A POWER QUALITY IMPROVED BRIDGELESS CONVERTER BASED COMPUTER POWER SUPPLY

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ABSTRACT
Poor power quality, slow dynamic response, high device stress, harmonic rich, periodically dense, peaky, distorted input current are the major problems which are frequently encountered in conventional switched mode power supplies (SMPSs) used in computers. To mitigate these problems, it is proposed here to use a non-isolated bridgeless buck-boost single ended primary inductance converter (SEPIC) in discontinuous conduction mode (DCM) at the front end of an SMPS. The bridgeless SEPIC at the front end provides stiffly regulated output dc voltage even under frequent input voltage and load variations. The output of the front end converter is connected to a half bridge dc-dc converter for isolation and also for obtaining different dc voltage levels at the load end that are needed in a personal computer. Controlling a single output voltage is able to regulate all the other dc output voltages as well. The design and simulation of the proposed power supply are carried out for obtaining an improved power quality which is verified through the experimental results.

INTRODUCTION

Many electronic appliances powered up from the utility, utilize the classical method of ac-dc rectification which involves a diode bridge rectifier (DBR) followed by a large electrolytic capacitor. The uncontrolled charging and discharging of this capacitor instigates harmonic rich current being drawn from the utility which goes against the international power quality standard limits [1-2]. Modern ac-dc converters incorporate power factor correction (PFC) and harmonic current reduction at the point of common coupling (PCC) which improves voltage regulation and efficiency [3-5] at the load end. Personal computer (PC) is one of the electronic equipment which is severely affected by power quality problems. Single stage and two stage conversions of ac voltage into dc voltage have been used in computers to maintain harmonic contents within limits and also to obtain stiffly regulated multiple outputs. Single stage power conversion is simple, compact and cost-effective. However, it suffers from poor dynamic response, control complexity, high capacitance value and high component stress. So, two stage conversion of ac voltage into multiple dc voltages is mostly preferred in computers [6]. The component count in a two stage power supply is much higher than its single stage counterpart. But, it provides better output voltage regulation, fast dynamic response and blocks the second harmonic (100Hz or 120Hz) component in the first stage itself so that large capacitors at the output side are avoided.

Various front end converters have been employed in the power supplies for providing PFC and output voltage regulation. A boost converter is the common choice for providing PFC in power supplies. However, it is not the preferred choice in computer power supplies due to its requirement for a large input voltage range [7]. The output voltage of a boost converter cannot be controlled to a value less than 300V for a 220V ac input. So, a buck-boost converter is preferred in PCs where wide variations in input voltages and load are expected [8-9]. Low output voltage ripple is preferred in a computer power supply as it is connected to various ICs. Single stage power supplies are used in many applications where power quality improvement and voltage regulation take place in a single stage. However, in computers, single stage configuration increases the stress across the switches and slows the voltage regulation under varying loads [10-11]. Hence, two stage PFC ac-dc converters based

SMPSs are being employed to improve the input power quality and also to obtain an acceptable output voltage regulation. But, the efficiency of a two stage SMPS is lower than the conventional SMPS [12-13]. To eliminate this disadvantage, a new bridgeless front end converter is proposed in this paper for computer power supplies [14-17] which offers low switching ripple, sinusoidal input current and good dynamic response as compared to other non-isolated buck-boost converters. The elimination of DBR at the front end results in reduced conduction losses and supports a larger output voltage range with enhanced efficiency. At the output of the front end converter, a half bridge converter is used which provides isolation, regulation and multiple dc outputs [18-20] with a better core utilization.

