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RESEARCH ARTICLE

FPGA CONTROLLED MPPT BASED BOOST CONVERTER FOR RENEWABLE ENERGY(SOLAR PV) POWER APPLICATIONS

Peerzada Ridwan Ul Zaman[1], Abdul Basit Sheikh[2] and Abdul Rauf[3]

1. Design Engineer, Electrical Department, Surbana Jurong Pte Ltd.
2. Design Engineer, Electrical Department, Surbana Jurong Pte Ltd.
3. Maintenance Engineer, Mechanical Department, Saudi Tabreed operations & Maintenance Co.

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Abstract

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This paper is proposing the Field Programmable Gate Array(FPGA) controlled multiphase DC-DC Boost. The proposed DC-DC boost converter is designed at high gain. The proposed converter is employed for higher power applications and controlled with the help of ZVS voltage mode control. The feasibility of proposed converting is verified by the simulation.

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Introduction:-

From the past few years of rapid increase in the growth of population, the need of electrical energy is increasing rapidly. On the other hand the fossil fuels that are limited are used extensively in the production of energy. The drawback of utilization of fossil fuels for energy production leads to the environmental pollution and causes the global warming. Focusing on the generation of clean electricity, the renewable energy sources are likely used for the generation of energy and its storage. Renewable sources of energy such as wind, hydro, solar are being developed and are powerful sources of energy. In particular, the photo voltaic(PV) or solar power energy systems are emerging to be most promising and attractive type of renewable energy sources due to the low maintenance costs, low operational costs, pollution free and also free from pollution.

Solar power refers to conversion of photons from sun's radiation to electricity. Solar cell as PN junction semiconductor devices arranged into arrays in order to capture the solar radiations and converting photons into electricity by the principle of photoelectric effect. This photo voltaic energy sources considered as the most useful energy sources has created an interest in the application of electrical power.

Because of the low energy conversion efficiency in PV arrays, the maximum power point tracking (MPPT) control technique is used to extract the maximum power from solar PV array so that maximum operating efficiency is required [1].

For large scale PV applications, at higher power operating conditions, single phase converters experience component stress. The low frequency operation of the DC DC converter results in higher output voltage ripples and due to this large turn OFF losses and conduction losses occurs in the switches, which is a harmful action in

Corresponding Author:- Peerzada Ridwan Ul Zaman
Address:- Design Engineer, Electrical Department, Surbana Jurong Pte Ltd.

converters. To overcome this problem many techniques can be used like higher filter inductance and huge output filter capacitances[2][3]. However these increases the cost of the converter and also results in less power density.The multiphase converter can reduce the voltage and current stress of the components very easily.

The multiphase DC-DC converter using a boost half bridge is introduced in [4]. In this converter the switch legs operate under soft switching. This multiphase configuration makes this converter to have lower filter rating as compared to the single phase. As the phase shift is increased, the converter losses also increase and the two switch legs require 12 power switches and increases switch losses.

Three phase shift PWM DC-DC converter proposed in [5][13] consists of three full bridge converters and three phase full bridge rectifiers consists of Δ-Y setting in three phase transformers and increases voltage without changing turns ratio. The phase shift modulation technique controls the each phase and achieves ZVS and ZCS operation without any of the auxiliary circuits. The main drawback of the converter is its complexity and the delta connection of transformer causes increase in the losses due to the circulating currents. The three phase current fed push pull DC-DC converter [6] is simplest in design and with less components butthere occurs dissipative losses and voltage spikes due to the inductance leakage of high frequency transformer.

To make the converter more reliable and cost effective the isolated can be replaced by non isolated or transformer less DC-DC converter [7-115]. In [7]This three phase boost converter as more efficient in transfer of energy obtains pure active conversion of the band limited input sources to a DC link. But its operation is in DCM. No doubt the reverse recovery effect are taken care, but it causes conduction losses and leads to the high input currents and so is not suitable in higher power applications.

The single switch converter topology based on switched circuit with capacitor [8,9,10,15] and switched capacitor/switched inductor structure [11] reduces the diode voltage stresses. The drawback is attainable voltage gains and power levels without degrading systems performance are restricted.

Since the conventional boost converter provides high voltage gain but leads voltage and current stresses. From the above on goingdiscussion it is concluded that the best option is to have a single stage in between PV module and DC load bus. Therefore from the above papers, this paper has presented and defined the more efficient MPPT based non isolated multi phase DC-DC boost converter which is having the fallowing features.

