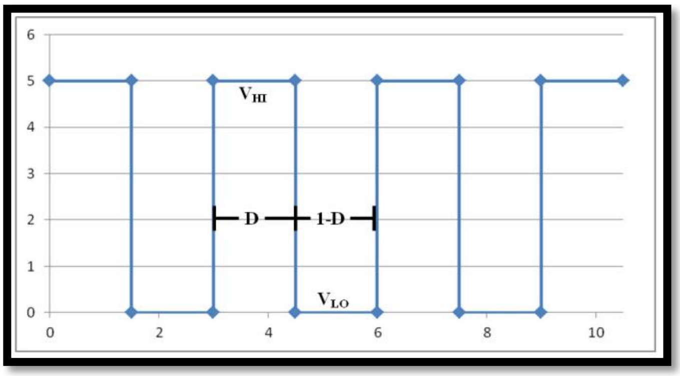

Figure 4.2: Gate Voltage on MOSFET

As the MOSFET gate switches to 0V, current is no longer sourced directly to ground, thus forcing current to the output. Conversely, when the gate is switched to 5V, the current in the inductor flows directly from the drain to the source which is connected to ground creating different voltages across the inductor. The voltage across the inductor is shown in Figure 5.3 and the voltage changes with the duty cycle.

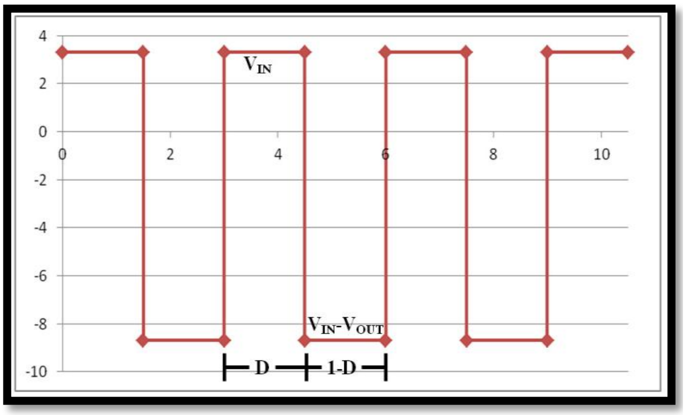

Figure 4.3 Voltage across the Inductor

The voltage across the inductor while VGS is at 5V is equal to VIN. The voltage across the inductor while VGS is at 0V is equal to VIN-VOUT. Because the constant voltages are applied to the inductor, the current through the inductor ramps up and down linearly with time according to Equation 4.1

$$V_L = L\frac{di}{dt}$$

Equation 4.1: Voltage Current Relationship in an Inductor

$$\frac{V_{IN}}{L}$$

The rising slope of the current through the inductor is show in Equation 4.2.

Equation 4.2: Rising Slope of Current through the Inductor

$$\frac{V_{IN} - V_{OUT}}{L}$$

The falling slope of the current through the inductor is show in Equation 4.3.

Equation 4.3: Falling Slope of Current through the Inductor

Based on the slope of the rising and falling slopes of the current through the inductor and the fact that the time duration is a known entity, the transfer function can be computed. The Relationship between the slope and time duration is shown in Figure 4.4 where the y-axis represents an arbitrary current value and the x-axis represents the time interval.

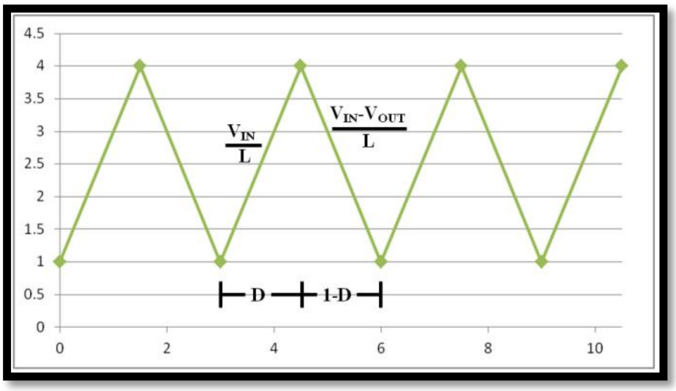

Figure 4.4: Current through the Inductor

$$\frac{V_{IN}}{L}(D) + \frac{V_{IN} - V_{OUT}}{L}(1 - D) = 0$$

After determining the slope and time interval, Equation 4.4 is derived.

Equation 4.4: Duty Cycle and Current Relationship

$$V_{OUT} = \frac{V_{IN}D}{1 - D} + V_{IN}$$

Algebraic steps were used to isolate VOUT which yields Equation 4.5.
Equation 4.5: VOUT of the Boost Converter

$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{1-D}$$

Lastly, the transfer function of the whole system is shown in Equation 4.6 below.
Equation 4.6: Transfer Function of the Boost Converter
The duty cycle of VGS is what allows a boost converter to function. As D increases, the gain also increases. In order to create a duty cycle, a PWM needed to be created. There are several methods of creating a PWM. The first of which is to use a function generator that can output an adjustable duty cycle square wave at a frequency up to 20MHz. However, most function generators cannot produce square waves up to 20MHz. The next method for creating a PWM is to compare a ramp wave to a DC value. As the DC value decreases or increases, the duty cycle increases or decreases respectively. This method is shown in Figure 4.5 below.

