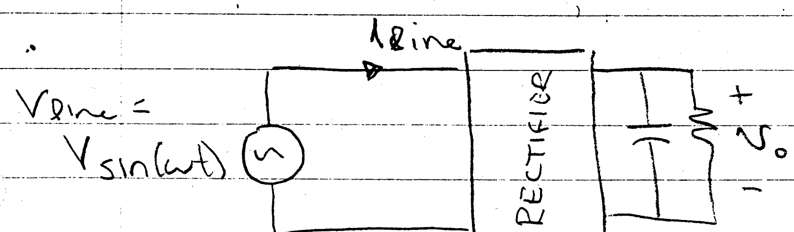
6.334 Power Electronics
Spring 2007

Power Electronics Notes - D. Perreault

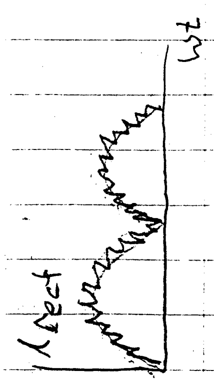
★★ Power Factor Correction (PFC) Rectifiers

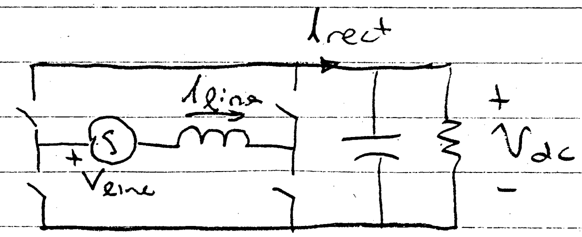
Power Quality issues and regulations are requiring rectifier loads connected to the utility to achieve high power factor (e.g. IEC1000). This means that (unlike phase controlled rectifiers), the rectifier needs to draw close to a sinusoidal current in phase with the line voltage. (Make rectifier "look like" resistor to the utility!
[IEC1000 places fixed limits on harmonic currents]

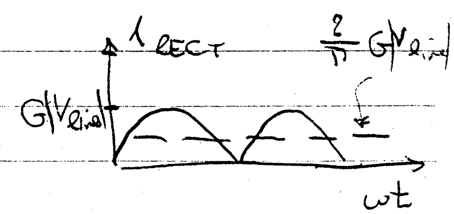


To achieve this, a switched-mode rectifier is used.

One way to do this is to use a current-controlled full-bridge converter, with $i_{ref} = -G\,V_{line}$.







The rectified current will be a rectified sine wave with peak magnitude KV_{line} and average value $\frac{2}{\pi}KV_{line}$

→ We can control output current + voltage by varying G.

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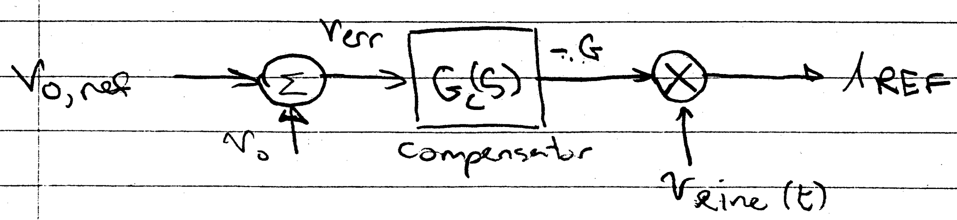
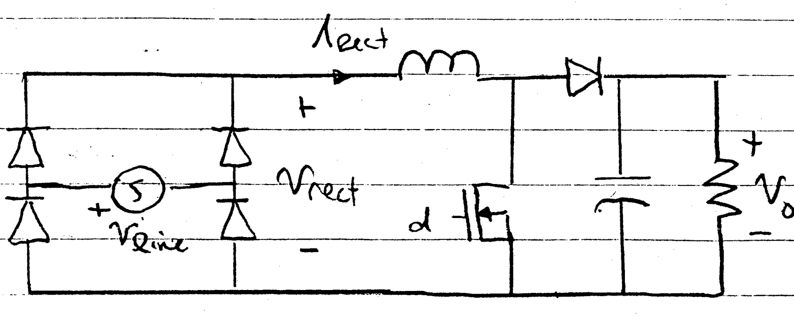
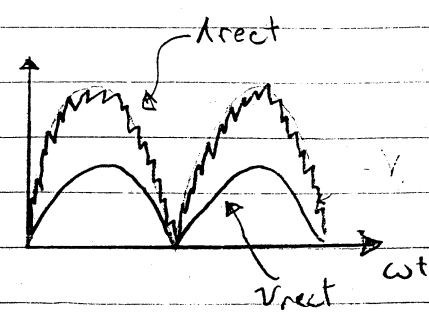


