A Combined Buck and Boost Converter for Single-Phase Power-Factor Correction

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10/7/2005
Introduction

- The AC/DC converters in IBM’s high-end servers connect to any 3-phase utility world-wide (up to 480V nominal, 576V for 2 seconds)
- Up to 3 converters per line cord provide as much as 22.5kW of bulk power
- Each converter operates line-to-line, without a neutral connection
- This results in voltages over 700V at the input to each converter
- A typical Boost converter would require a 750V intermediate bus voltage
- Buck + Boost topology was chosen to maintain a 400V intermediate bus
- Permits use of industry-standard 500-600V devices
Buck + Boost Power Train

Switches have independent duty cycles

Buck switch

Freewheeling diode

Boost switch
Operating Modes

(A) B+B PFC with block controls.dat (active)

- Boost region
- Buck Region
Boost Mode

Buck operates at 100% duty cycle

Boost is switching

Only boost error signal crosses ramp
Buck Mode

Buck is switching

Boost is off

Only buck error signal crosses ramp
Why use Buck+Boost for Single-Phase?

- Buck switch eliminates boost inrush problem
- Buck switch functions as prime-power disconnect
- Input current can be controlled
- Enhanced PLD immunity
Controls: Prior Art
Buck+Boost Control

- Buck+Boost converter is difficult to control in continuous-conduction mode
- Early applications operated the inductor on the verge of discontinuous conduction to maintain stability → impractical for high power applications
- In 1993 Dr. Ray Ridley developed a controller that maintains stability even in continuous conduction mode
- The addition of an inner current loop provides adaptability to changing power stage operation
Ridley Controller

Line and inductor current are sensed

Additional circuitry

From "Analysis and Design of a Wide Input Range Power Factor Correction Circuit for Three-Phase Applications" by Ridley, et. al.
Fuld & Kern Controller: eliminated one ramp

Two current sensors are used

Only one ramp is used

From "A Combined Buck and Boost PFC Controller for Three-Phase Applications" by Fuld, et. al.
Summary of prior art

- Both earlier schemes required two sensors for line and inductor current
- Efficiency penalty at lower power levels where resistive shunts are used
- Cost penalty at high power levels where Hall-effect sensors are used
- IBM controller requires that only inductor current be sensed
- Line current is synthesized by controller
IBM Controller

- Voltage Error Amplifier
- Line Current Controller
- Inductor Current Controller
- Low-Pass Filter
- Line Current Synthesizer
- Inductor Current Sense
- Zener Clamp Limits
- Windup at Zero Crossing
- Peak Current Limiter
Simulated Performance
Line Current Synthesis

Sensed inductor current

After blanking

Output of inverting filter is proportional to line current
VAC=300V

(H) B+B PFC with block controls.dat (active)

Output voltage
Rectified Input voltage
Line current
Multiplier out (red)
Synthesized line current (green)
Buck Error signal
Boost Error signal
Line amplifier output
Transition from Boost to Buck

(A) B+B PFC with block controls.dat (active)

Buck region

Boost region

Error signals and ramp

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Startup

Output voltage walking in

Spikes not really there!

Line current

Error signals
Lightning Strike

1200V peak
Input voltage

Peak current limited to 30A

Output increases only 5V
Measured Performance of 7.5kW Rectifier
Line Current Total Harmonic Distortion

Rise in THD largely caused by filtering after rectifier

Boost region
Buck region

Current Distortion

Line Voltage

Half load
Full load

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Power Factor

Power factor vs. Line Voltage

- Blue line: Half Load
- Red line: Full load

Boost region vs. Buck region

200 300 400 500

Power factor

0.9800 0.9850 0.9900 0.9950 1.0000
Efficiency (includes DC/DC isolation stage)

Efficiency

- Boost region
- Buck region

Line Voltage

- Half Load
- Full Load
Summary
Advantages of Buck+Boost topology

- No restrictions on output voltage
  - Enables use of 450V caps and 600V silicon regardless of line voltage
  - Enables operation from 277V while keeping output voltage unchanged

- Inherent control of input current
  - Permits use of fast blow line fuses (semiconductor fuses)
  - Permits N+1 operation from single line cord – fuses clear before upstream CB
  - Enables use of Silicon Carbide rectifiers
  - Permits operation from DC bus - no inrush current

- Enhanced PLD immunity: Lightning strike and Ring Wave

- Buck switch functions as prime-power disconnect \(\rightarrow\) simplifies Hotplug

- “Anti-Smoke” compliant
“Anti-smoke” Compliance

- Inherent protection against a shorted bulk cap or boost FET
- Buck switch limits fault current to a safe level and is then turned off to isolate the fault
- If a shorted buck switch causes an OV the boost switch functions as crowbar to clear the input fuses
- Input fuses are very fast-acting so this failure does not make a big noise or smoke!
Disadvantages of Buck+Boost topology

- Extra floating switch required \(\rightarrow\) increased complexity and cost
- Discontinuous input current in Buck region \(\rightarrow\) bigger input filter
- Filter not required if converter operates from low voltage only
IGBT bias and gate drive

- Additional floating bias and optical isolator required
- Cost ~$2.00
Optional Input Filter

3rd order elliptical

Filter not required if converter runs in boost mode steady state
Filter Response

Very steep fall off beyond the pass band
References
References:


