A Novel Control Method For Bridgeless Voltage Doubler Pfc Buck Converter

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Abstract

Switch mode power supplies without Power Factor Correction (PFC) tend to draw the AC line current in a non-linear fashion and may generate many unwanted harmonic content in the input current waveform. This leads to a very low power factor and less efficiency. The reason for the low and non-linear PF is that the AC input of a high frequency switched-mode conversion circuit consists of a diode bridge rectifier followed by bulk storage capacitor, This low power factor can be improved by using power factor correction circuit along with the rectifier circuit. A bridgeless Buck Converter can be used as a power factor correction circuit as well as a voltage doubler circuit for switched mode power supplies. This topology also have lesser number of conducting devices than the conventional bridge rectifier and buck converter, due to which it is having lesser conduction and switching losses. The voltage output of this circuit is also double the voltage produced by a single buck converter used as pfc circuit. A new control method called One Cycle control is introduced in this paper for the control of this circuit. This is a non linear control technique and produce faster response than the clamped mode current control. The simulation of bridgeless Buck converter using this control method is presented in this paper.

Index Terms: *Power Factor Correction, Bridgeless voltage Doubler, Buck Converter, One Cycle Control*

1. INTRODUCTION

Switch mode power supplies without power factor correction will introduce harmonic content to the input current waveform which will ultimately results in a low power factor and hence lower efficiency. A bridge diode rectifier followed by a power factor correction circuit which is either a buck or boost frontend is commonly used for all switched mode power supplies.

Boost converter as a PFC front-end exhibits 1-3% lower efficiency at 100-V line compared to that at 230-V line. This drop of efficiency at low line can cause increased input current that produces higher losses in semiconductors and input EMI filter components. Also it has relatively output voltage, typically in the 380-400-V range. This high voltage leads to switching losses of the primary switches of the downstream dc/dc output stage and the size and efficiency of its isolation transformer.

At lower power levels the drawbacks of the universal-line boost PFC front-end may be overcome by implementing the PFC front-end with the buck topology. Since the output voltage of a buck converter is less, the dc/dc stage can be implemented with lower-voltage-rated semiconductor devices and optimized loss and size of the transformer.

Conventional ac-dc converters has a diode bridge rectifier followed by power factor correction circuit .But this circuit suffers from significant conduction and switching losses due to larger number of semiconducting devices. This problem can be solved by using bridgeless converters to reduce the conduction losses and component count. A bridgeless buck PFC rectifier [1] combines both rectification and power factor correction using a single circuit. This circuit also act as a voltage doubler circuit whose output voltage is greater than a single buck converter. Usually clamped mode current control is used for controlling a buck converter .This paper explains a new control method called One Cycle Control [5] which is a non linear control technique and produce faster response than the later one.

2.BRIDGELESS BUCK PFC CONVERTER

Figure 1shows the PFC circuit formed by two buck dc/dc converters. Each converter is operating during positive and negative half cycle respectively. This PFC rectifier, employs two back-to-back connected buck converters that operate in alternative halves of the line-voltage cycle. The buck converter operating during positive half-cycles of line voltage V_{ac} consists of a unidirectional switch comprising of diode D_a in series with switch $S1$ freewheeling diode $D1$, filter inductor $L1$ and output capacitor $C1$. Similarly, the buck converter consisting of the unidirectional switch implemented by diode D_b in series with switch $S2$, freewheeling diode $D2$, filter inductor $L2$, and output capacitor $C2$ operates only during negative half-cycles of line voltage Vac .

Output voltage $V_{ou}t$ of the PFC rectifier is the sum of the voltages across output capacitors $C1$ and $C2$, is given by $V_{out} = 2DV_{in}$ where d is the duty ratio

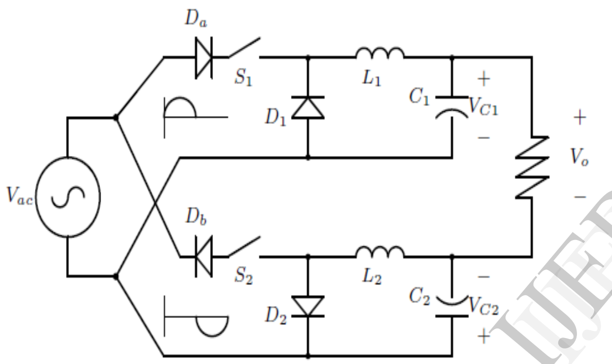

Fig 1.Bridgeless Buck Converter

The input current flows through only one diode during the conduction of a switch, i.e., either D_a or D_b . Efficiency is further improved by eliminating input bridge diodes in which two diodes carry the input current. An additional advantage of the proposed circuit is its inrush current control capability. Since the switches are located between the input and the output capacitors, switches $S1$ and $S2$ can actively control the input inrush current during start-up.