- Need multiplier to compute the current reference for the converter
- The bandwidth of the controller must be much lower than twice the line frequency, since rectifier power modulates zero to twice the average at twice the line frequency. ($G \approx$ constant over a line cycle).
- The output capacitor / energy storage must be large enough to support current ripple at 2X the line frequency.
- The converter does <u>not</u> provide isolation. If a 60Hz isolation xformer is not used the output of the system cannot be ground referenced.
- This topology is useful where bidirectional conversion is required. If only rectification is needed, one may use a much simpler topology:

UNITY POWER FACTOR BOOST RECTIFIER:





- needs only a single active switch (diode bridge unfolds i_{rect})

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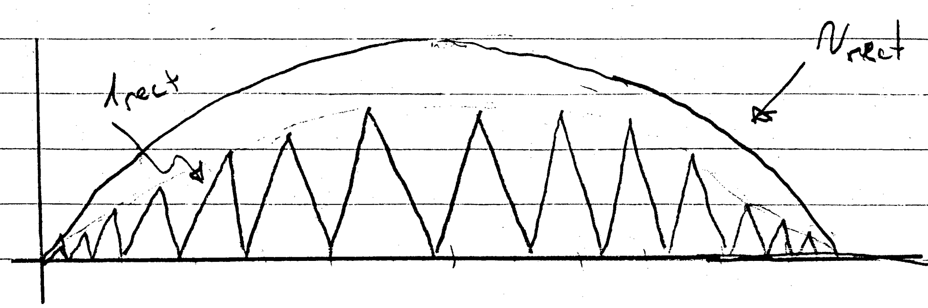
- As with the full-bridge, the boost rectifier can regulate the output voltage to values above the peak line voltage.
  - → Any current-control scheme is ok: hysteresis control, average current mode control, peak current-mode control, etc.
  - → The outer loop (V_o control) can be similar to that shown for the full bridge, but uses V_{rect} instead of V_{line} to generate the current reference. Similar limitations on control bandwidth, capacitor sizing, etc apply.

Interesting alternative control technique sometimes used at low power: <u>const on-time control at edge of discontinuous conduction</u>. (Unitrode chip exists to implement this control. requires no multiplier):

$\Delta I = \frac{V}{L}\Delta t$

Inductor current starts at zero. Turn on fet for controlled time t_{on}. Current rise of inductor $\propto$ to V_{rect} $(= \frac{1}{L} V_{rect} \cdot t_{on})$. Then turn off switch while inductor current discharges to zero into output. Repeat when I reaches zero.



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within each switching cycle (of variable period T),