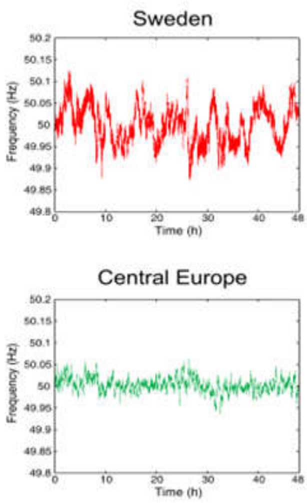
It is observed from the available literature that the power quality improvement in SMPSs using bridgeless PFC converter has not been attempted by many researchers so far. In this work, a bridgeless single ended primary inductance converter (SEPIC) operating in discontinuous conduction mode (DCM) is being used at the front end of the SMPS which offers excellent PFC at the rated as well as light load condition. Upper converter operates in the positive half cycle of the ac voltage while the lower converter operates in the negative half cycle. The output of the bridgeless PFC converter is connected to the isolated converter. Test results of the proposed multiple-output SMPS are found in line with the simulated performance demonstrating its improved power quality and output voltage regulation.

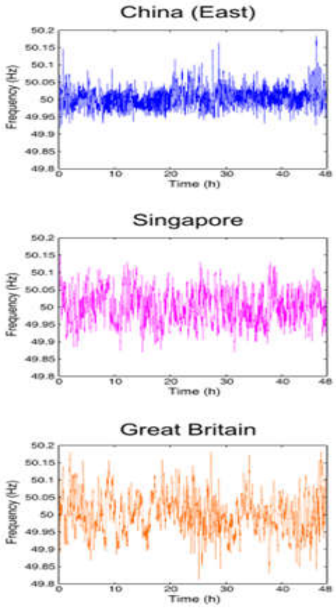
POWER QUALITY

Power quality determines the fitness of electric power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

The electric power industry comprises electricity generation (AC power), electric power transmission and ultimately electric power distribution to an electricity meter located at the premises of the end user of the electric power. The electricity then moves through the wiring system of the end user until it reaches the load. The complexity of the system to move electric energy from the point of production to the point of consumption combined with variations in weather, generation, demand and other factors provide many opportunities for the quality of supply to be compromised.

The tolerance of data-processing equipment to voltage variations is often characterized by the CBEMA curve, which give the duration and magnitude of voltage variations that can be tolerated.





Ideally, AC voltage is supplied by a utility as sinusoidal having an amplitude and frequency given by national standards (in the case of mains) or system specifications (in the case of a power feed not directly attached to the mains) with an impedance of zero ohms at all frequencies.

No real-life power source is ideal and generally can deviate in at least the following ways:

- Variations in the peak or RMS voltage are both important to different types of equipment.
- When the RMS voltage exceeds the nominal voltage by 10 to 80% for 0.5 cycle to 1 minute, the event is called a "swell".
- A "dip" (in British English) or a "sag" (in American English the two terms are equivalent) is the opposite situation: the RMS voltage is below the nominal voltage by 10 to 90% for 0.5 cycle to 1 minute.
- Random or repetitive variations in the RMS voltage between 90 and 110% of nominal can produce a phenomenon known as "flicker" in lighting equipment. Flicker is rapid visible changes of light level. Definition of the characteristics of voltage fluctuations that produce objectionable light flicker has been the subject of ongoing research.
- Abrupt, very brief increases in voltage, called "spikes", "impulses", or "surges", generally caused by large inductive loads being turned off, or more severely by lightning.
- "Under voltage" occurs when the nominal voltage drops below 90% for more than 1 minute. The term "brownout" is an apt description for voltage drops somewhere between full power (bright lights) and a blackout (no power – no light). It comes from the noticeable to significant dimming of regular incandescent lights, during system faults or overloading etc., when insufficient power is available to achieve full brightness in (usually) domestic lighting. This term is in common usage has no formal definition but is commonly used to describe a reduction in system voltage by the utility or system operator to decrease demand or to increase system operating margins.

POWER CONDITIONING

Power conditioning is modifying the power to improve its quality.An uninterruptible power supply can be used to switch off of mains power if there is a transient (temporary) condition on the line. However, cheaper UPS units create poor-quality power themselves, akin to imposing a higher-frequency and lower-amplitude square wave atop the sine wave. High-quality UPS units utilize a double conversion topology which breaks down incoming AC power into DC, charges the batteries, then remanufactures an AC sine wave. This remanufactured sine wave is of higher quality than the original AC power feed.