1. The converter has high voltage gain and desired power level.
2. Low current stresses and low losses and operates in CCM.
3. By increasing the ripple frequency because of multiphase topology the filter size will get reduced.
4. Simple in structure and is having less number of switches.

Proposed System: -

The configuration of proposed system is shown in Fig.1. it consists of photo voltaic array, multi phase DC-DC boost converter and MPPT based charge controller. The fallowing blocks in the proposed systems are explained in detail below.

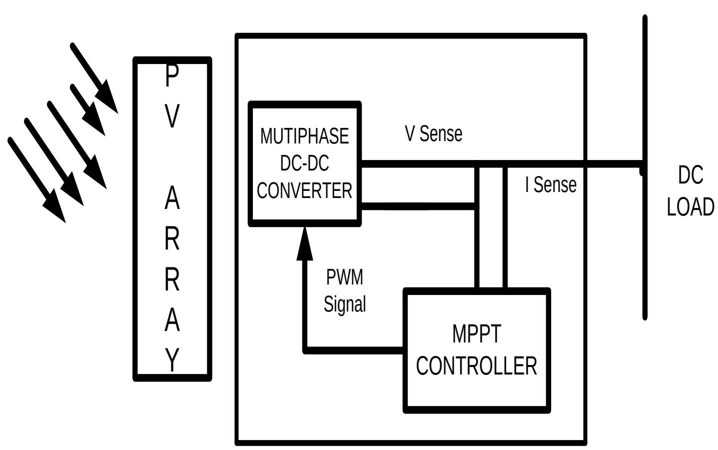

Fig.1:- Proposed system.

PV Module

PV cells connected in series and parallel combination from PV module and further combination of PV module form array in order to come up the higher ratings. The single diode circuit model of PV module is shown in Fig.2. The current and voltage equations of the related PV module are given below [7]

$$I_{LG} - I_D - \frac{V_D}{R_{Sh}} - I_{PV} = 0 \quad (1)$$

$$V_{PV} - V_D + I_{PV} R_S = 0 \quad (2)$$

Where,

I_{LG}= current generated by solar radiations

I_D= diode current

V_D= Voltage across the diode of circuit

I_{PV}= photo voltaic current

V_{PV}= photo voltaic voltage

R_{Sh}= shunt resistance

R_S= series resistance

$$I_{PV} = I_{LG} - I_{Sat}\left(e^{\frac{q(Vpv + Ipv .Rs)}{\alpha kT}} - 1\right) - \frac{Vpv + IpvRs}{Rsh} \quad (3)$$

$I_{Sat=}$saturation current of PV module

T= temperature of PV module(k)

K= Boltzmann constant(j/k)(1.380×10^{-23})

Q=electron in charge (C)(-1.602×10^{-19})

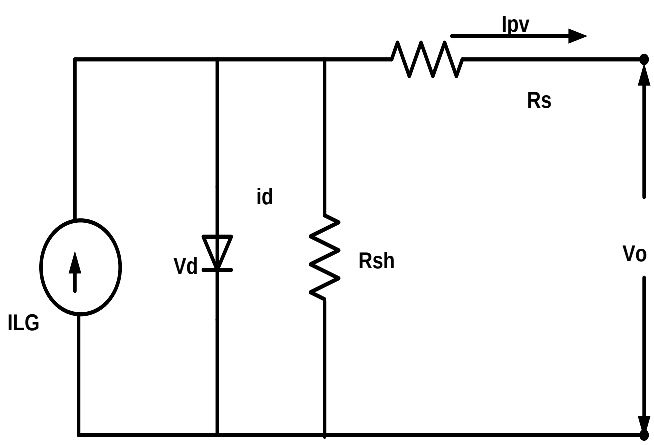

Fig.2:- Solar PV cell equivalent circuit.

MPPT

The maximum power point tracking (MPPT) is the point on the V-I and V-P curve at which PV system operates in efficient way and produces maximum output power. The maximum power point techniques are used for PV module to operate at maximum power point (MPP)[12]. For MPPT, the controller used provides pulse width modulation (PWM) signals. The MPPT algorithm assigns specific duty cycle for operation of the switch of DC-DC converter so as to locate the operating point close to MPP. Since PV array voltage-current characteristics varies with temperature and incident ray intensity at all times. Thus to locate maximum power point is difficult. In order to overcome this problem, the various methods have been developed for MPPT algorithm of solar PV array. In the present available techniques, the constant voltage based maximum power point technique (CVMPPT) used for extraction of maximum power from the solar PV module, is the easiest and simple technique for it. The V_{MPP} and V_{oc} are having linear relationship which is given by

