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A Two Stage And Isolated Bridgeless AC/DC Converter

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Abstract:

Harmonic pollution and low power factor in power systems caused by power converters have been of great concern. To overcome these problems several converter topologies using advanced semiconductor devices and control schemes have been proposed. This investigation is to identify a low cost, small size, efficient and reliable ac to dc converter. The performance of single phase and three phase ac to dc converter along with various control techniques are studied and compared. For improving power quality in terms of power-factor correction (PFC), reduced total harmonic distortion at input ac mains and precisely regulated dc output. This paper introduces a closed loop two stage converter and isolated bridgeless AC to DC converter with unity power factor. This power factor correction (PFC) circuit is capable to perform the AC to DC conversion without the diode bridge rectifier and able to obtain low output voltage which is more suitable to most applications. The detail small signal and steady state analysis of the converter operated in discontinuous conduction mode (DCM) are presented using the current injected equivalent circuit approach (CIECA).The proposed boost rectifier can reduce the conduction losses.

Keywords: *PFC; Bridgeless; DCM; CIECA.*

1.Introduction

An ac to dc converter is an integral part of any power supply unit used in the all electronic equipments. Also, it is used as an interface between utility and most of the power electronic equipments. These electronic equipments form a major part of load on the utility. Generally, to convert line frequency ac to dc, a line frequency diode bridge rectifier is used. To reduce the ripple in the dc output voltage, a large filter capacitor is used at the rectifier output. But due to this large capacitor, the current drawn by this converter is peaky in nature. This input current is rich in low order harmonics. Also, as power electronics equipments are increasingly being used in power conversion, they inject low order harmonics into the utility. Due to the presence of these harmonics, the total harmonic distortion is high and the input power factor is poor. Due to problems associated with low power factor and harmonics, utilities will enforce harmonic standards and guidelines which will limit the amount of current distortion allowed into the utility and thus the simple diode rectifiers may not in use. So, there is a need to achieve rectification at close to unity power factor and low input current distortion. Initially, power factor correction schemes have been implemented mainly for heavy industrial loads like induction motors, induction heating furnaces etc., which forms a major part of lagging power factor load. However, the trend is changing as electronic equipments are increasingly being used in everyday life nowadays. Hence, PFC is becoming an important aspect even for low power application electronic equipments.

In earlier days when power electronics were introduced to obtain DC voltage half bridge and full bridge rectifiers were used. To maintain the constant DC voltage at the output side of diode bridge rectifier a capacitor is used which effects the supply power factor as shown in figure 1a and 1b.

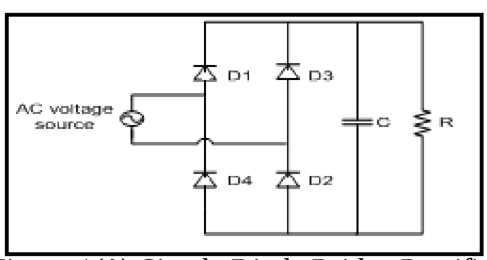

Figure 1(A):Simple Diode Bridge Rectifier

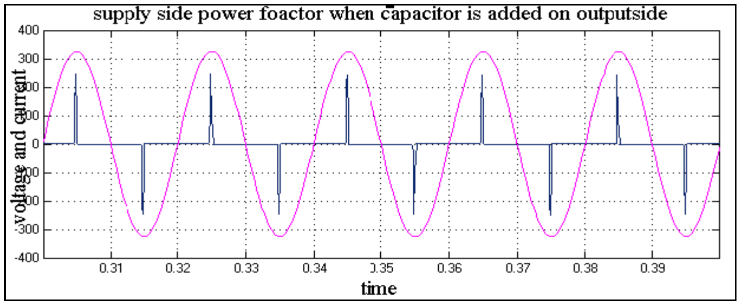

Figure 1(B):Its Input Side Power Factor

Normally, this Power Factor can be corrected by cascading a diode-bridge rectifier with either a single DC-DC converter or two DC-DC converters [2,3]as shown in figure 2. In this type of converter, the DC-DC converter is combined with the diode rectifier in such a way so that the AC-DC conversion can be realized. Unity power factor and tight output voltage regulation are achieved with the very well known two stage approach. Since the power stage is composed by two converters, size, cost and efficiency are penalized, mainly in low power applications. However, this is probably the best option for ac-dc converters due to the following reasons.

