International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8, Issue-1S5, June 2019

# DC-DC Converter for Renewable Energy Integration

**Ch.Santosh Kumar, S.Tara Kalyani**

***Abstract*:***Electricity shortage became a problem due to increase in load demand and to overcome this it is necessary to concentrate on non-conventional energy sources to extract electric power. This study gives the stability analysis of closed loop voltage mode control of buck converter in continuous conduction mode. Initially the mathematical analysis is carried out and frequency response is obtained for system stability. In the buck converter input voltage at one level is regulated to output voltage of other level based on frequency response of compensator by bode plots and feedback controller using PID. The analysis and design of circuit is done using MATLAB -Simulink software and results are also presented.*

***Index Terms*:** *Control Strategies, DC-DC Converters, Pulse Width Modulation, Renewable Energy Sources(RES).*

## I. INTRODUCTION

In recent trends shortage of power has became huge problem due to increase in electricity demand and is not possible to meet only by conventional power generation [1][2]. Hence green electricity is getting demand because of limited conventional power generation. To generate green electricity, different RES are used like sun, wind etc. Utilization of green electricity is increased exponentially and is integrated to grid. Even stand-alone applications are also increased but requires battery backup when ever renewable source is unavailable.In standalone solar applications two ways are there for giving supply to the loads one way is supplying continuously all the day and other way is supplying load form solar during day time and storing energy into the battery which is utilized remaining day. Hence it is not only necessary to extract the power from non conventional energy sources [3] but also to control it. DC-DC converters play a vital role for increasing the Power efficiency. Different types of DC-DC converters are there such as buck converter, boost converter, buck-boost converter etc. In this paper, analysis is carried out for buck converter, based on mathematical equations and stability analysis of the converter system is done using transfer function and switching frequency is obtained for the stability. The output of the solar is fed to buck converter to get controlled voltage and is fed to the battery, hence it is necessary to have buck converter in between Solar Input and load as shown in figure 1.

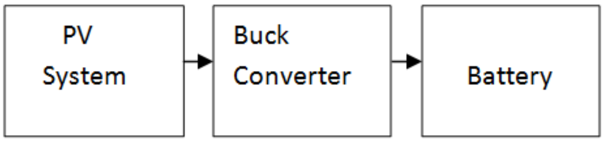


Figure 1: Block Diagram of Buck Converter for a PV System.

## II. OPERATION AND ANALYSIS OF BUCK CONVERTER

In buck converter the average output voltage $V_0$ is less than the input voltage $V_i$. as similar to step down converter. The circuit is operated in two modes. In mode one Switch is open and in mode two switch is closed as shown in figure 2 & figure 3 where L is filter inductor, C is filter capacitor , R is load resistor, i is input current, $i_L$ is current passing through inductor, $i_c$ is capacitor current, $i_o$ is output current.

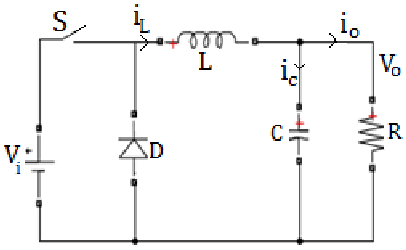


Figure 2: Buck converter when Switch S is in open condition

The figure 2 shows buck converter with input $V_i$ and switch is in open condition.

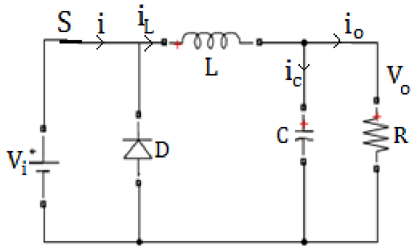


Figure 3: Buck Converter when Switch S is in closed condition.

Revised Manuscript Received on May 30, 2019.