A surge protector or simple capacitor or varistor can protect against most overvoltage conditions, while a lightning arresterprotects against severe spikes.

Electronic filters can remove harmonics.

SMART GRID AND POWER QUALITY:

Modern systems use sensors called phasor measurement units (PMU) distributed throughout their network to monitor power quality and in some cases respond automatically to them. Using such smart grids features of rapid sensing and automated self healing of anomalies in the network promises to bring higher quality power and less downtime while simultaneously supporting power from intermittent power sources and distributed generation, which would if unchecked degrade power quality.

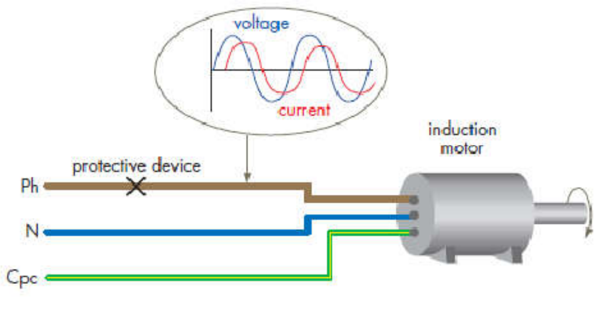
POWER FACTOR CORRECTION (PFC)

POWER FACTOR is the ratio between the useful (true) power (kW) to the total (apparent) power (KVA) consumed by an item of AC. electrical equipment or a complete electrical installation. It is a measure of how efficiently electrical power is converted into useful work output. The ideal power factor is unity, or one. Anything less than one means that extra power is required to achieve the actual task at hand.

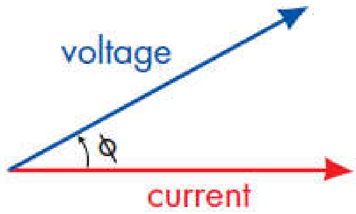
All current flow causes losses both in the supply and distribution system. A load with a power factor of 1.0 results in the most efficient loading of the supply. A load with a power factor of, say, 0.8, results in much higher losses in the supply system and a higher bill for the consumer. A comparatively small improvement in power factor can bring about a significant reduction in losses since losses are proportional to the square of the current.

When the power factor is less than one the ‘missing’ power is known as reactive power which unfortunately is necessary to provide a magnetizing field required by motors and other inductive loads to perform their desired functions. Reactive power can also be interpreted as wattles, magnetizing or wasted power and it represents an extra burden on the electricity supply system and on the consumer’s bill.

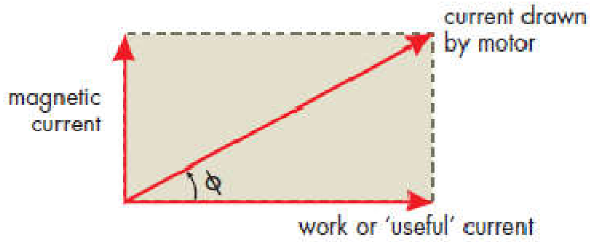
A poor power factor is usually the result of a significant phase difference between the voltage and current at the load terminals, or it can be due to a high harmonic content or a distorted current waveform. A poor power factor is generally the result of an inductive load such as an induction motor, a power transformer, a ballast in a luminaries, a welding set or an induction furnace. A distorted current waveform can be the result of a rectifier, an inverter, a variable speed drive, a switched mode power supply, discharge lighting or other electronic loads.