$$V_{MPP} = kV_{OC}$$

Whereas, the V_{OC} is the open circuit voltage provided by the manufacture of the solar PV modules. V_{MPP} is the voltage at maximum power point. The value of factor k is between 0.71 to 0.78 [8]. Therefore the voltage at MPP can be calculated by using the formula given above and can be set as a reference voltage. The reference voltage is compared with the input voltage from the solar module and the error obtained is amplified and used to generate duty cycle for DC-DC boost converter. The algorithm used in this MPPT technique is shown in the below given Fig.3.

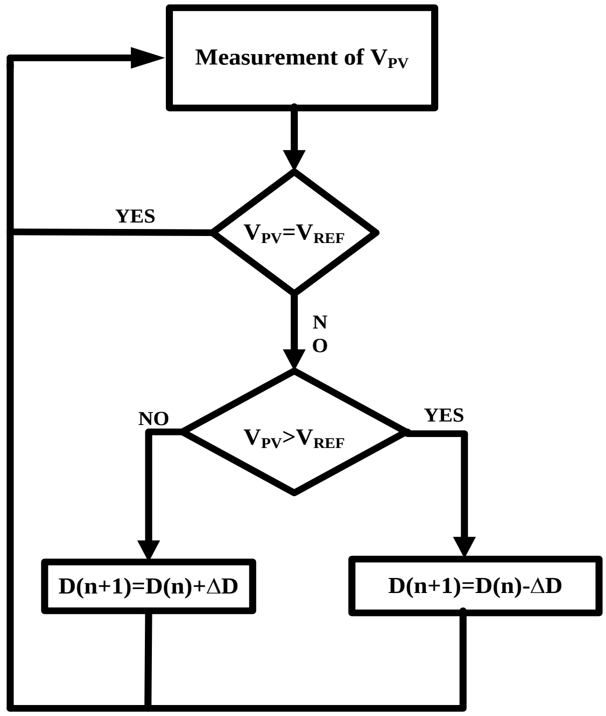

Fig.3:- Algorithm of CVMPPT method.

FPGA

The field programmable gate array(FPGA) is an integrated circuit, which is useful and suitable in power converters for switching applications. The control technique i.e; PWM can be easily implemented through the programming and provides the fast operating capability. Because of this it is the suitable choice for control system applications

Multiphase Boost Converter

The structure of multiphase boost converter is shown in fig.4. This converter consists of three switches and three diodes connected in parallel in each phase. The converter interleaves the inductor current across the phase to reduce the input and output current ripples without increasing the switching frequency. Therefore the reduced ripple current, increases in the ripple frequency contributes to the small filter for same ripple voltage requirement, thereby decreasing the size of filter component and also reduction in cost. This improves the dynamic response to load transient.

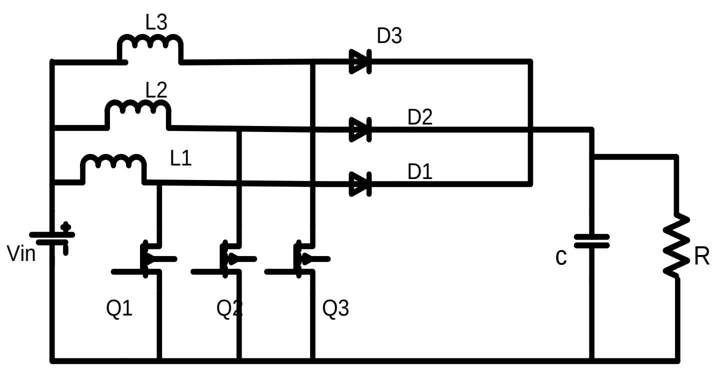

Fig.4:- Three phase converter.