**Mr Ch.Santosh Kumar**, Assistant Professor , Electrical & Electronics Engineering Department,BVRIT Hyderabad College of Engineering for Women, Hyderabad,Jawaharlal Nehru Technological University, Kukatpally, Hyderabad ,India

**Dr. S Tara Kalyani**, Professor,Electrical & Electronics EngineeringDepartment,Jawaharlal Nehru Technological University, Kukatpally, Hyderabad ,India


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The figure 3 represents the corresponding circuit of buck converter when switch S is in closed condition and the output voltage of buck converter is [4] $V_o = \delta \times V_i$ where $\delta$is duty cycle. Change in inductor current with respect to time is

$$\frac{di}{dt} = \frac{V_i - \delta V_i}{L} \quad (1)$$

The input current and capacitor current equations are

$$i = \int \frac{di}{dt} dt \quad (2) \quad (2$$

$$i_c = C\frac{dV_o}{dt} (3) \quad (3)$$

According to Kirchhoff's current law

$$i_L = i_c + i_o \quad (4)$$

The output current is

$$i_o = \frac{V_o}{R} \quad (5)$$

## III. FILTER CHARACTERISTICS

The figure 4 shows L-C filter with load R fed with input supply $V_i$.

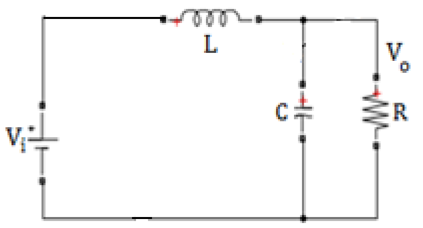


Figure 4: Frequency response of a L-C filter Circuit

The transfer function is

$$\frac{V_o(s)}{V_i(s)} = \frac{\frac{1}{LC}}{s^2 + \frac{S}{RC} + \frac{1}{LC}} (6)$$

Parameters [5] of circuit mentioned in figure 4 are L=16µH, C=540µF, R=0.5Ω.

The bode plot for above transfer function is represented in figure 5 and indicates that the filter has unity gain at lower frequencies , experiences a resonant peak and falls with a slope of 20dB/decade at higher frequencies and at these frequencies phase goes to $180^0$ lag. The gain margin is found to be infinity and phase margin is $29^0$ and this plot gives frequency response of filter without any voltage mode control.

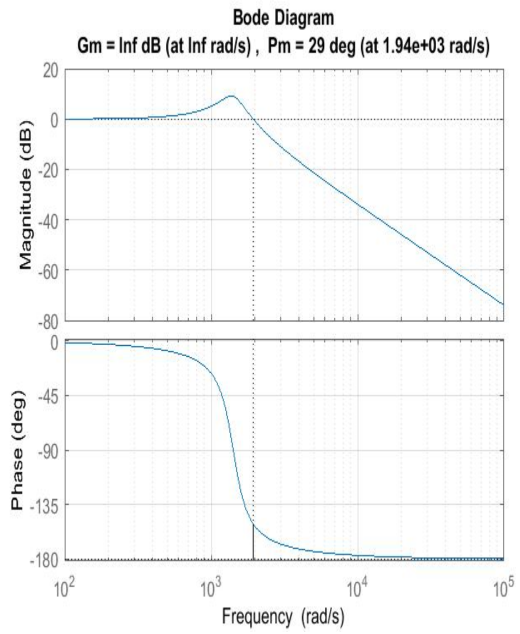


Figure 5: Magnitude and Phase plots of L-C filter

## IV. BUCK CONVERTER LINEARIZATION

This process involves separating of each variable into its DC (incapitals) and signal frequency ac components, and neglecting the products of twoterms. The product $V_i d$ is linearized about theoperating point, $V_i D$ [6] where D is turns ratio as shown in figure 6.

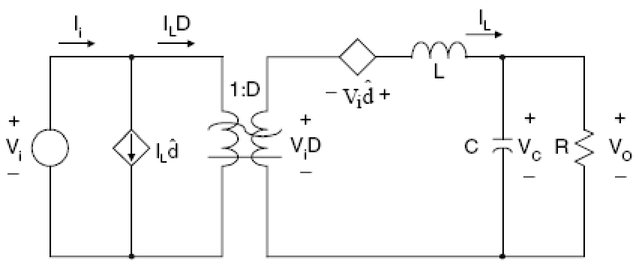


Figure 6:Linearized Buck Converter



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The purpose of linearization[5], [6] is to take application of Laplace Transform so that closed loop solutions can be found represented in block diagram as shown in figure 7 and respective bode plots can be drawn for stability analysis.

In Voltage mode control, the output voltage is returned through a feedback loop and this is compared to reference voltage and differential voltage is obtained by an error amplifier as shown in figure 7.

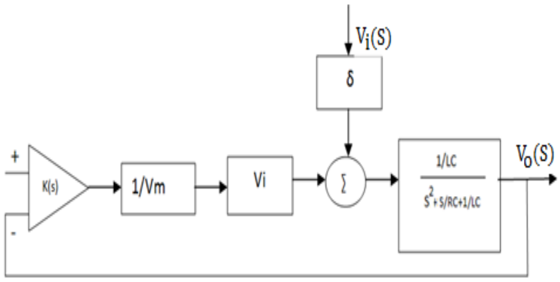


Figure 7: Block Diagram of linearized buck converter with voltage mode control

The overall open-loop gain is equal to product of individual gains of the error amplifier K(s), modulator $\frac{V_i}{V_m}$ and output filter as shown in equation (7).

$$G(s)\,H(s) = \frac{\frac{V_i \times K(s)}{V_m \times LC}}{s^2+\frac{s}{RC}+\frac{1}{LC}} \quad (7)$$

The above transfer function is solved as a function of frequency which results in bode plot. The figure 8 shows bode plot for the open loop gain for the parameters [6] and from the bode diagram the gain at low frequencies is high. To decrease this gain at less frequency such that unity-gain pointis reached with positive phase margin by compensated switching frequency.

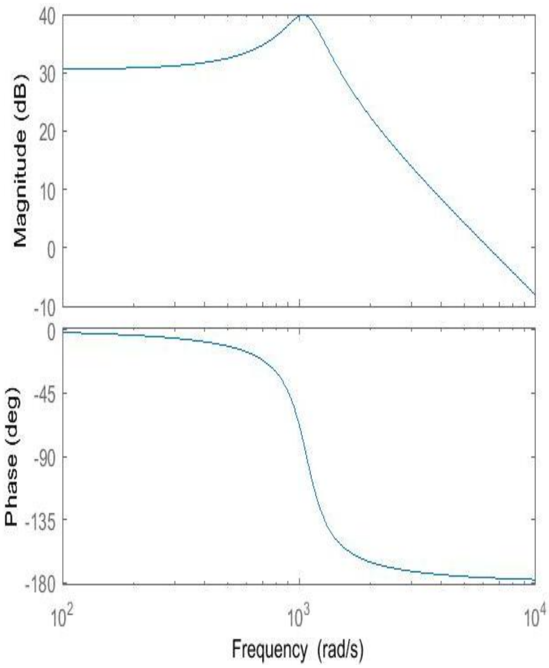


Figure 8: Frequency Response for open loop gain of Buck Converter

The amplifier gain with feedback is given as

$K(s) = \frac{R_2}{R_1(1+R_2C_2S)}$ with added pole $1/R_2C_2$, for parameters $R_2$=59KΩ, $R_1$=10.5KΩ and $C_2$=0.02μF.

The figure 9 shows the bode plot with compensator (solid line) and without compensator (dotted line). With feedback compensator peak gain is reduced from 39.8dB to 15.6dB with phase margin $42.5^0$ and gain margin 35.8dB and closed loop system is stable.

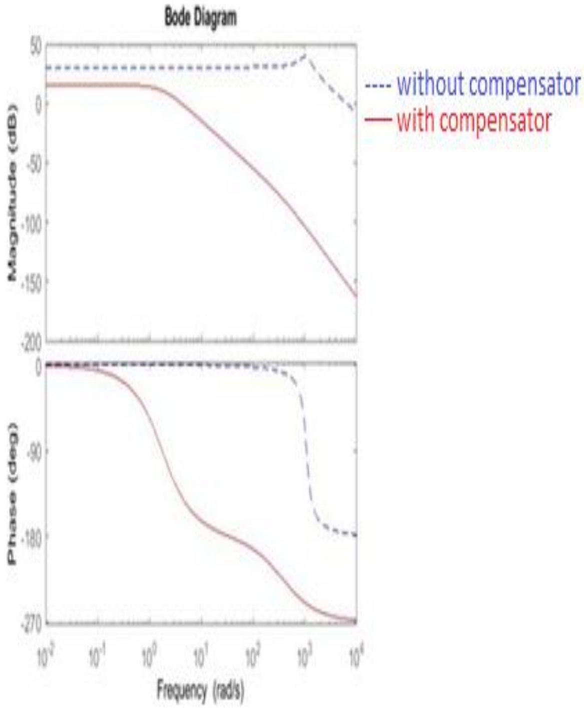


Figure 9: Frequency response of Voltage Mode Control of Buck Converter without and with compensator.

