ECCE 2024
IEEE ENERGY CONVERSION CONGRESS & EXPO PHOENIX, ARIZONA, USA OCT. 20-24

A Rectifier with Inherent Unity Power Factor

v research
Industrial Research and Development

Sayed Reza Afzali Arani[1], Alireza Ramezan Ghanbari [1], Heinz Seyringer [1], ….

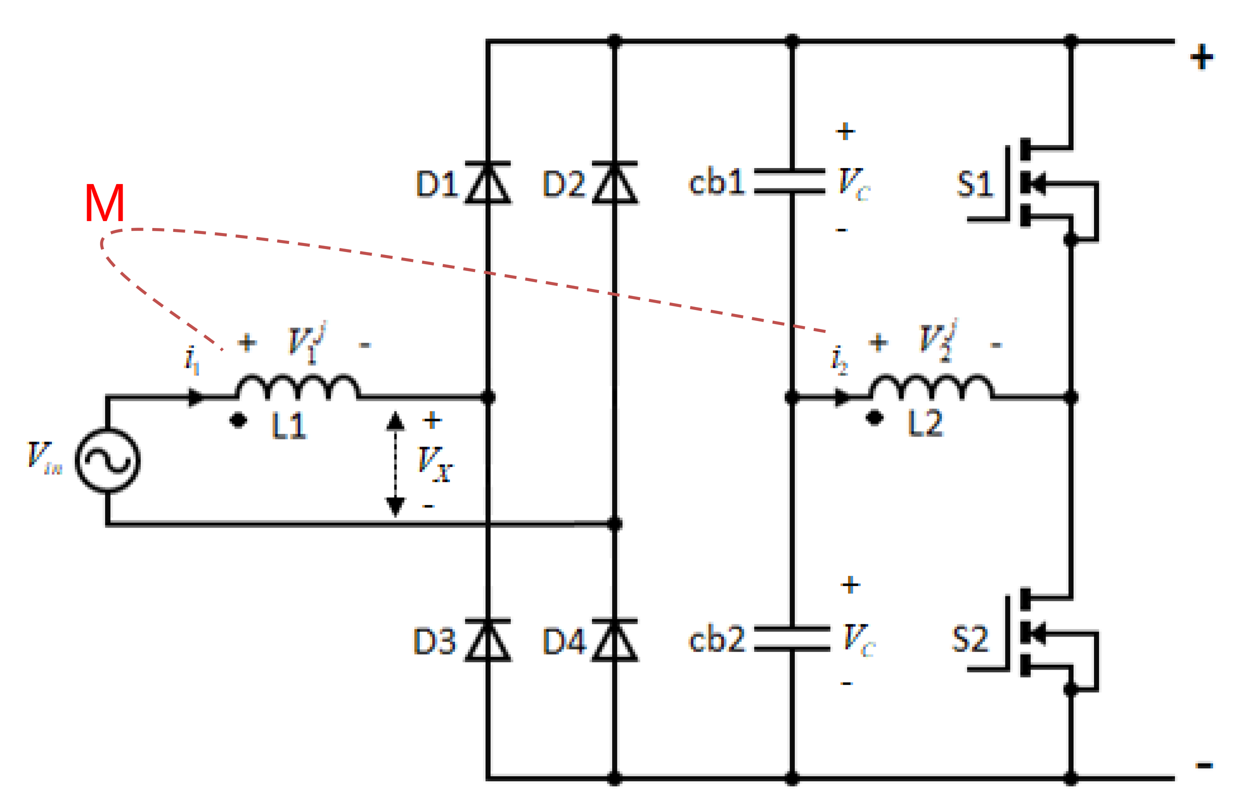
[1] V-Research GmbH

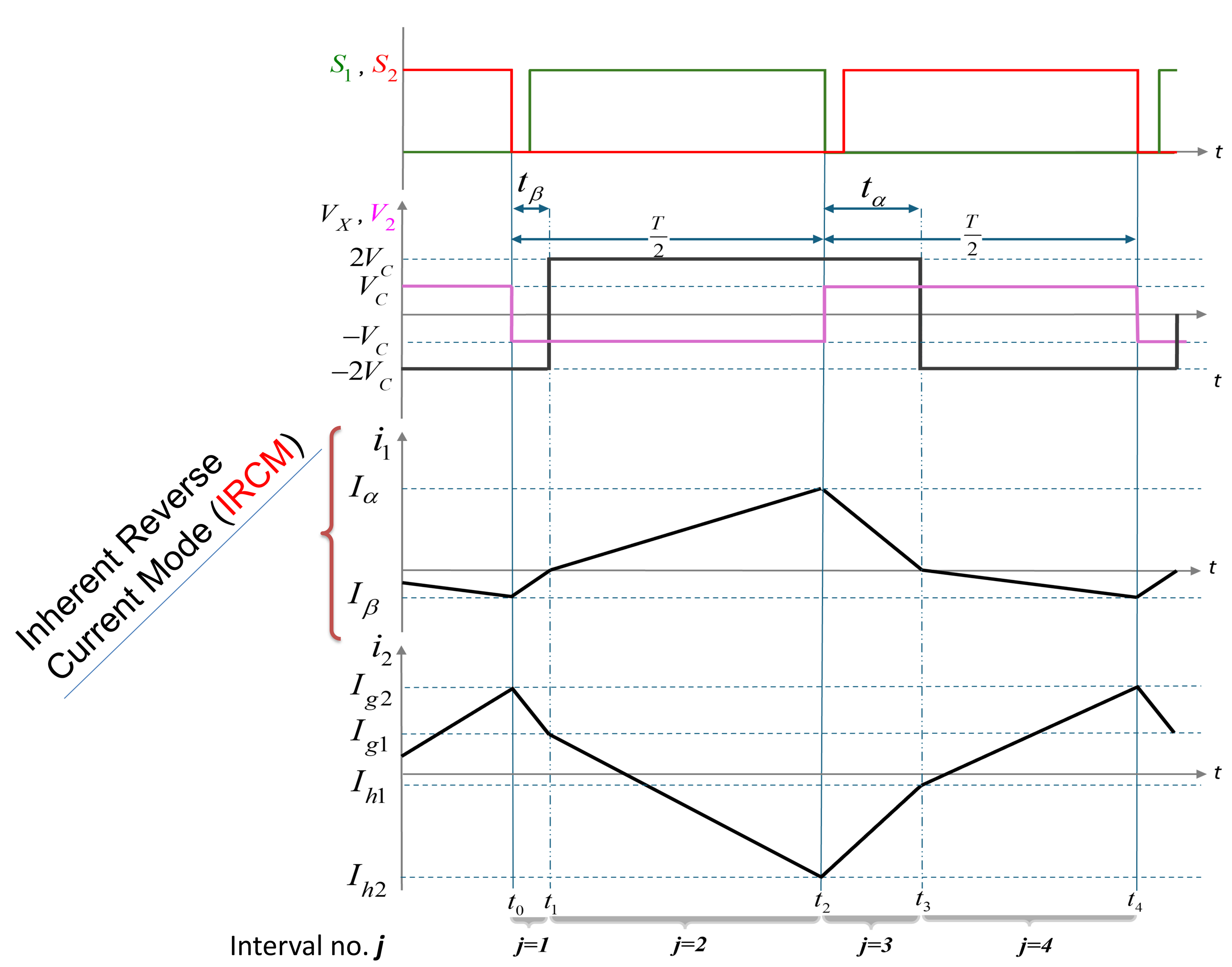
Abstract

A new **rectifier topology** with a unity power factor, introducing a new current mode, is presented.

- No need for a current control loop (inherent)
- It is mathematically proven that the input impedance behaves as a constant resistor.
- Inherent soft switching occurs during the entire line cycle.

Topology and Switching Waveforms





Analysis

Flux Linkage of L_1 and L_2 in each interval

$$\begin{cases} d\lambda_1^j = L_1 di_1^j + M di_2^j = V_1^j dt^j \\ d\lambda_2^j = M di_1^j + L_2 di_2^j = V_2^j dt^j \end{cases} \Rightarrow \begin{pmatrix} di_1^j \\ di_2^j \end{pmatrix} = \Gamma \begin{pmatrix} V_1^j \\ V_2^j \end{pmatrix} dt^j$$

$$\Gamma = \begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{21} & \Gamma_{22} \end{pmatrix} = \frac{1}{L_1 L_2 - M^2} \begin{pmatrix} L_2 & -M \\ -M & L_1 \end{pmatrix}$$

$$j=1 \rightarrow \begin{pmatrix} -I_\beta \\ I_{g1} - I_{g2} \end{pmatrix} = \Gamma \begin{pmatrix} V_{in} + 2V_C \\ -V_C \end{pmatrix} t_\beta$$