3. PWM CONTROL OF SWITCHING CONVERTER

In pulse width modulation (PWM) control, the duty ratio is linearly modulated in a direction so as to reduces the error. Any change in the input voltage must be sensed as an output voltage change and error produced in the output voltage is used to change the duty ratio to keep the output voltage constant. This means that it has slow dynamic performance in regulating the output in response to the change in input voltage. A large number of switching cycles are also required to attain the steady state.

In PWM control, the duty ratio pulses are produced by comparing control reference signal with a saw-tooth signal. As a result the control reference is linearly modulated into the duty ratio signal. If the power supply voltage is changed , for example by a large step up, the duty ratio control does not see the change instantaneously since the error signal must change first. Therefore, the output voltage jumps up and the typical output voltage transient overshoot will be observed at the output voltage. Then the error produced in the output voltage is amplified and compared with the saw tooth signal to control the duty ratio pulses. A large number of switching cycles is required before the steady-state is reached. The output is always influenced by the input voltage perturbation.

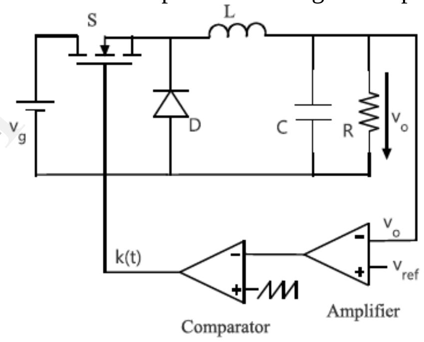

Fig 2.Buck converter using PWM technique

The above figure shows a typical buck converter using PWM technique .The voltage output V_o is compared with V_{ref} to generate an error signal and it is amplified.The error signal thus obtainedand saw tooth waveform is given as input to the comparator where it is compared is compared to generate the PWM signal for the switch.Since the error generated is used to vary the duty ratio to keep the voltage constant ,this method produce a slow response.

PWM based Clamped Mode voltage control or current control is the most commonly used method for controlling the buck converter. In voltage mode control duty ratio is directly determined by the voltage feedback.Current mode control has an inner current loop and an outer voltage loop.the output voltage is sensed and compared with the reference to generate the error signal.This error signal is used as the reference for the inner current loop which is being sensed with the inductor current feedback.Thus this method requires two feedback loops which makes the system more complex and hence provides a slow response.The above mentioned methods are linear methods where the output varies with any variation in the input supply side.To eliminate the need for the control loops and to obtain a dynamic response a new control method is introduced called the One Cycle Control which is discussed the the next section.

4.ONE CYCLE CONTROL-NOVEL CONTROL METHOD

One Cycle Control is a new nonlinear control technique implemented to control the duty ratio of the switch in real time such that in each cycle the average value input waveform at the switch rectifier output diode is exactly equal to the control reference. One-Cycle Control method reject input voltage perturbations in only one switching cycle and follow the control reference very quickly. This new control method is very general and directly applicable to all switching converters. Switching converters are pulsed and nonlinear dynamic systems. This technique takes advantage of the pulsed and nonlinear nature of switching converters and achieves instantaneous control of the average value of the

chopped voltage or current. This technique provides fast dynamic response and good input-perturbation rejection.