$$i_{pk} = \frac{1}{L} t_{on} V_{rect}(t)$$

and local average current $\bar{I}_{rect}$

$$\bar{I}_{rect} = \frac{1}{2L} t_{on} V_{rect}(t)$$

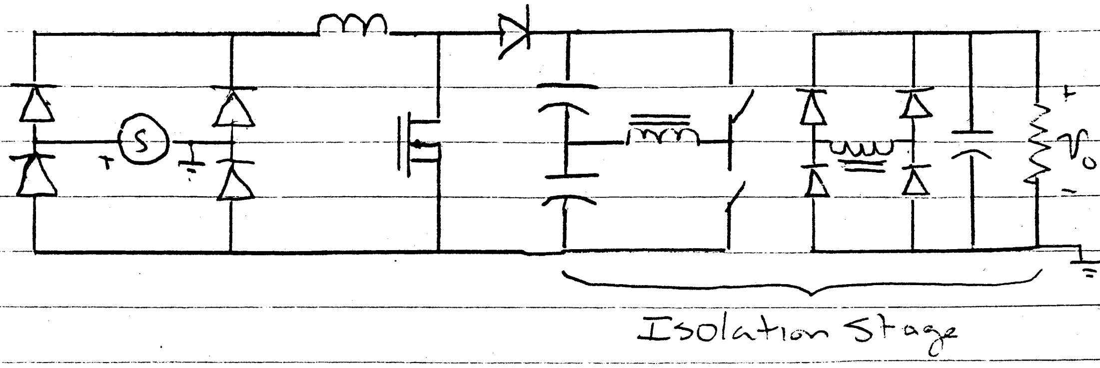
∴ we naturally get unity power factor drawn from the line (average i proportional to t_{on}) without needing a multiplier to calculate
→ control V_o by varying t_{on} slowly.

But: the input ripple current is large ∴ input EMI filter will be large.

Note: The UPF boost rectifier provides <u>no</u> isolation. Thus, unless there is a 60Hz isolation Xformer at the input, the output <u>cannot</u> be ground referenced.

Often, a second isolation stage is used to fix this problem. The isolation stage does not need to regulate voltage because the UPF rectifier does this.

One method



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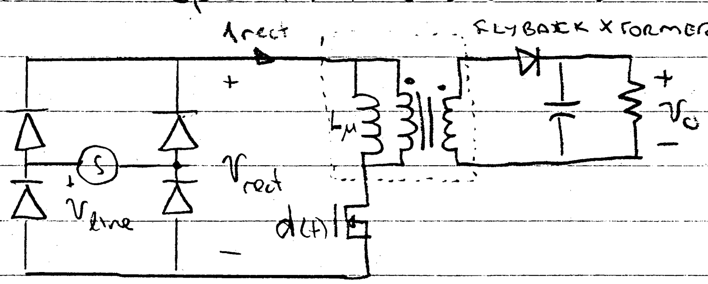
In this example, a half-bridge converter is operated at 50% duty cycle as an isolation stage.

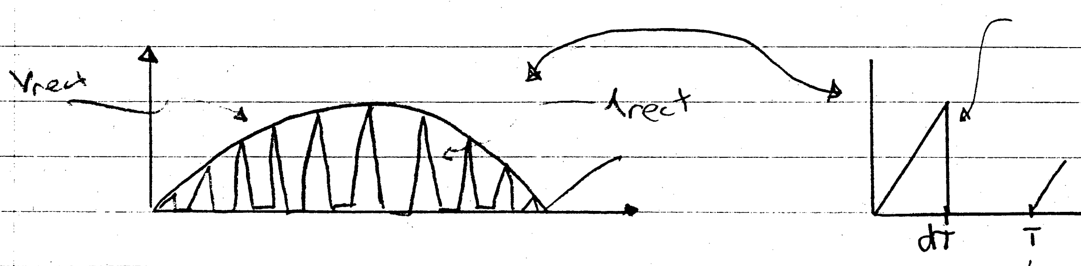
One area of ongoing research is the search for a better "single-stage" isolated PFC: one in which only one stage of conversion is needed for both UPF and Isolation.

An example of one way this can be done (though it has significant drawbacks at even moderate power levels) is as follows:

Switched-mode rectifier based on Flyback converter operated in discontinuous conduction mode (DCM):



$$i_{pk} = \frac{V_{rect}}{L_\mu} dT$$



$$\bar{i}_{rect} = \frac{T}{2L_\mu} d^2 \tilde{v}_{rect}(t)$$

So we get an average input current proportional to the input voltage and the square of the duty ratio.

$\Rightarrow$ UPF with very simple duty ratio control of V_o.

$\Rightarrow$ But DCM Flyback has high device and passive component stresses + requires significant input EMI filtering. These problems outweigh the simplicity advantages at moderate power levels.