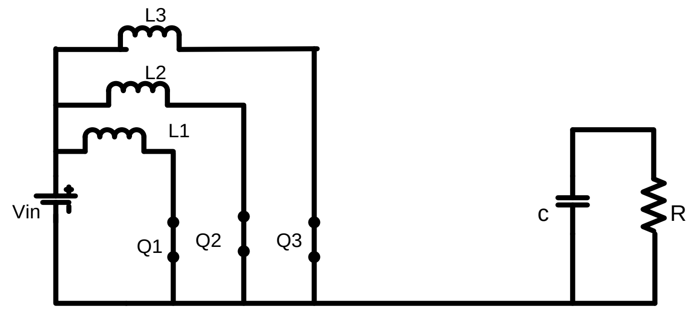

Fig.5:- Phase 1,2,3 closed

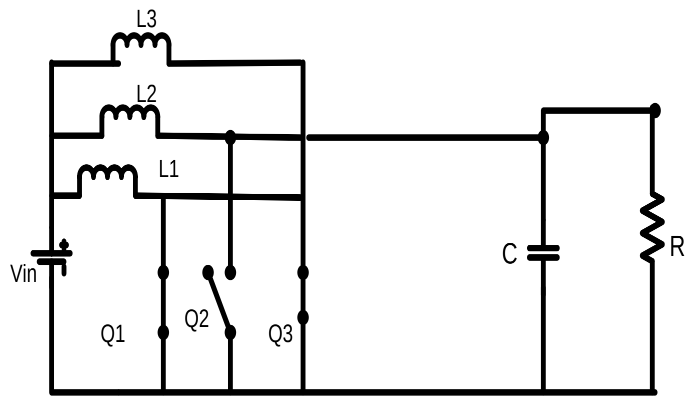

Fig. 6:- Phase 2 open phase 1,3 closed.

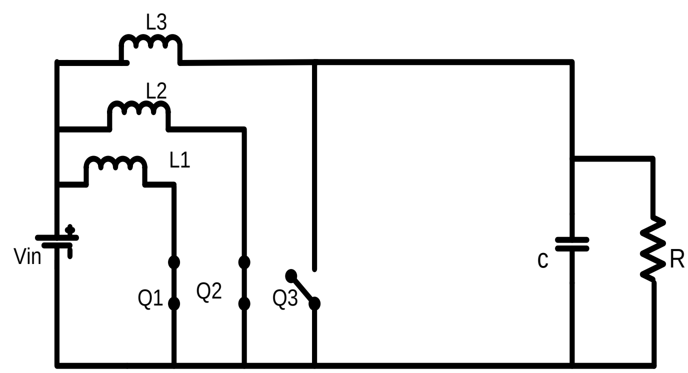

Fig.7:- Phase 3 open phase 1,2 closed.

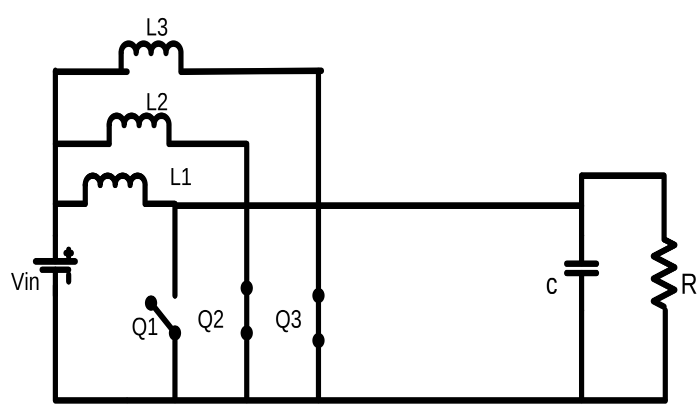

Fig. 8:- Phase 1 open phase 2,3 closed.

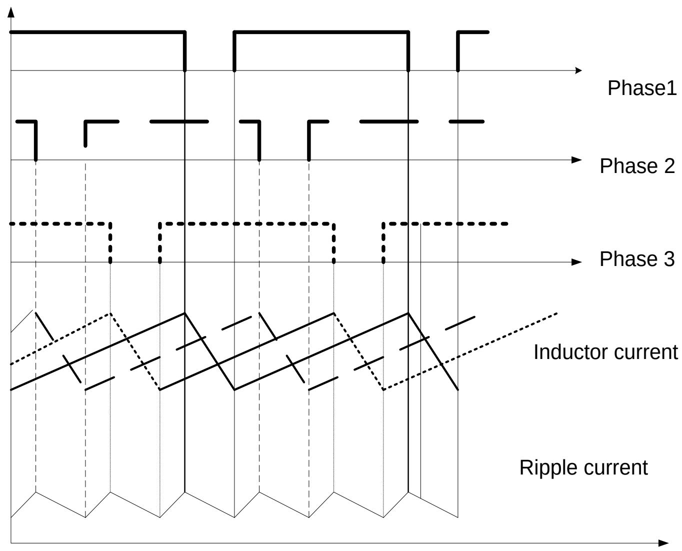

Fig. 9:- Reduction of ripple current in three phase boost converter.