Sinusoidal line current guarantees the compliance of any regulation.

It gives good performance under universal line voltage.

It offers many possibilities to implement both the isolation between line and load, and the hold-up time.

The penalty on the efficiency due to the double energy processing is partially compensated by the fact that the voltage on the storage capacitor is controlled. The fact of having constant input voltage allows a good design of second stage.

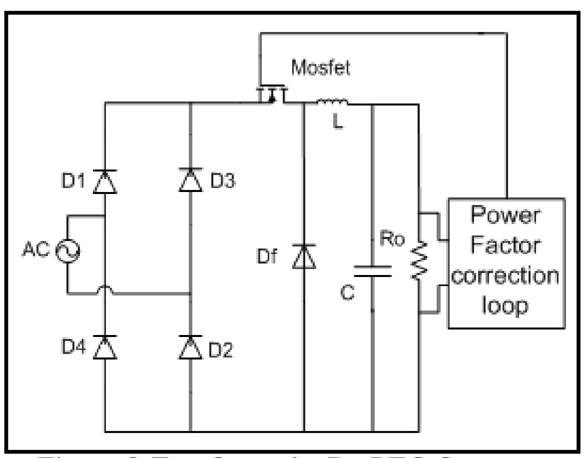

Figure 2:Two Stage Ac-Dc PFC Converter

Therefore, the penalty for the highest quality waveform (sinusoidal) and tight output voltage regulation is

Control loops;

A big storage capacitor;

An additional dc–dc converter with its own control circuit.

A new bridgeless PFC circuit is proposed in this paper with isolated transformer for smaller DC output voltage and to create an electrical isolation between the input and output side. Normally, an SMPS converter is work based on two stage converter due to the first converter.

Output voltage is very large such that second converter is required to step-down the output voltage to a smaller value. On the other hand, most of current SMPS also uses Fly back converter as it first stage DC-DC converter due to its capability to step-down the output voltage with larger ratio and capable to isolate the input and output part with high frequency transformer.

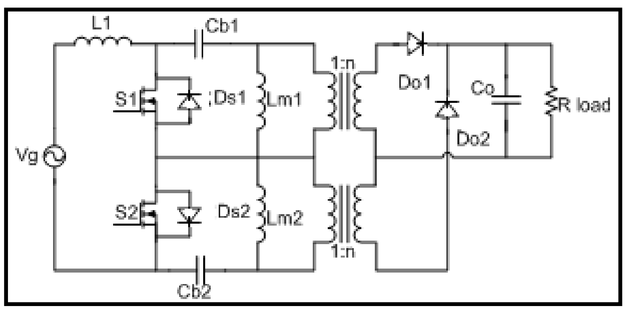

Figure 3:The Proposed Converter Circuit

Thus, the proposed converter enhances the input current characteristic while retaining the isolation capability existed in Fly back converter. Figure 3 shows the schematic diagram of the proposed converter. It is obvious that in this converter, the diodes bridge rectifier and two sets of DC-DC converter are eliminated.

