Designing the Stable Compensation Networks for Buck Boost Converter for Solar Energy System

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Abstract*— *Because of combustion of fossil fuels global warming caused by environmental problems, the raising prices of crude oils and natural gases. They promote continuous effort to improve energy system and its efficiency. There is a need to search for abundant and clean energy sources due to the depleted and increasing prices of oil. Solar energy acts as an alternative renewable energy source.

Photovoltaic cells are used as renewable energy system. Photovoltaic (PV) cells can be used to generate dc voltages and given to Buck boost converter. The buck boost converter output is given to battery to inverter and load.

Buck boost converter gives constant output which will control by PWM controller and feedback control system. Feedback control system has compensation network with different types and parameters. Depending upon parameters and controlling method, we have to decide stability analysis using Bode Plot. This analysis is carried out by using MATLAB software.

It will be used to design buck boost converter with different parameters which gives constant output. It is helpful for optimizing feedback-loop design for the best transient response while maintaining a comfortable margin for stability. Design for highest gain and bandwidth feedback loop. It is useful to study different controlling methods and comparison. It is used to select switching frequency, power inductor, selecting capacitors and verify the quality of the output voltage, harmonic content of the output voltage.

Keywords- ***Photovoltaic cell model, buck boost converter, compensation network, Design parameters, stability.***

I. INTRODUCTION

With the prices of oil at its highest and the increasing demand every year, it is causing environment concerns which lead to global warming around the world. New energy sources like solar and wind power are readily available and much sought after. They produce clean energy power which does not affect the Ozone layer. With free solar energy available, cutting down on electrical bills on industrial and home seems a possibility in the near future as the photovoltaic conversion into electrical energy. Large scale solar energy systems are being tested and might even be implemented in the coming years to cut down the emission of CO2. Demand for photovoltaic energy will increase over the years as the breakthrough in this new technology will sustain it at a lower cost.

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In this system output of solar system is variable with respect to different operating condition. So as to get constant output from solar system we connect buck boost converter to battery and battery to inverter and load. For making the constant output, we have to design system parameters and stability circuits. We developed the compensating circuit which gives stable output under different conditions.

II. MODELING OF SOLAR PV CELL

The working condition of the solar cell depends mainly on the load and solar isolation. They operate in the open circuit mode and short circuit mode. Based these characteristics, the output voltage, current and power can be computed.[1]

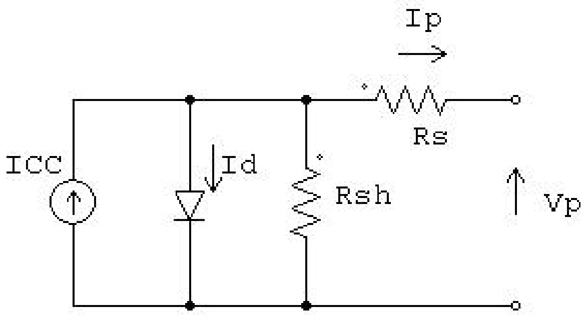

Fig.1 Equivalent Solar cell model

Iph – Photodiode current
Vd – Diode voltage
Id – Diode current
n - Diode factor (1 for ideal and >2 for real conditions)
Io - Reverse saturation current
T - Temperature for the solar arrays panel in kelvin
K – Boltzmann's constant = 1.38 x 10^{-23} J/K
Q – Electron charge = 1.6 x 10^{-19}C
Rs – Intrinsic series resistance usually in milli-ohms Rsh – Shunt resistance usually in kilo-ohms
The I-V characteristics of a solar cell while neglecting the internal shunt resistance is given by

$$I_{out} = I_{ph} - I_o \left| \exp\left(\frac{q}{nKTln(V + LoutRs)}\right) - 1 \right|$$

In the event that the circuit is shorted indicating that the output voltage is =0. The current through the diode is being omitted. The short-circuit current, Isc = I can be represent by

$$I = I_{ph} - \frac{RsI}{Rsh}$$

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Generally with the relationship that exists between Isc and Iph, the output current is given below. From the relationship, output current is approximately the almost the same as the photocurrent.