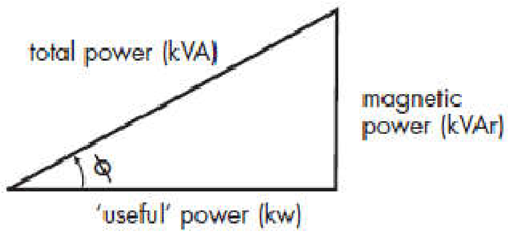
Power supply to induction motor



Phaser diagram of voltage and current



Phaser diagram of currents



Phaser diagram of KW, KVA, and KVA

DESIGN OF PROPOSED BRIDGELESS CONVERTER BASED SMPS SYSTEM

The design of proposed bridgeless converter based SMPS is described in the following section.

DESIGN OF PROPOSED SMPS SYSTEM

The design for the positive half cycle operated PFC converter is carried out here. The negative half cycle operated converter is designed in the same way. The average voltage Vacav is calculated as,

$$V_{acav} = \frac{2\sqrt{2}V_{ac}}{\pi} = \frac{2\sqrt{2} \times 220V}{3.14} = 198V \qquad (1)$$

The duty cycle D of the PFC buck-boost converter is expressed as the ratio of its output dc voltage to the sum of output dc voltage and input voltage.

$$D = \frac{V_{PFC}}{V_{PFC} + V_{acav}} = \frac{300V}{300V + 198V} = 0.6 \qquad (2)$$

Irrespective of variation in the input voltage from 170V to 270V, the output voltage is maintained constant at 300V. Hence, the duty cycles for supply voltages of 170V voltage, 220V and 270V are calculated as, D170V=0.66, D220V=0.6, D270V=0.552 respectively. The duty cycle D of the PFC converter is taken less than D220V for an efficient control during DCM operation. Therefore, it is considered as 0.25 for the design of the PFC converter.

The input inductor value is calculated for the permitted ripple of 40% of input current.

$$L_{p1} = \frac{DV_{acavg}}{f \times (i_{inripple})} = \frac{0.25 \times 198V}{20kHz \times 0.58A} = 4.35mH \quad (3)$$

where, f is the switching frequency of the PFC converter.
The critical conduction parameter is given as [21],

$$K_a < \frac{1}{2\left(\frac{V_{PFC}}{\sqrt{2}V_{...}} + n\right)^2} = \frac{1}{2\left(\frac{300V}{311V} + 1\right)^2} = 0.129 \quad (4)$$

where, n is taken as 1 for the non-isolated PFC converter. To operate the PFC converter in DCM, the conduction parameter should be taken less than Ka for efficient control. Hence, it is selected as 0.08.
The equivalent value of inductance of the PFC converter is given as,

$$L_{eq} = \frac{R_{dc}K_a}{2f} = \frac{281.2\Omega \times 0.08}{2 \times 20kHz} = 225\mu H \quad (5)$$

Therefore, the output inductor value is calculated as,

$$L_{p2} = \frac{L_{p1}L_{eq}}{L_{p1} - L_{eq}} = \frac{4.31mH \times 225\mu H}{4.31mH - 225\mu H} = 237\mu H \quad (6)$$

The selected value of output inductor is 100 µH to ensure DCM condition in all operating conditions of input voltages, load and unity PF operation at a low input voltage.
The intermediate capacitor value is estimated as,

$$C_p = \frac{1}{\omega_r\left(L_{p1} + L_{p2}\right)} = \frac{1}{2 \times \pi \times 2000Hz\left(4.3mH + 0.1mH\right)} = 0.18\mu F \quad (7)$$

where, ωr is the angular frequency (ωr=2πfr). A fr is considered as 2000Hz (f>fr>fL). A capacitor value of 0.22µF is selected for the hardware implementation.
An L-C filter is used at the input side to mitigate higher order harmonics [22]. The maximum value of the capacitor is as,

$$C_{ac} = \frac{I_p \tan\theta}{\omega V_p} = \frac{2.25A \times 0.017}{314 \times 311V} = 391nF \quad (8)$$

The filter capacitor value is selected such that it is less than Cac. Hence, a 330nF capacitor is selected in hardware implementation.
The filter inductor Lac is calculated for mitigating high order harmonics close to 5 kHz frequency.

$$L_{ac} = \frac{1}{4\pi^2 f_c^2 C_d} = \frac{1}{4 \times \left(3.14 \times 5 \times 10^3\right)^2 \times 330 \times 10^{-9}} = 3.07mH \quad (9)$$

A 3.1mH inductor is selected for simulation and experimental system.

The input capacitors of the isolated half bridge dc-dc converter act as the output filter capacitors for the PFC converter. So, the design of the capacitor is important to eliminate the second order harmonic component as well as to provide maximum power for that duration when input voltage falls. This is very crucial for PC power supplies as the rating of the capacitor affects the size and the cost of the overall SMPS.
The expression for calculating the capacitor to reduce second order harmonic is as [3],

$$\frac{C_1}{2} = \frac{C_2}{2} = \frac{I_{PFC}}{2\omega\Delta V_{PFC}} = \frac{1.06A}{2 \times 314 \times 6V} = 0.28mF \quad (10)$$

The hold-up capability can be estimated as,

$$t_{hold\text{-}up} = \left(V_{PFCm}{}^{2} - V_{PFC\min}{}^{2}\right)\frac{C}{2P_o} \tag{11}$$

where, thold-up is the holdup time of the capacitor, Po is the maximum output power, VPFCm is the minimum output voltage (2% ripple is considered) and VPFCmin is the minimum voltage at which the output voltage holds regulation.

Therefore, to maintain 10ms hold-up time, the required capacitance is calculated as,

$$C = \frac{2t_{hold\text{-}up}P_o}{\left(V_{PFCm}{}^{2} - V_{PFC\min}{}^{2}\right)} = \frac{2\times 10ms \times 320W}{(294V)^2 - (260V)^2} = 0.339mF \tag{12}$$

Two capacitors are connected in series. Therefore, the value of C1=C2=0.679 mF. The selected value of the capacitors is 0.6mF each to meet both the conditions.

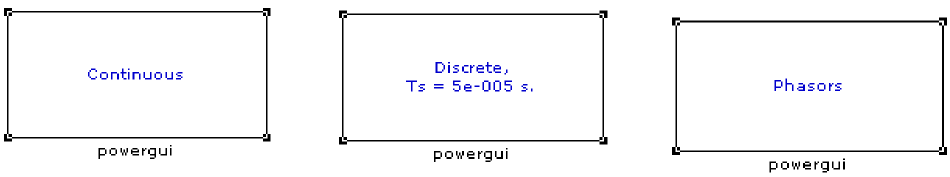
The calculation of inductance for the secondary winding with highest rating is shown here, while the calculation for rest of the secondary windings remains same. The inductance Lo1 is expressed as,

$$L_{o1} = \frac{V_{o1}(0.5 - D_s)}{f_s \Delta i_{Lo1}} = \frac{12V(0.5-0.4)}{60kHz \times 0.625A} = 0.032mH \tag{13}$$

Similarly, the inductances for the other secondary windings are calculated as 9.5 µH, 6.8 µH and 1.5 mH. **SOURCES AND SINKS:**The sources library contains the sources of data/signals that one would use in a dynamic system simulation. One may want to use a constant input, a sinusoidal wave, a step, a repeating sequence such as a pulse train, a ramp etc. One may want to test disturbance effects, and can use the random signal generator to simulate noise. The clock may be used to create a time index for plotting purposes. The ground could be used to connect to any unused port, to avoid warning messages indicating unconnected ports.The sinks are blocks where signals are terminated or ultimately used. In most cases, we would want to store the resulting data in a file, or a matrix of variables. The data could be displayed or even stored to a file. the stop block could be used to stop the simulation if the input to that block (the signal being sunk) is non-zero. Figure 3 shows the available blocks in the sources and sinks libraries. Unused signals must be terminated, to prevent warnings about unconnected signals.