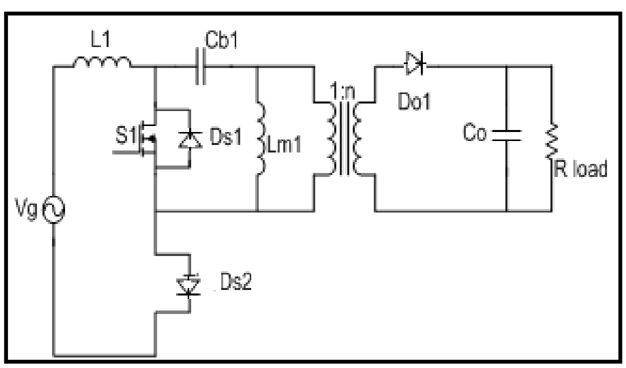

Figure 4(A):The Proposed Converter Operated At Positive Half Cycle

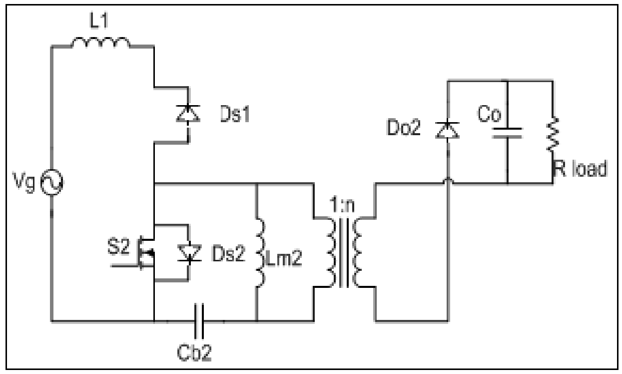

Figure 4(B):The Proposed Converter Operated At Negative Half-Cycle Of Vg.

5.Circuit Operation And Analysis

In this paper, the proposed circuit is simulated in two cases. Case (1).An open loop isolated bridgeless AC/DC Converter. Case (2).An closed loop isolated bridgeless AC/DC Converter. As shown in Figure 4(a),(b) the proposed converter has two distinguish equivalent circuit during positive and negative half-line cycle. Only the operation during positive half-line cycle will be analyzed while the same analysis can be carried out for the negative part. Since low output power is our main concern for this converter, thus the discontinuous conduction mode (DCM) is the best operating condition for this kind of power rating. Therefore, the current injected equivalent circuit approach (CIECA) is adopted to construct the steady-state and the small-signal model of the proposed converter [8]. In CIECA method, the equations for current injected inwards and outwards the converter is identified within each switching period. These two current equations will then be perturbed and linearized to get the small signal equation for the control to output transfer function. This transfer function is vital in modeling the closed-loop control of the proposed converter. Furthermore, the steady state equation will be derived from the injected current equation obtained earlier.

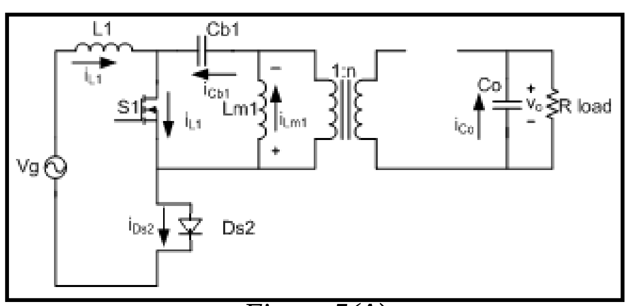

Figure 5(A)

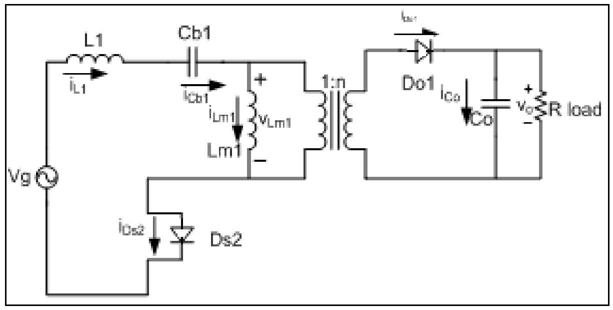

Figure 5(B)

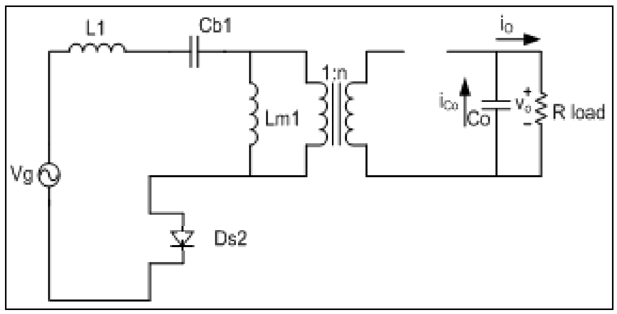

Figure 5(C)