$$I = I_{sc} = \frac{I_{ph}}{\left(\frac{1+Rs}{Rsh}\right)}$$

When the circuit is in open-circuit mode, the output current I is =0. At this point, the open-circuit voltage, Voc is calculated.

$$Voc = Vmax = \left(\frac{(nkT)}{q * ln * \left(\frac{Iph}{Io}\right)}\right)$$

The output power can be expressed based on the open circuit voltage and short circuit current.

$$P = IV = \left(\frac{Iph - Id - Vd}{Rsh}\right) = V$$

The Pmax relationship is also represented in terms of Vmppt. The Pmax is the maximum output power and Vmppt is the optimal output voltage.[2]

$$Pmax = I_{ph} \left\{ \begin{matrix} Voc - \left(\frac{nkT}{q}\right) 1n\left(\frac{1 + qV_{mppt}}{nkT}\right) - \frac{Voc}{\left(qV_{mppt} + nkT\right)} + \\ nkt\left(\frac{1}{V_{mpt}}\right) 1n\left(1 + \frac{qV_{mppt}}{nkt}\right) \end{matrix} \right\}$$

Iph – Photodiode current
Vd – Diode voltage

III. DESIGNING OF BUCK BOOST CONVERTER TOPOLOGIES

Buck-Boost converter is combination of a buck and boost converter. It can be an inverting topology where the output voltage is of opposite polarity as the input. It can also act as a buck converter follow by the boost converter function.

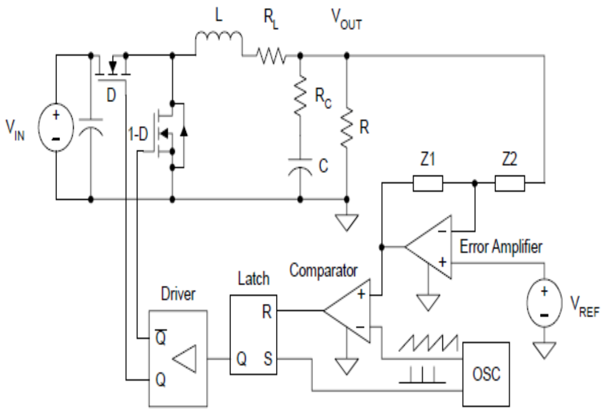

Fig No. 2 Buck converter with feedback system

when the switch is in the "on state", the inductor stored the energy in the magnetic field as it is connected with the source voltage where currents will flow through. The diode is reversed biased and hence no current can flow to the load through the diode. The capacitance will provide current in this "Ton" situation. When the switch is off, inductance is disconnected from the source and there will be no current drop which the inductance will reverse it EMF. A voltage is generated as the diode at this time is forward biased; current will flow in the load and charged up the capacitance.

The converter is made up of an input source voltage, an inductor, a switch, capacitor and the output load. This type of configuration is use to boost up the output voltage with a lower input source. Most of the designs usually specified they require value of input voltage, output voltage and the load current whereas the inductor and ripple current are free parameters. To reduce a ripple, a larger value of inductor should be able to reduce it since it is inversely proportional to the ripple current. Likewise when choosing the inductor, it should ensure the saturation current is greater than the inductor peak current and able to cope with the rms current. While designing the buck boost converters following main points are considered [3,4]

1) Input voltage to converter
2) Desired supply output voltage magnitude
3) DC-DC converter efficiency (Pout / Pin)
4) Output voltage ripple (5)
5) Output load transient response
6) Output load transient response
7) Duty cycle of PWM controller

For design of this buck boost converter, the output of the converter is designed for 24 V which is given to the Battery. Output voltage=24V

3.1 Design of Power Inductor

The power inductor is a very important component within the boost dc-dc design. The inductor value is closely linked with the input voltage, the output voltage, the forward voltage of the diode, the duty cycle, the load current as well as the switching frequency.

$$L = \frac{[V_{out} - V_{in} + V_D][1 - D]}{\min\,(i_{load})f}$$

Current rating of inductor is given by

$$I_{pk} = \frac{V_{input}}{2 * f * L}$$

The minimum inductor value can be found.