POWERGUI

Environment block for Sim Power Systems models



The Powergui block allows you to choose one of the following methods to solve your circuit:

- Continuous method, which uses a variable step Simulink solver
- Ideal Switching continuous method
- Discretization of the electrical system for a solution at fixed time steps
- Phasor solution method

The Powergui block is necessary for simulation of any Simulink model containing SimPowerSystems blocks. It is used to store the equivalent Simulink circuit that represents the state-space equations of the model.

You must follow these rules when using this block in a model:

- Place the Powergui block at the top level of diagram for optimal performance. However, you can place it anywhere inside subsystems for your convenience; its functionality will not be affected.
- You can have a maximum of one Powergui block per model

- You must name the block powergui

SIMULATION AND CONFIGURATION OPTIONS

To specify the simulation type, parameters, and preferences, select **Configure parameters** in the Powergui dialog. This opens another dialog box with the Powergui block parameters. This dialog box contains the following tabs:

- Solver Tab
- Load Flow Tab
- Preferences Tab

STEADY-STATE VOLTAGES AND CURRENTS

Open the Steady-State Voltages and Currents Tool dialog box that displays the steady-state voltages and currents of the model. For more information, see the power_steadystate reference page.

INITIAL STATES SETTING

Open the Initial States Setting Tool dialog box that allows you to display and modify initial capacitor voltages and inductor currents of the model. For more information, see the power_initstates reference page.

LOAD FLOW

Open the Load Flow Tool dialog box to perform load flow and initialize three-phase networks and machines, so that the simulation starts in steady state. The Load Flow Tool offers most of the functionality of other tools available in the power utility industry. It uses the Newton-Raphson method to provide robust and fast convergence solution. For more information, see the power_loadflow reference page.

MACHINE INITIALIZATION

Open the Machine Initialization Tool dialog box to initialize three-phase networks containing three-phase machines, so that the simulation starts in steady state. This tool also offers simplified load flow features that are helpful in initializing machine initial currents of your models. For more information, see the power_loadflow reference page.

USE LTI VIEWER

Open a window to generate the state-space model of your system (if you have Control System Toolbox software installed) and automatically open the LTI Viewer interface for time and frequency domain responses. For more information, see the power_ltiview reference page.

IMPEDANCE VS FREQUENCY MEASUREMENT

Open the Impedance vs Frequency Measurement Tool dialog box to display the impedance versus frequency defined by the Impedance Measurement blocks. For more information, see the power_zmeter reference page.

FFT Analysis

Open the FFT Analysis Tool dialog box to perform Fourier analysis of signals stored in a Structure with Time format. For more information, see the power_fftscope reference page. An example of using the FFT Analysis tool is described in Performing Harmonic Analysis Using the FFT Tool.

Generate Report

Open the Generate Report Tool dialog box that allow you to generate a report of steady state variables, initial states, and machine load flow for a model. For more information, see the power_report reference page.

Hysteresis Design Tool

Open a window to design a hysteresis characteristic for the saturable core of the Saturable Transformer block and the Three-Phase Transformer blocks (two- and three-windings). For more information, see the power_hysteresis reference page.

Compute RLC Line Parameters

Open a window to compute RLC parameters of overhead transmission line from its conductor characteristics and tower geometry. For more information, see the power_lineparam reference page.

CONCLUSION

A bridgeless non-isolated SEPIC based power supply has been proposed here to mitigate the power quality problems prevalent in any conventional computer power supply. The proposed power supply is able to operate satisfactorily under wide variations in input voltages and loads. The design and simulation of the proposed power supply are initially carried to demonstrate its improved performance. Further, a laboratory prototype is built and experiments are conducted on this prototype. Test results obtained are found to be in line with the simulated performance. They corroborate the fact that the power quality problems at the front end are mitigated and hence, the proposed circuit can be a recommended solution for computers and other similar appliances.

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