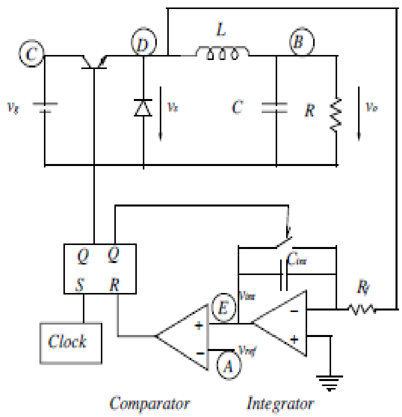

Fig 3.Buck converter using One Cycle Contol

Figure shows a typical buck converter employing One Cycle control. The one-cycle controller is comprised of an integrator with reset, a comparator, a flip-flop, a clock and an adder. The clock triggers the RS flip-flop to turn ON the transistor with a constant frequency..When the switch is turned on by a fixed frequency clock pulse, voltage available across the diode is being integrated. The output of the integrator is compared with the control reference in real time using a comparator.

When the integrated value of the diode-voltage becomes equal to the control reference, the transistor is turned OFF and the integration is immediately reset to zero to prepare for the next cycle. In each cycle, the diode-voltage waveform may be different. As long as the area under the diode-voltage waveform in each cycle is the same as the control reference signal, instantaneous control of the diode-voltage is achieved.

4.1.OCC CONTROLLER FOR BRIDGELESS BUCK CONVERTER

Figure 3 shows an OCC controller for controlling a bridgeless buckconverter.Here V_o is the output voltage obtained across the two capacitors C1and C2.The output obtained is amplified and is fed to an integrator with reset.At each instant the integral value is being compared with a reference V_{ref} .When integral value V_{int} reaches the control reference,V_{ref} comparator changes its state and turns the switch (transistor) off and the integrator is reset to zero at the same time. Since the reset signal is a pulse with very short width, the reset time is very short, and the integration is activated immediately after the resetting.

Thus, $V_{int} = 1/RC \int kV_o(t)dt$

The output of comparator is given to a flip flop to give signals to switches Q1 and Q2

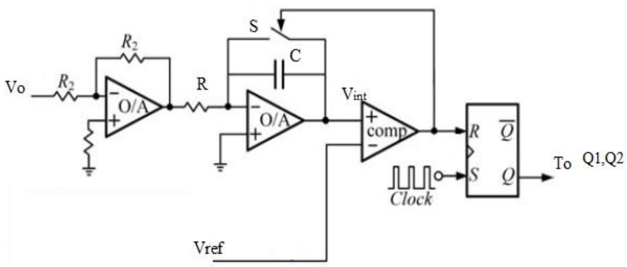

Fig 4.OCC controller for bridgeless buck converter

The operation of an OCC controller is explained by means of the following waveforms

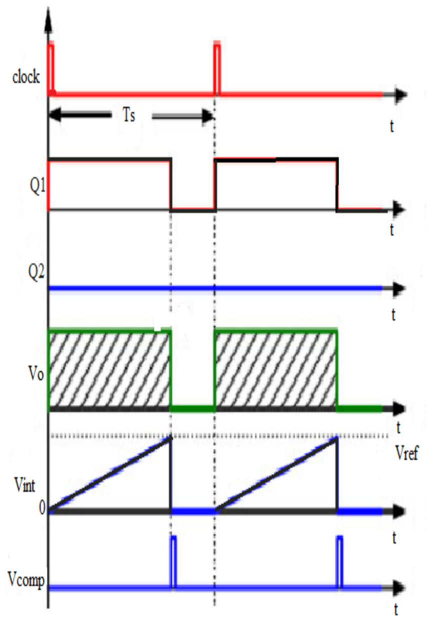

Fig 5.waveforms of one cycle controller

Here T_s is the time period of one switching cycle. The operation is explained for positive half cycle during which switch Q1 is operating and Q2 is off ,V_{ref} is the reference voltage .The output voltage is obtained across the capacitor according the ON and OFF of the switch. The integrator is also activated during the start of each switching cycle. When the integral value of V_o reaches the V_{ref} ,the comparator

changes its state from low to high which is indicated by a short pulse as shown in the graph. When this condition is reached the switch is turned off till the starting of the next switching cycle and this process repeats for both positive and negative half. By increasing the switching frequency almost constant output voltage can be obtained by this control method. This also eliminates any variation of the input supply voltage and provides a dynamic performance

The simulink model of a bridgeless buck converter and one cycle controller is discussed in the coming section