3.2 Selecting Switching frequency

For the different values of frequency the values of inductors are calculated.

Switching Frequency	Inductor Value
50	158
100	79
200	40
400	20
500	16
1000	8
1500	5
2000	4

3.3 Design of Power MOSFET

Low power loss Mosfet is selected depending on rating.

3.4 PWM Controller

The basic idea is to control the duty cycle of a switch such that a load sees a controllable average voltage. To achieve this, the switching frequency is chosen high enough. With pulse-width modulation control, the regulation of output voltage is achieved by varying the duty cycle of the switch, keeping the frequency of operation constant.

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Duty ratio-

D = ton/ (ton + toff)

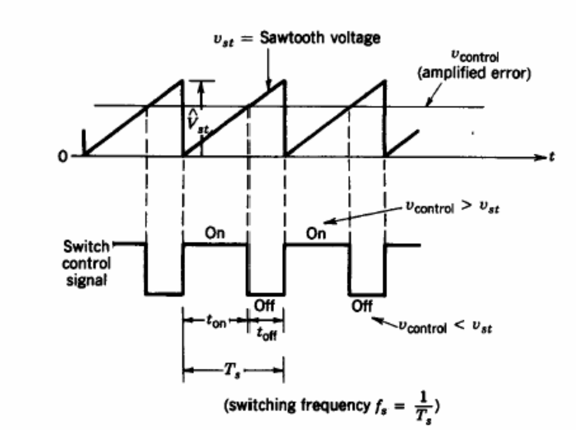

Fig No.3 Duty cycle

3.5 Power Efficiency-Power Efficiency of a Buck Converter changes with a change in the load

IV. CONTROLLING METHODS

4.1 Voltage Mode Control

This is a simple method in which there is only one feedback from the output voltage. The input voltage is a main parameter in the loop gain, any changes in the input voltage will alter the gain and will change the dynamics of the system. The voltage mode controller alone cannot correct any disturbances or changes until they are detected at the output. In the voltage based controllers the compensation loop is difficult to implement.[8]

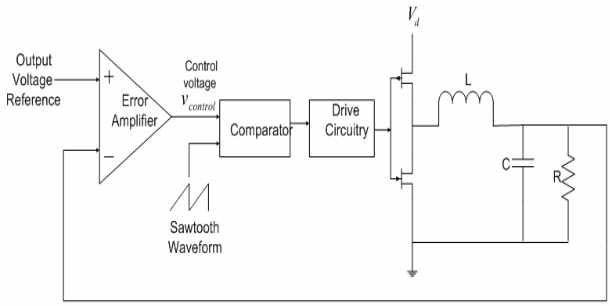

Fig No. 4 voltage mode control

4.2 Current Mode Control

In a current-mode control, an additional inner control loop is used. The control voltage directly controls the output inductor current that feeds the output stage and thus the output voltage. The control voltage should act to directly control the *average* value of the inductor for the faster response.

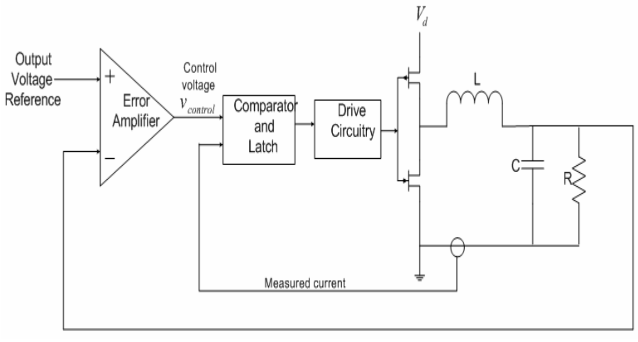

Fig No. 5 current mode control

V. STABILITY CRITERIA

To accomplish regulation we need to add a feedback loop Also we need to introduce a high DC gain. But with high gain again comes the possibility of instability. These two issues determine the need to have stability criteria 1) feedback compensation design involves selection of a suitable compensation circuit configuration 2) positioning of its poles and zeros to yield an open loop transfer function. Following points to be considered for stability [5,6]