## V. SIMULATION

Buck Converter circuit is simulated in matlab/simulink software. Simulation circuits are designed using analysis equations, proportional integral derivative controllers. The figure 10 gives theblock diagram of buck converter with PID controller which represents the simulation circuit given in figure 10.


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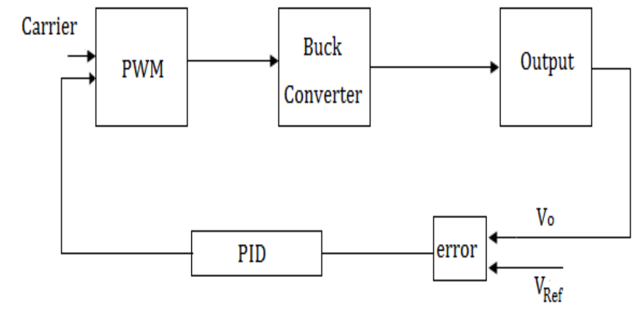


Figure10: Block Diagram with PID controller of Buck Converter

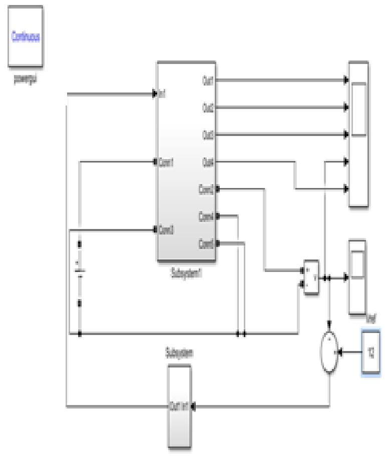

Figure11: Simulink Diagram with PID controller of Buck Converter

The figure 11 indicates simulation of buck converter with PID controller and values are P=10, I=3, D=0.00001 and simulation result is shown in figure 13 and from waveform it is observed that initially output voltage transient occurred and damped out at 9.5 milli seconds.

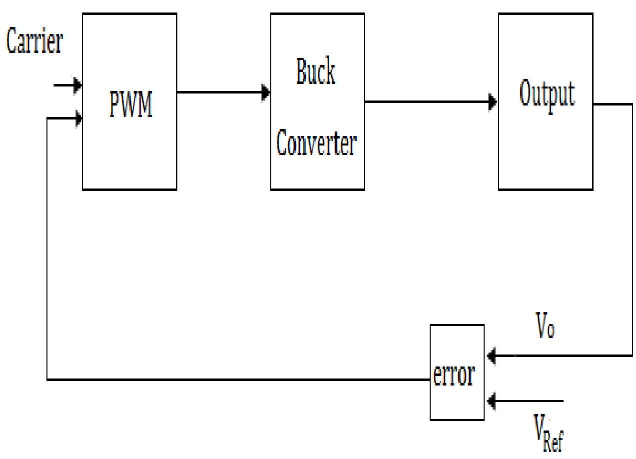


Figure 12: Block diagram without PID controller

The figure 12 indicates the overall diagram without PID controller represents the simulation circuit shown in figure 13.

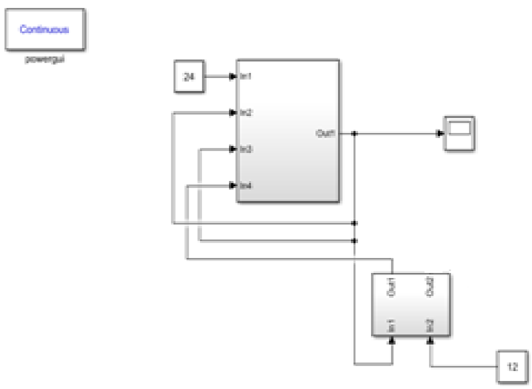


Figure 13: Simulation diagram without PID controller

The figure 13 represents simulation diagram without controller but the designed as per frequency response of Bode plot with compensator where the stability of the system occurred for the frequency 10 KHz.

TABLE I.