Figure 5:Three Modes Of Operation During (A) $D_1 t_s$, (B) $D_2 t_s$, And (C) $D_3 t_s$

As shown in figure 5 and 6, there are three sub intervals modes exist if the circuit operates in DCM. The three modes can be classified as MODE 1(d_1T_s), MODE 2(d_2T_s), and MODE 3 (d3Ts). First the slope equations of each current waveform within each mode should be derived based on the equivalent circuit configuration shown in figure 5. As can be seen, the equation slope for each subinterval modes is represented in Figure 6. By using these information, the average value of the input current which in this case the input inductor current is represented as

$$i_{L1-AVG-T_s} = (V_g (d_1+d_2) d_1 T_s)/(2L_1) \qquad (1)$$

while the current injected from the converter without the inclusion of the output capacitor and load is defined as the output diode average current,

$$i_{(D_{(0\,1-AVG-Ts)})} = (d_1 d_2 T_s)/2 \; (V_g/L_a) \qquad (2)$$

However, these two equations have the d2 function which represents the second subinterval mode and is unwanted in modeling this circuit. Thus, by examining the ripple current waveform at L1 with the assumption that

$V_{cb1} = V_g$ and $V_{(L1-AVG)} = V_{(L2-AVG)}$, it is found that

$$d_2 = \frac{v_g}{v_o} n d_1 \qquad (3)$$

which will further simplifies equations (1) and (2) to

$$i_{l1-AVG-T_s} = \frac{d_1^2 T_S}{2}\Big(\frac{v_g}{}$$

i_(Do1-AVG-T_s)=(nd_1^2 T_s v_g^2)/(2v_o L_a) (5)

where La=L1//Lm1.

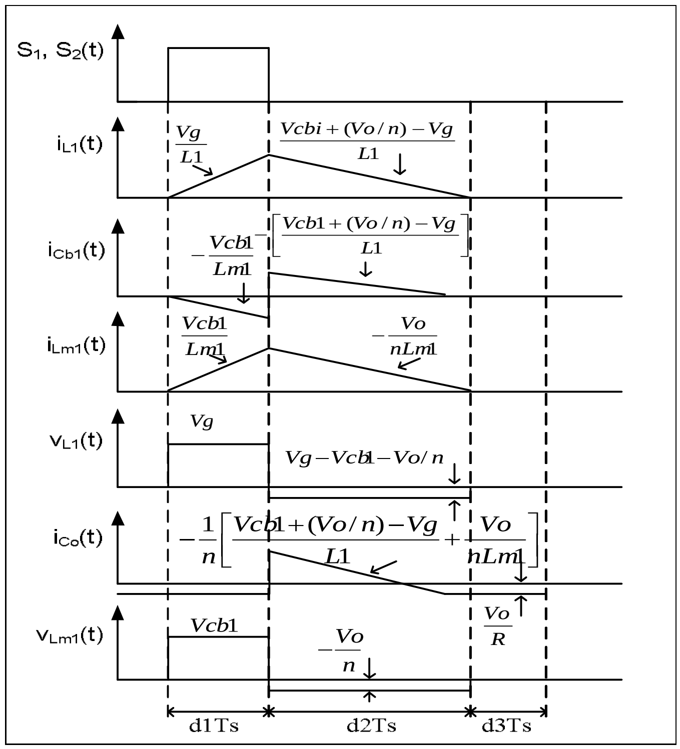

Figure 6: Key Waveforms Of The Proposed Converter

The mathematical model derived so far will only valid for high switching frequency. As for PFC, the low frequency or line frequency model is the main concern. This low frequency model will be derived based on the high frequency by integrating the equations at line frequency. Thus, by integrating equation (4) and (5) within half line frequency, the low frequency model are

$$i_{L1-AVG-TL} = \frac{1}{\pi}\int_0^{\pi} \frac{d_1^2}{2} \qquad (6)$$

$$= \frac{v_m d_1^2 T_S}{v_o L_1}\Big(\frac{v_o}{\pi}$$

$$i_{Do1-A}$$

(7)