5.SIMULINK MODEL OF BRIDGELESS BUCK CONVERTER AND OCC

The simplified simulink model of bridgeless buck converter is shown here

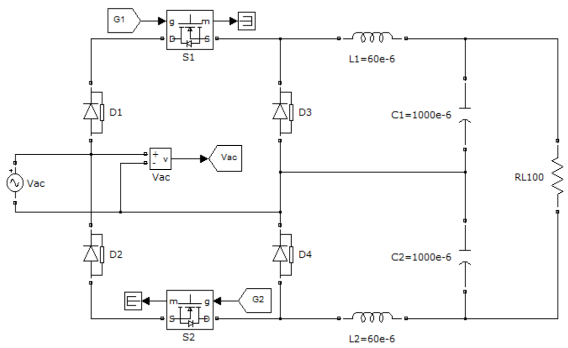

Fig 6.Simulink model of bridgeless buck converter

The simulation of this bridgeless buck converter was done in MATLABSIMULINK environment. The design consideration for this converter is same as that for a conventional buck converter operating in continuous conduction mode since it is having two individual buck converters each operating during a particular half cycle.MOSFET is being used as the switching device and the gating pulses for this device is provided by the one cycle controller. The pulses are provided at the beginning of each switching cycle .Two inductors can be replaced by a single inductor for effective magnetic utilization.

The simulink model of One Cycle Controller is also shown below

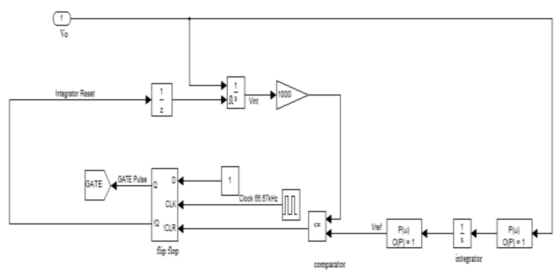

Fig 7.Simulink model of One Cycle Controller

The output voltage is integrated and given a proper gain and is being fed to a comparator where it is compared with a reference. The output of the comparator is used to set and reset the D flip flop. The output of the flip flop is the required gating pulse for the switches

6. SIMULATION RESULTS OF OCC BRIDGELESS BUCKCONVERTER

The simulation of the bridgeless buck converter operating at a switching frequency of 65kHz is done using SIMULINK.The buck converter is generating an output voltage of 12V using One Cycle Control method. The gating signals given to the switches during the positive and negative half cycle, input and the output waveforms obtained during the simulation are shown below. When switching pulses are given to one of the switches the other switch will be off. Thus it is important to identify whether the incoming waveform is from the positive half or from the negative half.

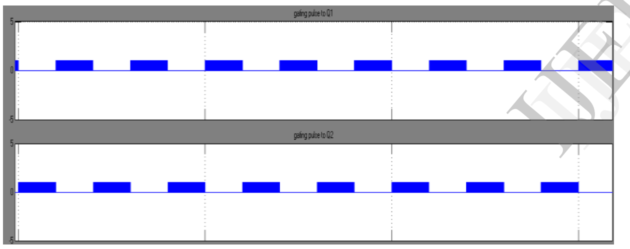

Fig 8.Gating signals for switches S1and S2

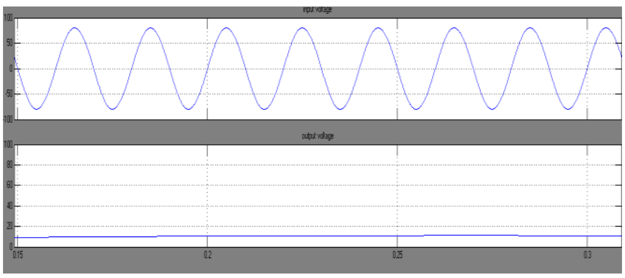

Fig 9 Input and output waveforms

7.CONCLUSION

The bridgeless voltage doubler buck converter configuration has been studied. This circuit generates the output voltage which is double than a conventional buck converter since it is having two buck converters operating in a complete cycle. The PWM control method which was already used for controlling the switching has been mentioned. A new control method called One Cycle Control has been implemented to the bridgeless buck converter in order to get dynamic response and to eliminate the input voltage perturbations. Since the output voltage always follows the switched variable the output remains constant at the reference value .This method also eliminates the use of various control loops thus reducing the complexity of the conventional circuit. The simulation of bridgeless buck voltage doubler circuit using One Cycle Control was done in Matlab simulink and the waveforms obtained at the time of simulation is presented here

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