The operation of DC-DC boost converter is explained in the reference to Fig. 5-8. The three phase boost converter operates in six stages. The clock is phase shifted by 120 degree for the switches in fig.8. The three phase current waveforms are shown in figure with reference to the clock signals. Because of the interleaving of the clock pulses, the switches are closed for the duration of (D-2/3). T, three times the period with an interval of (1-D)T.

The operation of this proposed converter is shown in the fallowing six stages.
Stage 1. When the switches Q_1, Q_2 and Q_3 are ON as shown in fig.5, the energy is stored in all the three inductors. The load is supplied with the energy stored in the capacitor.
Stage 2. In fig.6,When Q_3, Q_1 is ON and Q_2 is OFF, the stored energy of inductor L_2 is supplied to load through diode D_2.
Stage 3. When all the three switches are ON as in Fig.5, in the similar way as in stage 1, all the three conductors store energy.
Stage 4. When Q_1,Q_2 are ON and Q_3 is OFF as shown in Fig.7, the energy stored in the inductor L_3 is transferred through diode D_3 to load.
Stage 5. Q_1,Q_2,Q_3 are ON , it is same as stage 1 and stage 3.
Stage 6. Q_1 is OFF and Q_2,Q_3 is ON as shown in Fig.8, the energy stored in L_1 is shifted to load through diode D_1.

Controlling Technique:-
A DC-DC boost converter designed must present regulated output DC voltage and load changing conditions. The component value gets changed with timely increase in temperature. Therefore to control output voltage the method required on close loop basis using the negative feedback control method comes in consideration. The current mode control consisting of extra loop of feedback inductor current signal is complex and alters dynamic behavior of converters. Where as the voltage control method is simpler and is flexible.

Voltage Mode Control Method:-
In this mode of control the output voltage sensed is compared with the reference voltage (V_r), and produces error voltage. This voltage is corrected at controller and that controller sends the controlled voltage signal to modulator. At the modulator the controlled signal is compared with saw tooth wave form of constant amplitude and the pulse width modulated voltage signal (V_m) is produced and the required duty cycle is generated. The Fig.10 shows the block diagram of boost converter with close loop feedback system.

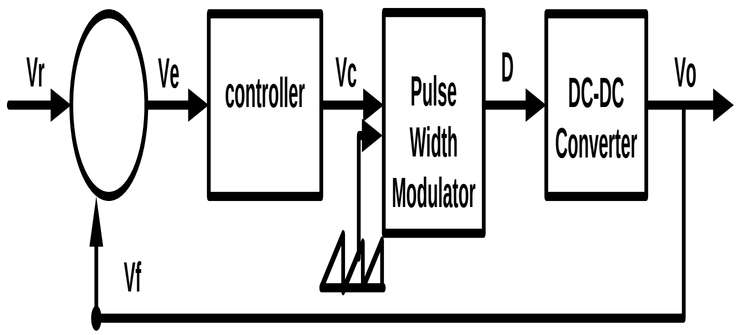

Fig.10:- Voltage control scheme for DC-DC converter.

Design Analysis For Boost Converter: -

1.Equivalent resistance

The equivalent resistance in inductor branch is

$$r = Dr_{DS} + (1 - D) + r_l \quad 4$$

2. Pulse width modulated DC-DC power converter

DC current transfer function,

$$M_{IDC} \equiv \frac{I_o}{I_i} = 1 - D \quad 5$$

The input to output voltage transfer function

$$M_{VDC} \equiv \frac{V_o}{V_I} = \frac{1}{1-D}\frac{1}{[1+\frac{V_F}{V_o}+\frac{r}{(1-D)^2 R_L}]} \quad 6$$

V_F is the diode offset voltage.

And the DC control to output transfer function

$$T_{PDC} \equiv \frac{V_o}{V_I} = \frac{V_1}{[1+\frac{V_F}{V_o}+\frac{r}{(1-D)^2 R_L}]} \quad 7$$

The efficiency of converter is

$$n \equiv \frac{I_o V_o}{I_I V_I} = M_{IDC} M_{VDC} = (1 - D) M_{VDC}$$

$$= \frac{1}{\left[1+\frac{V_F}{V_o}+\frac{r}{(1-D)^2 R_L}\right]} \quad 8$$

2. Open-loop control to output transfer function

The control to output transfer function

$$T_P(s) \equiv \frac{V_O(s)}{d(s)} = \frac{V_o}{1-D}\frac{1-\frac{Z_1}{(1-D)^2 R_L}}{1+\frac{Z_1}{(1-D)^2 Z_2}} \quad 9$$