where the input voltage is defined as = | sin(ωt) |
By further introducing perturbation and linearization to equation (6) and (7) for , , , and , the small signal AC models are

$$\widehat{i_{L1}} = \frac{1}{r_1}\widehat{v_x} \quad (8)$$

$$\widehat{i_{Do1}} = g_2\widehat{v_m} \quad (9)$$

Where

$$\frac{1}{r_1} = \frac{T_s}{4\pi v_o L_1}\left(4D_1^2 V_o + 2\pi n D_1^2 V_m\right)$$

$$j_1 = \frac{T_s}{4\pi L_1 v_o}\left(8 v_m D_1 V_o + 2\pi n V_m^2 D_1\right)$$

$$g_1 = \frac{nD_1^2 T_s}{4L_1}\left(\frac{V_m}{V_o}\right)^2$$

$$g_2 = \frac{nD_1^2 T_s}{2L_a}\left(\frac{V_m}{V_o}\right)$$

$$j_2 = \frac{nT_s D_1}{2L_a}\left(\frac{V_m^2}{V_o}\right)$$

$$\frac{1}{r_2} = \frac{nD_1^2 T_s}{4L_a}\left(\frac{V_m}{V_o}\right)^2$$

From equation (9), the block diagram of the converter is depicted in Figure 7. From this figure, the input-to-output and control-to-output transfer functions of the converter are

├ (V_o)ˆ/(V_m)ˆ┤ |=g_2/((sCo+1/R+1/r_2)) (10)
├ (V_o)ˆ/(d_1)ˆ┤ |=j_2/((sCo+1/R+1/r_2)) (11)

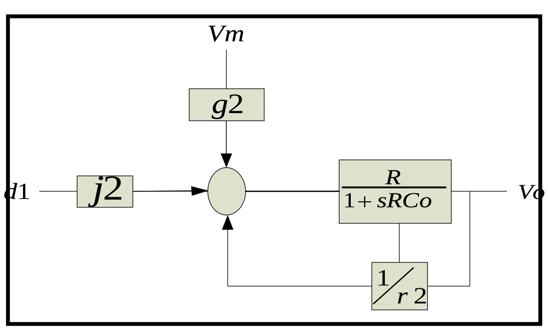

Figure 7:Block Diagram Of Proposed Converter

6.Converter Design And Simulation Results

In this section, the simulation results obtained using MAT LAB/SIMULINK will be presented. Table I shows the important parameters that has been determine for this particular bridgeless PFC converter. As can be seen, the converter will accept universal input voltage 240V rms.

Input voltage Vg	240Vrms
Inductor L1	150uH
Magnetizing Inductance Lm1,Lm2	75uH
Capacitors Cb1,Cb2	1uF
Desired Output Voltage	15VDC to 25VDC
Switching frequency, fs	50KHZ
Output capacitor, Co	3.3mF
Transformer turn ratio, n	0.2

Table 1:Key Parameters For The Proposed Converter

The circuit is designed at very high frequency such that any change in the load made by the controller would not interfere the input current waveform operates at line frequency. Then, based on the state variables equations obtained to find the slope in Figure 6, the state space large-signal model is developed. By closing the loop for the state-space model in Figure 11 with PI controller, the proposed circuit is simulated closed loop conditions. The input current and input voltage waveforms are depicted in Figure 10. It shows that the input current is in phase with the input voltage with sinusoidal waveform.

Here the simulation is carried out in two cases

An open loop isolated bridgeless AC/DC Converter.

An closed loop isolated bridgeless AC/DC Converter.