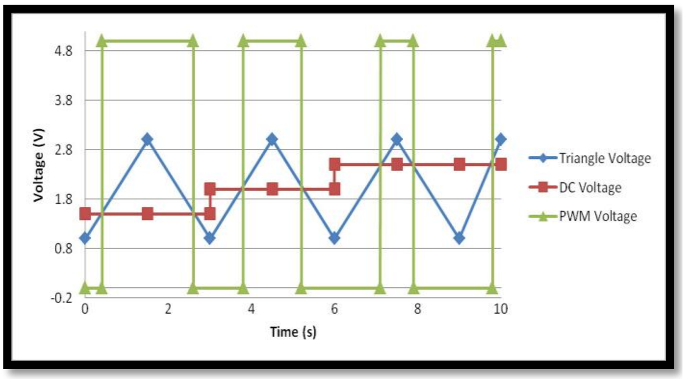

Figure 4.5: Creating a PWM by Comparing Two Waveforms
A triangle waveform is one wave that can be used to create a PWM. The other waveform is a saw tooth wave. The PWM created by using a saw tooth wave is shown in Figure 4.6 below.

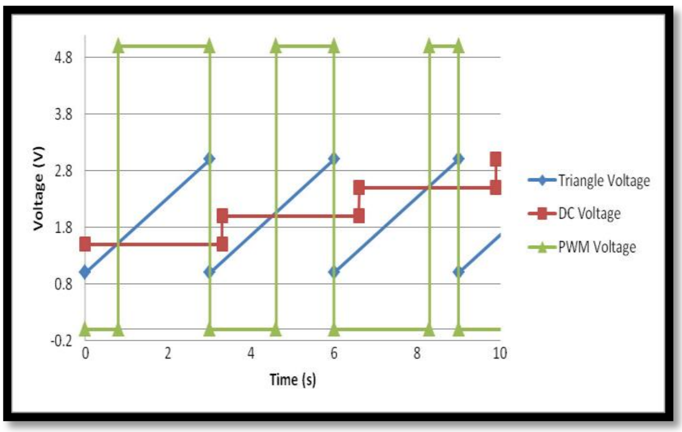

Figure 4.6: Creating a PWM by Comparing Two Waveforms
Either a saw tooth or a triangle wave would work to create a PWM needed for the boost Converter, but the triangle is an easier shape to create and the Triangle has a few distinct Advantages over the saw tooth.“An intrinsic advantage of modulation using a triangle carrier Wave is that the odd harmonic sideband components around odd multiples of the carrier Fundamental and even harmonic sideband components around even multiples of the carrier Fundamental are eliminated.” Additionally, a small change in the input voltage using the Triangle wave will result in a larger change in the PWM than when using a saw tooth.

V. SIMULATION WORK

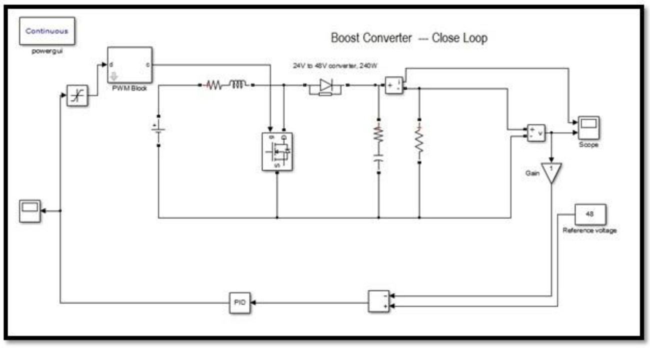

Figure 5.1 Close loop configuration of boost converter

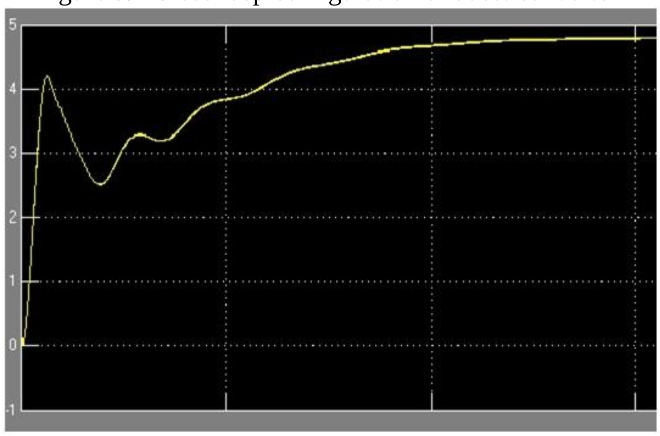

Figure 5.2 Voltage waveform of close loop boost converter

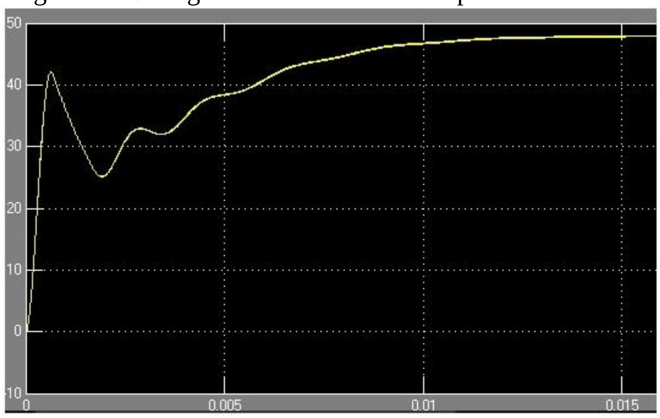

Figure 5.3 Current waveform of close loop boost converter

VI. CONCLUSION

DC-DC converters are an excellent way to get the most use out of a single power supply. Though the total power must remain constant, one can efficiently tradeoff between current strength and voltage levels to power a variety of sub-circuits without costly extra batteries.

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