The impedance z1 and z2 are

$$Z_1 = r + sL$$

$$Z_2 = \frac{R_L(r_c+\frac{1}{sC})}{R_L+R_C+\frac{1}{sC}} \quad 10$$

The above equations gives the transfer function in s-domain

$$T_P(s) = \frac{V_O(s)}{d(s)}$$

$$T_P(s) = \frac{V_o r_c}{(1-D)(R_L+r_c)}\frac{\left(s+\frac{1}{Cr_c}\right)\left\{s-\frac{1}{L}[R_L(1-D)^2-r]\right\}}{s^2+s\frac{c[r(R_L+r_c)+(1-D)^2 R_L r_c]+L}{LC(R_L+r_c)}+\frac{r+(1-D)^2 R_L}{LC(R_L+r_c)}} \quad 11$$

Pulse width modulated dc dc power converter

$$= T_{px}\frac{(s+\omega_{zn})(s-\omega_{zp})}{s^2+2\xi\omega_o s+\omega_o^2} = \frac{(s+z_n)(s-z_p)}{(s-p_1)(s-p_2)}$$

$$= \frac{V_O r_c \omega_{zn} \omega_{zp}}{(1-D)(R_L + r_C)\omega_o^2} \frac{\left(1+\frac{s}{\omega_{zn}}\right)\left(1-\frac{s}{\omega_{zp}}\right)}{1+\frac{2\xi}{\omega_o}s+\left(\frac{s}{\omega_o}\right)^2}$$

$$= T_{po} \frac{\left(1+\frac{s}{\omega_{zn}}\right)\left(1-\frac{s}{\omega_{zp}}\right)}{1+\frac{s}{Q\omega_o}+\left(\frac{s}{\omega_o}\right)^2} \quad 13$$

3. Open loop response of output voltage to step change in input voltage

$$V_i(s) = \frac{\Delta V_I}{s}$$

The transient component of output voltage of the open loop boost converter in s domain is given by.

$$V_o(s) = M_v(s)v_i(s) = \frac{\Delta V_I M_v(s)}{s}$$

$$= \Delta V_I M_{vo} \frac{\omega_o^2}{\omega_{zn}} \frac{s+\omega_{zn}}{s(s^2+2\xi\omega_0 s+\omega_0^2)} \quad 14$$

The highest max. value of v_o is given by

$$v_{omax} = \Delta V_I M_{vo}\left[1+\sqrt{1-\frac{2C\omega_0}{\omega_{zn}}+\left(\frac{\omega_0}{\omega_{zn}}\right)^2}\, e^{-\pi\xi/\sqrt{1-\xi^2}}\right] \quad 15$$

Resulting the maximum overshoot of transient component of output voltage v_o

$$S_{max} \equiv \frac{v_{omax} - v_o(\infty)}{v_o(\infty)} = \frac{v_{omax}}{v_o(\infty)} - 1 = \frac{v_{omax}}{\Delta V_I M_{vo}} - 1$$

$$= \sqrt{1-\frac{2C\omega_0}{\omega_{zn}}+\left(\frac{\omega_0}{\omega_{zn}}\right)^2}\, e^{-\pi\xi/\sqrt{1-\xi^2}} \quad 16$$

The max. relative transient ripple of total output voltage is defined as

$$\delta_{max} \equiv \frac{v_{omax} - v_o(\infty)}{v_o(\infty)} \quad 17$$

The transient component of output voltage of the open loop boost converter in s domain is given by.

$$v_0(s) = T_p(s)d(s) = -\frac{\Delta d_T T_p(s)}{s}$$

$$= -\Delta d_T T_{po} \frac{\omega_0^2}{\omega_{zn}\omega_{zp}} \frac{(s+\omega_{zn})(s-\omega_{zp})}{s(s^2+2\xi\omega_0 s+\omega_0^2)} \quad 18$$

Simulation Results:-

In this paper, the proposed bi-directional converter is designed with 8.33 voltage gain. And then done small signal analysis for bi-directional DC DC converter to get transfer functions in both the modes and their transfer functions have been presented below.

Boost mode:

Transfer Function

$$\frac{-1.1922e04s + 0.6818e07}{s^2 + 492.2s + 1.936e05}$$

To validate the practical viability of the proposed system, real-time implementation results were examined using a Xilinx system interfaced with MATLAB Simulink, as depicted in Figures 11 to 14.