6.1.Case 1

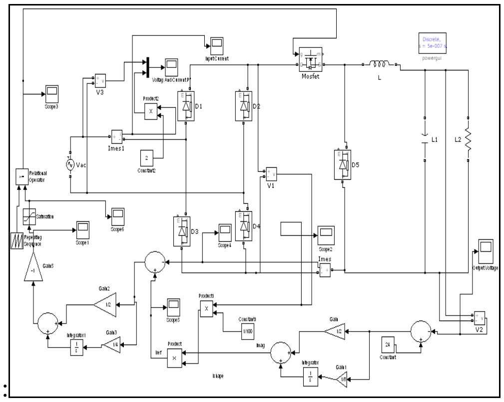

Figure 6.1:Simulation Circuit Of Two Stage Conversion

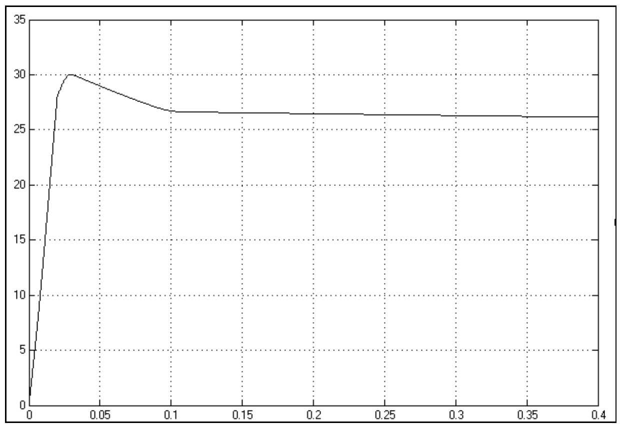

Figure 6.1.1: Output Voltage Of The Converter

Fig.6.1.1shows the simulation circuit of the two stage converter. Fig.9 shows the output voltage waveform of the converter shown in figure 8 and Fig.10 shows the source voltage and current waveforms plotted on the same axis. This shows the power factor of the source.

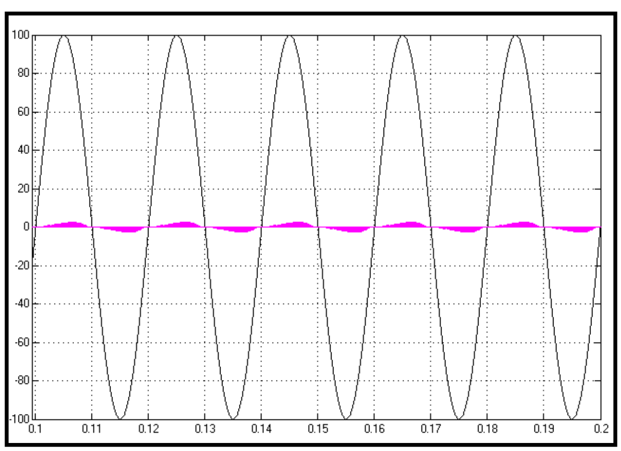

Figure6.1.2: Source Voltage And Current

6.2.Case 2

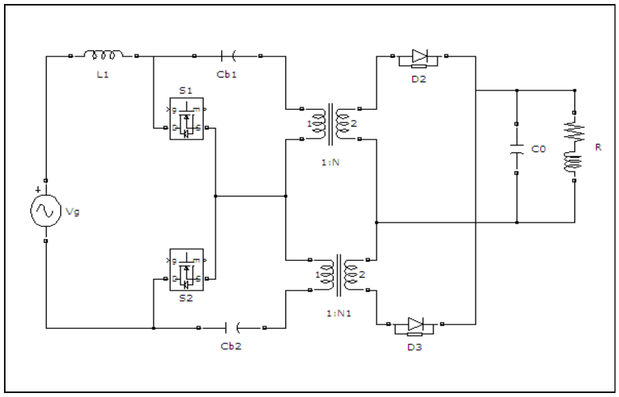

Figure 6.2: Case (1) MATLAB/Simulink Model Of A Open Loop Isolated Bridgeless AC/DC Converter