$$j=2 \rightarrow \begin{pmatrix} I_\alpha \\ I_{h2} - I_{g1} \end{pmatrix} = \Gamma \begin{pmatrix} V_{in} - 2V_C \\ -V_C \end{pmatrix} (\frac{T}{2} - t_\beta)$$

$$j=3 \rightarrow \begin{pmatrix} -I_\alpha \\ I_{h1} - I_{h2} \end{pmatrix} = \Gamma \begin{pmatrix} V_{in} - 2V_C \\ V_C \end{pmatrix} t_\alpha$$

$$j=4 \rightarrow \begin{pmatrix} I_\beta \\ I_{g2} - I_{h1} \end{pmatrix} = \Gamma \begin{pmatrix} V_{in} + 2V_C \\ V_C \end{pmatrix} (\frac{T}{2} - t_\alpha)$$

The first elements form a system of 4 equations. Solving the 4 unknowns:

$$t_\alpha = T\omega(1-\gamma)/2(1-\gamma\omega)$$

$$t_\beta = T\gamma(1-\omega)/2(1-\gamma\omega)$$

$$I_\alpha = T\omega(-\Gamma_{11}(V_{in}-2V_C) - \Gamma_{12}V_C)(1-\gamma)/2(1-\gamma\omega)$$

$$I_\beta = T\gamma(-\Gamma_{11}(V_{in}+2V_C) + \Gamma_{12}V_C)(1-\omega)/2(1-\gamma\omega)$$

$$\omega = \frac{\Gamma_{11}(V_{in}-2V_C) - \Gamma_{12}V_C}{-\Gamma_{11}(V_{in}-2V_C) - \Gamma_{12}V_C}$$

$$\gamma = \frac{\Gamma_{11}(V_{in}+2V_C) + \Gamma_{12}V_C}{-\Gamma_{11}(V_{in}+2V_C) + \Gamma_{12}V_C}$$

Average forward current

$$I_{in} = \bar{i}_1 = \bar{I}_\alpha + \bar{I}_\beta = \frac{I_\alpha}{2T}(\frac{T}{2} - t_\beta + t_\alpha) + \frac{I_\beta}{2T}(\frac{T}{2} - t_\alpha + t_\beta) \Rightarrow I_{in} = -\frac{\Gamma_{12} T}{8} V_{in}$$

Average reverse current

$$R_{in} = \frac{8}{-\Gamma_{12} T} = 8 f_s \sqrt{L_1 L_2} \frac{(1-k^2)}{k}$$

k is the coupling factor
fs is the switching frequency

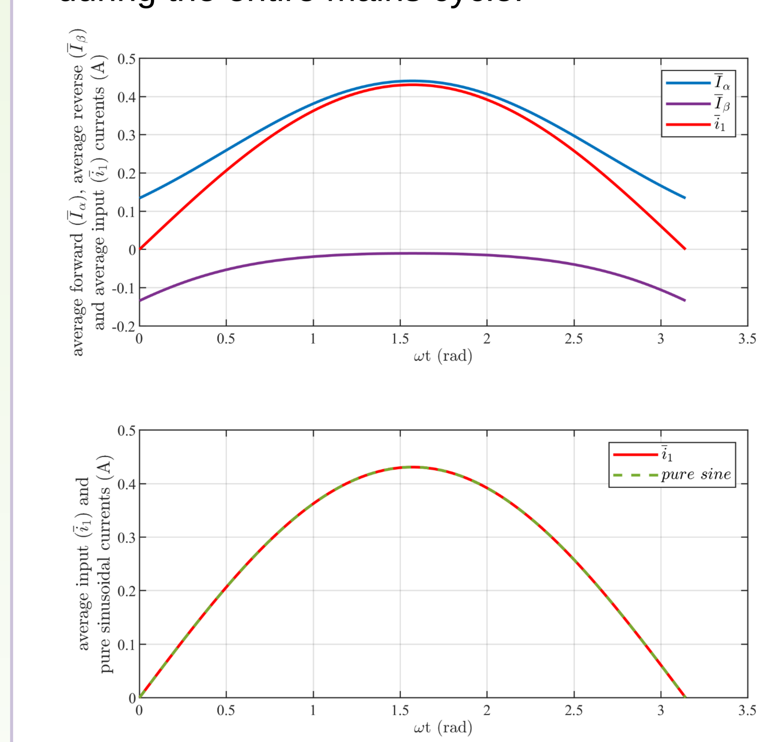
Operational Conditions

1) $\frac{|V_{in}|}{2} \leq V_C$ (condition for preventing CCM)