1) Variations in input voltage do not cause instability.
2) Allow for variations in the peak-to-peak oscillator voltage.
3) Error amplifier has sufficient attenuation at the switching frequency.
4) Mid-frequency gain is greater than zero to prevent a large overshoot at turn-on and during transient conditions.
5) Error amplifier has the drive capability to drive the feedback network properly.
6) The phase margin determines the transient response of the output voltage in response to sudden changes in the load and the input voltage
7) Gain Margin is the difference between unity gain (zero dB) and the actual gain when the phase reaches 180°. The
   recommended value is -6dB to -12 dB.

5.1 TYPE III COMPENSATION

The Type III compensation circuit has two poles, with two zeros and a pole at its origin providing an integration function for better DC accuracy. Optimal selection of the compensation circuit depends on the power-stage frequency response.[6]

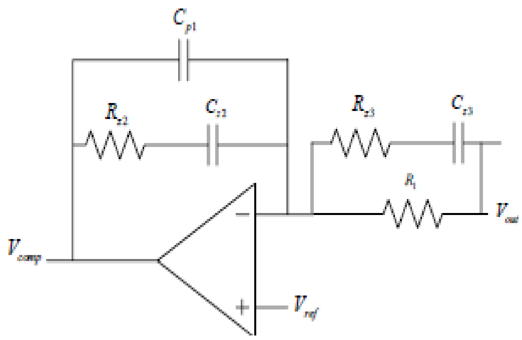

Fig No. 6 Type III compensation

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There are certain guidelines that can be used for positioning the poles and zeros and for calculating the component values.

1) Choose a value of R1

2) Select a gain (*R*2 / *R*1) that will shift the Open Loop Gain up to give the desired bandwidth. Following equation will calculate an 2 *R*, that will accomplish this given the system parameters and a chosen R1.

$$R_2 = \frac{DBW}{F_{LC}} \cdot \frac{\Delta V_{OSC}}{V_{IN}} \cdot R_1$$

3) Calculate C2 by placing the zero at 50% of the output filter double pole Frequency

$$C_2 = \frac{1}{\pi R_2 F_{LC}}$$

4) Calculate 1 *C* by placing the first pole at the ESR zero frequency

$$C_1 = \frac{C_2}{(2\pi R_2 C_2 F_{ESR}) - 1}$$

5) Set the second pole at half the switching frequency and also set the second zero at the output filter double pole This combination will yield the following component calculations

$$R_3 = \frac{R_1}{\left(\frac{f_{SW}}{2F_{LC}}\right) - 1}$$

$$C_3 = \frac{1}{\pi R_3 f_{SW}}$$

Transfer function for type III compensation is given by

$$GAIN_{TYPEIII} = \frac{R_1 + R_{z3}}{R_1 . R_{z3} . C_{p1}} \cdot \frac{\left(s + \frac{1}{R_{z2} \cdot C_{z2}}\right) \cdot \left(s + \frac{1}{(R_1 + R_{z3}) \cdot C_{z3}}\right)}{s\left(s + \frac{C_1 + C_2}{R_{z2} \cdot C_{p1} \cdot C_{z2}}\right)\left(s + \frac{1}{R_{z3} \cdot C_{z3}}\right)}$$

Type III compensator is used to compensate a second-order LC filter. A traditional type III compensator is sufficient to stabilize the synchronous buck converter for all three modes subsequently being voltage mode control, current mode control.

VI. CALCULATIONS AND RESULTS

According to the above steps if we design buck boost converter for the output of 24 V for any input voltage to the converter from the solar panel or system. We write a MATLAB programming for finding the different parameters for type III compensation. [5]

For this consider

RL = 5Ω,

ESR = DCR = 1,

R1 = 60 kΩ.