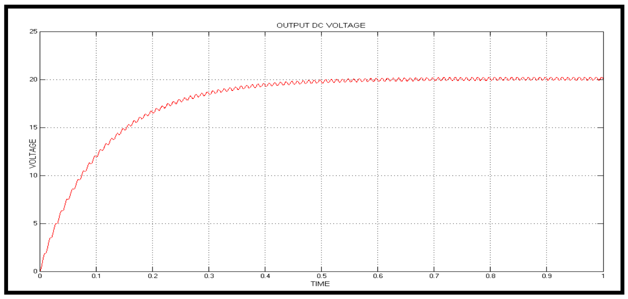

Figure 6.2.1: Constant Dc Output Voltage

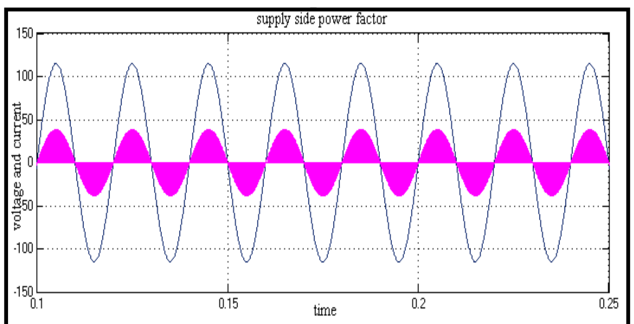

Figure 6.2.2: Source Side Voltage And Current

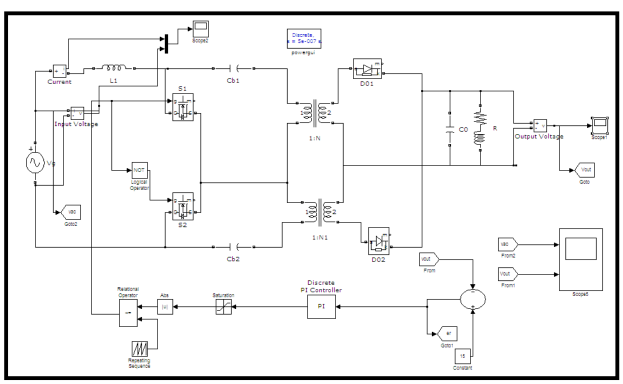

Figure 6.2.3:Case(2) MATLAB/Simulink Of The Closed Loop Isolated Bridgeless AC/DC Converter

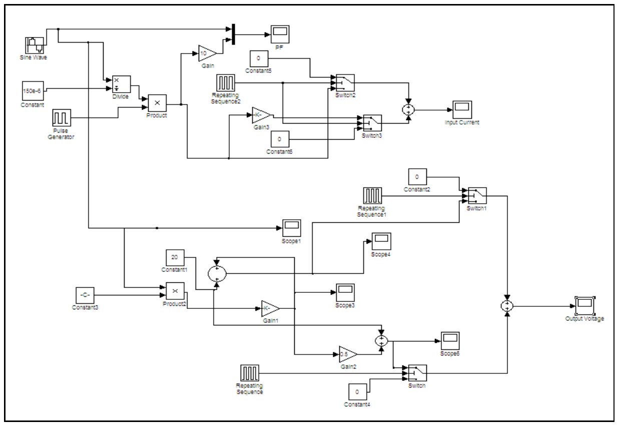

Figure 6.3.4:State-Space Large Signal Model Developed In Simulink

The input current waveform is depicted in Figure 6.3.5(a) with respect to the input voltage at 325V peak (240Vrms). As can be seen, the input current is reshaped such that it follows the sinusoidal wave-shape of the input voltage and in phase with it. The output voltage waveform is shown is Figure 6.3.5(b) regulated at 20VDC. The dynamic response for the converter at 240Vrms input voltage is depicted in Figure 6.3.6(a) and (b). As can be seen, the load changes from 50W to 100W and back to 50W at 0.6s and 0.9s respectively. In open loop cases, the converter is capable to regulate the output voltage to 20VDC within 0.6s. But in closed loop case the converter is designed such that it allows out voltage change from 15V to 25V within 0.03s. When the output load changes from 100W to 50W, overshoot exist at the output voltage in which it tends to increase rapidly to 23V and slowly regulated to 20V afterwards. For the input current, the regulation is inherent in DCM and the response is very much similar with the output voltage only without current overshoot. At full load, peak input current is 4.1A while at half load, the peak current is 3A.