SIMULATION CIRCUIT PARAMETERS

| | |
|---|---|
| Input Voltage | 24V |
| Output Voltage | 12V |
| Inductor | 160µH |
| Capacitor | 540µF |
| Resistance | 0.5Ω |
| Switching Frequency | 10KHz |



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The figure 14 and figure 15 indicates the output waveforms for PID controller and Compensator design. In figure 15 there are no transients found when compared with figure 14.

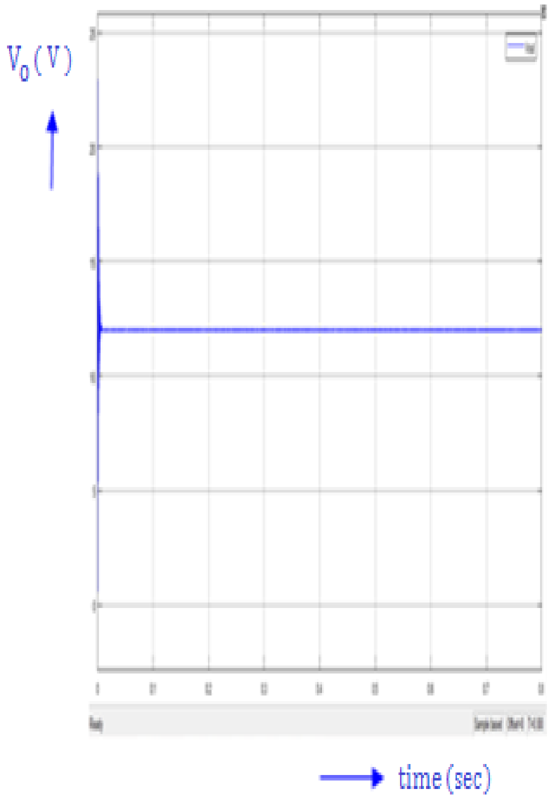


Figure 14: Output Voltage

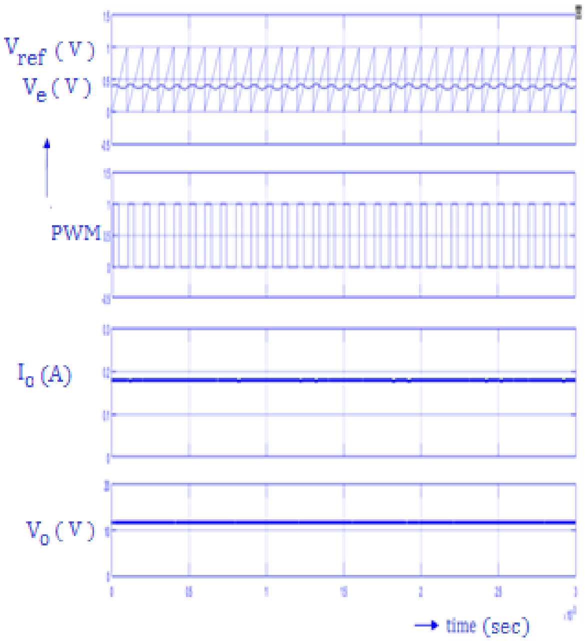


Figure 15: Output Waveforms

## VI. CONCLUSION

At present the importance of power electronic applications for non conventional sources are getting increased. This Paper concentrated on the importance of DC-DC Converter and itsanalysis is carried out to determine the stability of the system by comparing with and without compensator. The circuit is simulated in matlab/simulink environment and same is shown in simulation results which shows that there is no transients found when the compensated switching frequency is used in the design.

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## AUTHORS PROFILE

**Mr Ch.Santosh Kumar,** received the M.Tech . degree in Electrical & Electronics Engineeringfrom GRIET, underJawaharlal Nehru Technological University, Kukatpally, Hyderabad , India. He is an Assistant Professor at BVRIT Hyderabad College of Engineering for Women, Hyderabad,under*Jawaharlal Nehru Technological University, Kukatpally, Hyderabad* , India. His research interests include Power Quality , Power Electronics, Renewable Energy Sources.

**Dr. S Tara Kalyani,** received the degreesMS, Ph.D (EEE) .She is the Professorin Electrical & Electronics EngineeringDepartment,Jawaharlal Nehru Technological University, Kukatpally, Hyderabad ,India. Her research interests includes Flexible AC Transmission System, Power Quality, Drives, Power Electronics, Control Systems, Energy Systems, Power Systems.


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