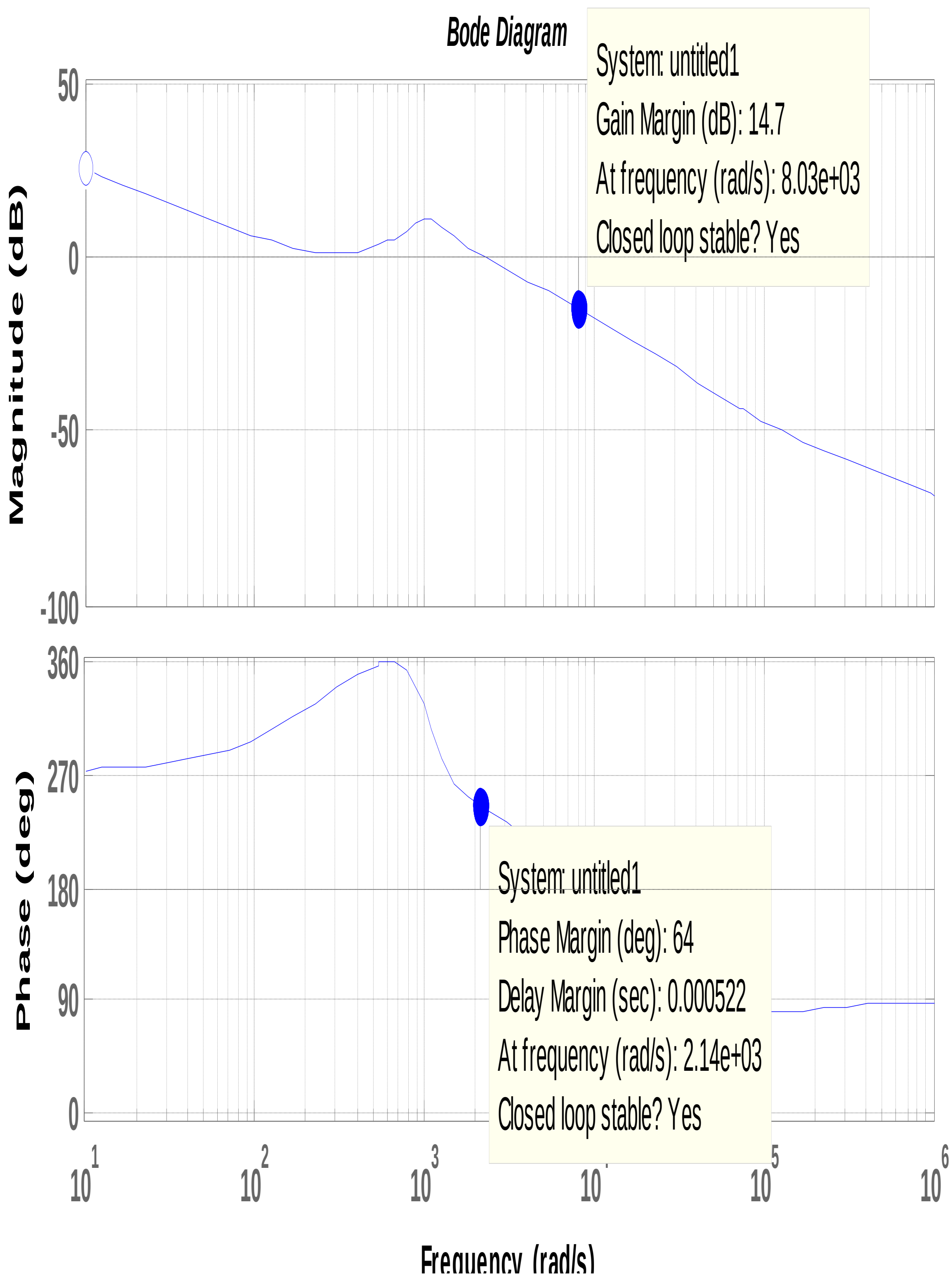

Fig11:- Bode plot of Boost converter loop gain with type-3 controller.