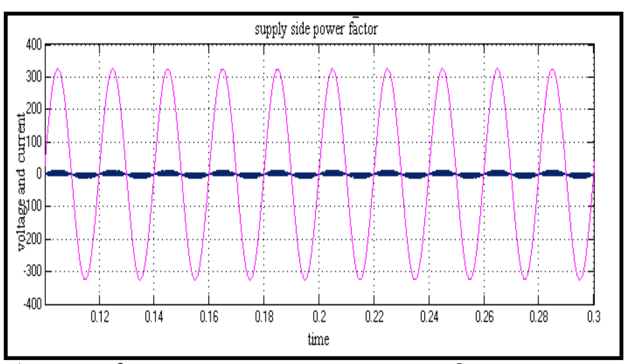

Figure 6.3.5(A): Waveforms For Input Current With Respect To Input Voltage

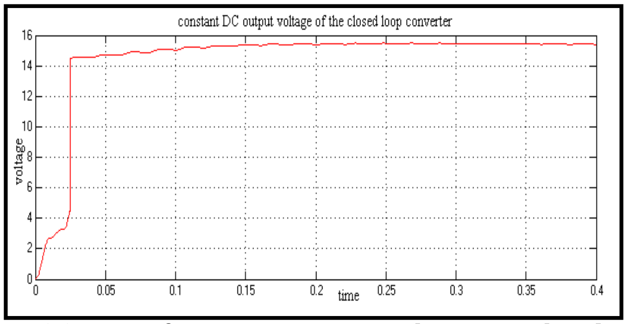

Figure 6.3.5(B): Waveforms For Output Voltage Regulated At 15VDC

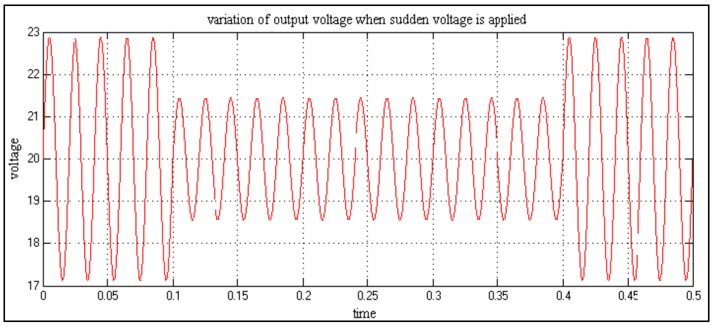

Figure 6.3.6(A)

Figure 6.3.6(A): The Output Voltage

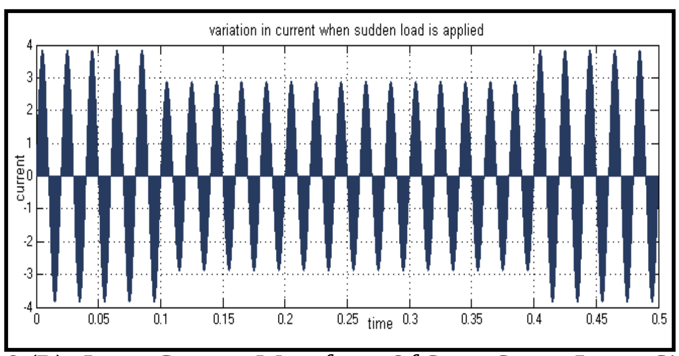

Figure 6.3.6 (B): Input Current Waveform Of State-Space Large Signal Model Developed

7.Conclusion

The large signal and steady-state model for the two stage converter and proposed bridgeless PFC converter are successfully developed Open loop and closed loop Models are also simulated in this paper. The models are used to design the required parameters of the converter operating in DCM condition. The steady-state operation of the proposed converter is determined at first place to obtain the required components parameters. Only then, the closed-loop control is designed based on the large-signal model with PI compensator. It is shown that the designed PI controller is capable to regulate the output voltage to 20VDC in open loop model and 15V DC to 20V DC in closed loop model with minimum settling time while the input current and voltage are in phase. Simulation results are done by using Matlab/Simulink Platform.

8.Reference

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