2) $\frac{|V_{in}|}{\frac{M}{L_2} - 2} \leq V_C$ (condition for Unity PF and preventing DCM)

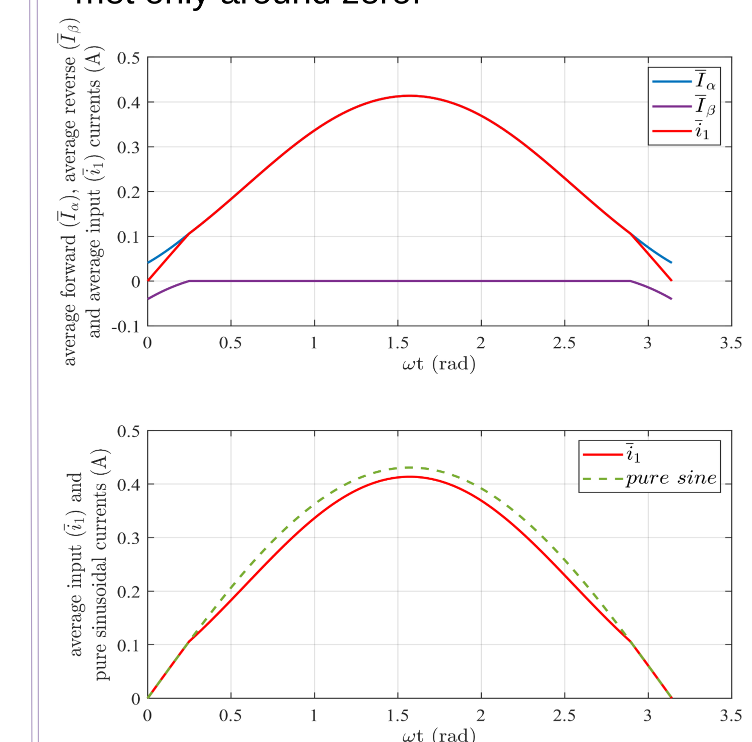
3) $2 < \frac{M}{L_2}$ (condition for preventing zero-crossing distortion)

All conditions are met and IRCM holds during the entire mains cycle:



P_{in} = 70W , M/L_2 = 4, Vc = 270V, calculated THD = 0%

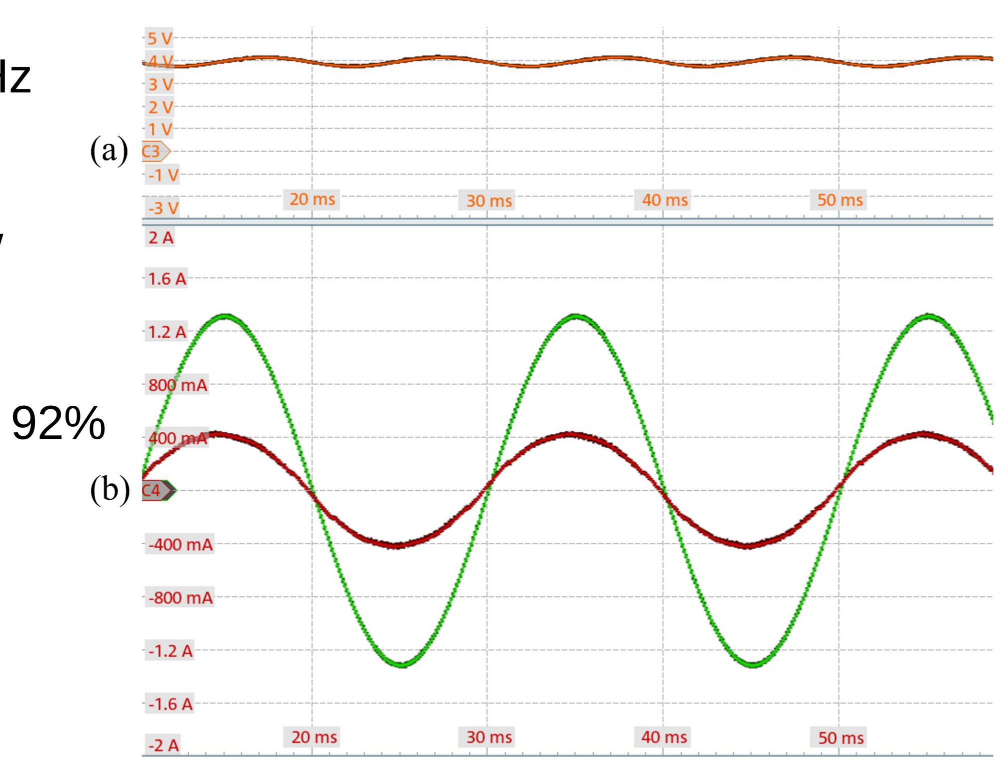
Conditions 1 and 3 are met, but condition 2 is met only around zero:



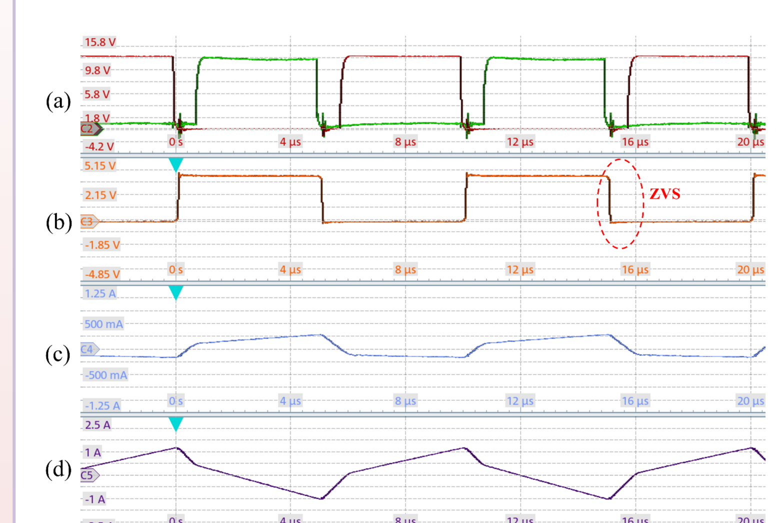
P_{in} = 70W, M/L_2 = 2.4, Vc = 170V, calculated THD = 2.6%

Experimental Results

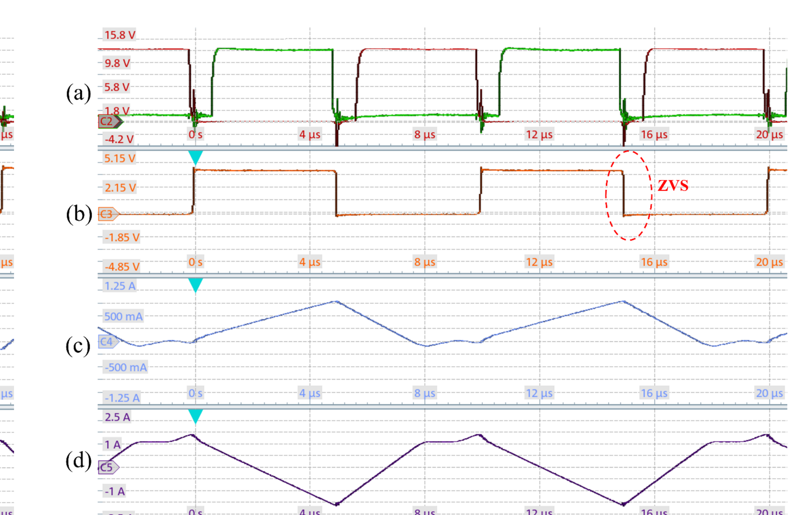
- fs = 100 kHz
- M/L_2 = 2.4
- Vc= 200V,
- Pout = 65W
- PF > 0.99
- THD < 3%
- Efficiency = 92%



a) the rectified output voltage (100/div), **b)** the mains voltage (green) and the input current (red)



Switching waveforms during IRCM: **a)** the gate to source voltage of switches S_1 (green) and S_2 (red), **b)** drain to source voltage of switch S_2 (100/div), **c)** current of L_1 (i_1), **d)** current of L_2 (i_2)



Switching waveforms during DCM: **a)** the gate to source voltage of switches S_1 (green) and S_2 (red), **b)** drain to source voltage of switch S_2, **c)** current of L_1 (i_1), **d)** current of L_2 (i_2)

Power Electronics Team | Photonics Group
V-Research GmbH, Stadtstraße 33, 6850 Dornbirn, Austria