Switching frequency =20Khz

From MATLAB programme results are as follows

C	5 µF
L	88.71µH
R1	60 kΩ
Cz2	274 pF
Rz2	153 kΩ
Cp1	36 pF
Rz3	10 kΩ
Cz3	297 pF
Vripple	33.958 mV
Iripple	34.631 mA
Efficiency (%)	76.2

For the above values, we can calculate the transfer function for the Buck Boost converter, compensation network. From transfer function we plot BODE PLOT for Stability analysis and find out Gain Margin and phase Margin.

We write programming for plotting the BODE PLOT and results are shown below.

6.1 Bode Plot of Buck Converter

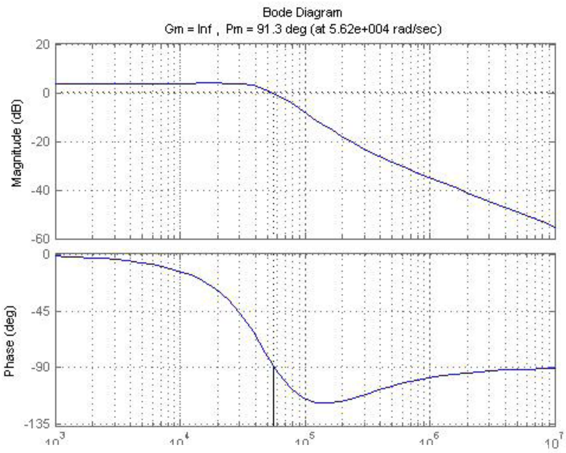

Fig No. 7 Bode plot Buck Converter

6.2 Bode Plot of Type III Compensation Network

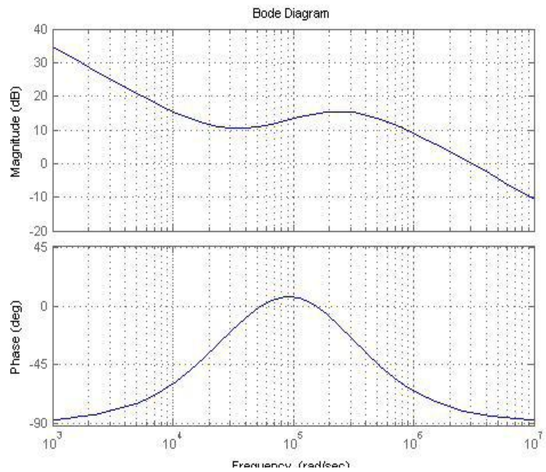

Fig No8. Bode plot Type 3 network

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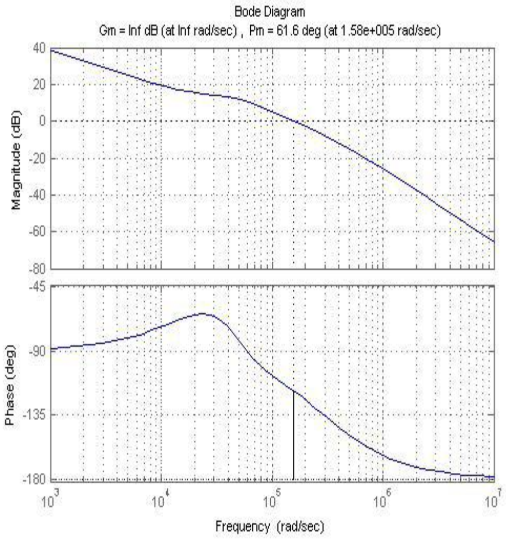
6.3 Bode Plot of Total Open Loop Buck Converter



VII. CONCLUSION

In this paper we develop renewable energy system using solar energy as the main source of energy. The output of solar is given to buck boost converter. We have calculated different parameters of buck boost converter such as power inductor, duty cycle for PWM controller and capacitors. For stability analysis we designed feedback control system compensating network with type III and its transfer function gives detailed stability analysis by plotting bode plot. Design for highest gain and bandwidth feedback loop. It is helpful for optimizing feedback-loop design for the best transient response while maintaining a comfortable margin for stability. A phase margin ranging between 45°and 60° is recommended to avoid instability. The type 3 compensation circuit is used for voltage-mode control because of design flexibility.

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