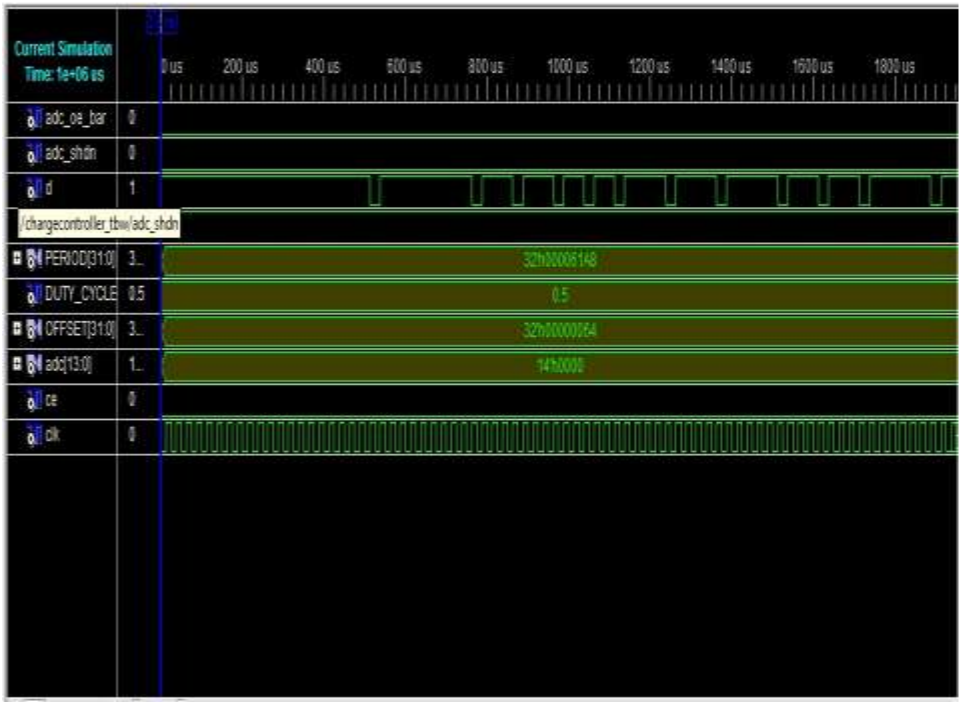

Fig.12:- Firing pulses to BDC in boost mode.

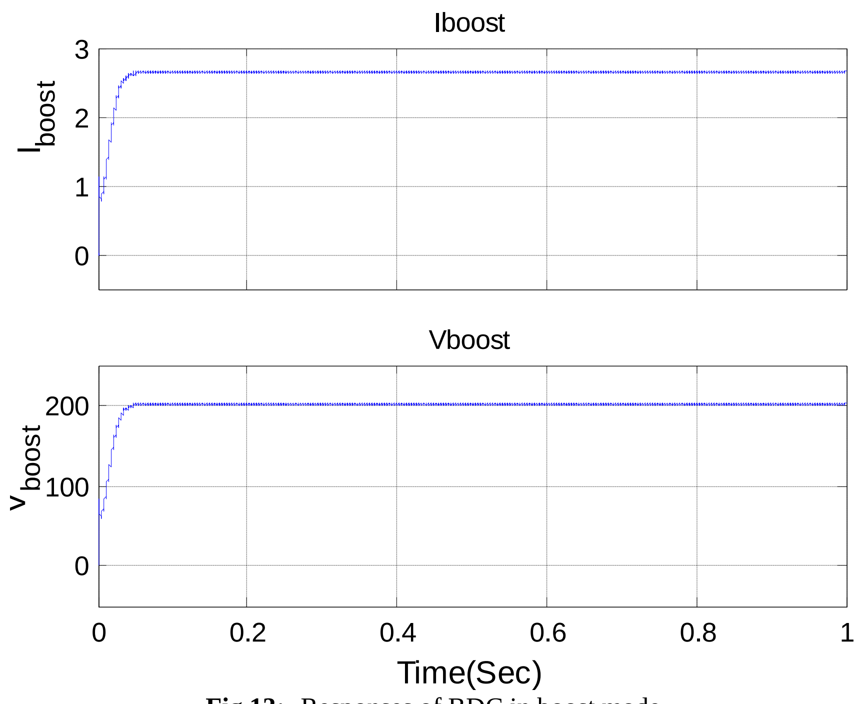

Fig.13:- Responses of BDC in boost mode.

Conclusion:-

In this paper the multiphase high gain DC-DC boost converter for higher power applications without storage device is presented. The system block diagram, design of boost converter and the control algorithm is presented. The proposed topology provides efficient converter, with reduced switching losses and in particular provides the ripple free input current. With this characteristic the lifetime of the PV module (low voltage side) increases. The simulation results have shown that the proposed converter is feasiable for higher power applications.

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