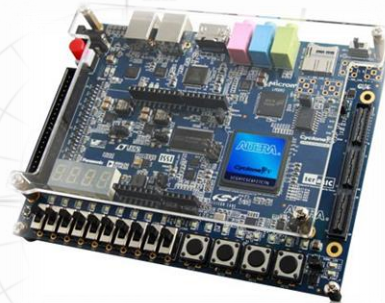


Aula 4: Retificadores a Diodos

Prof. Allan Fagner Cupertino
afcupertino@ieee.org

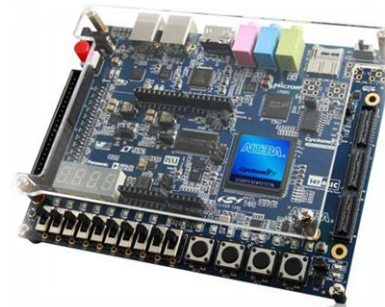


Conteúdo

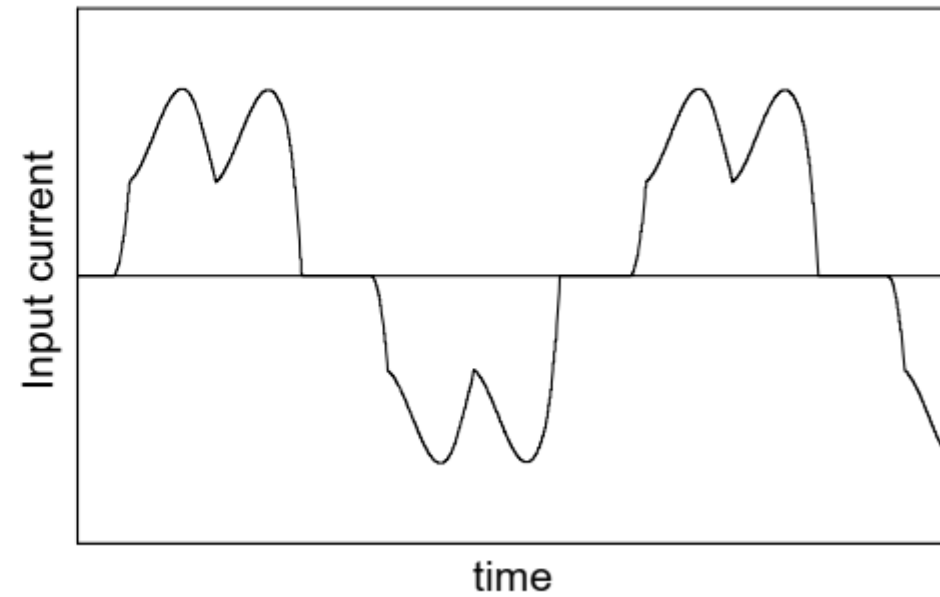
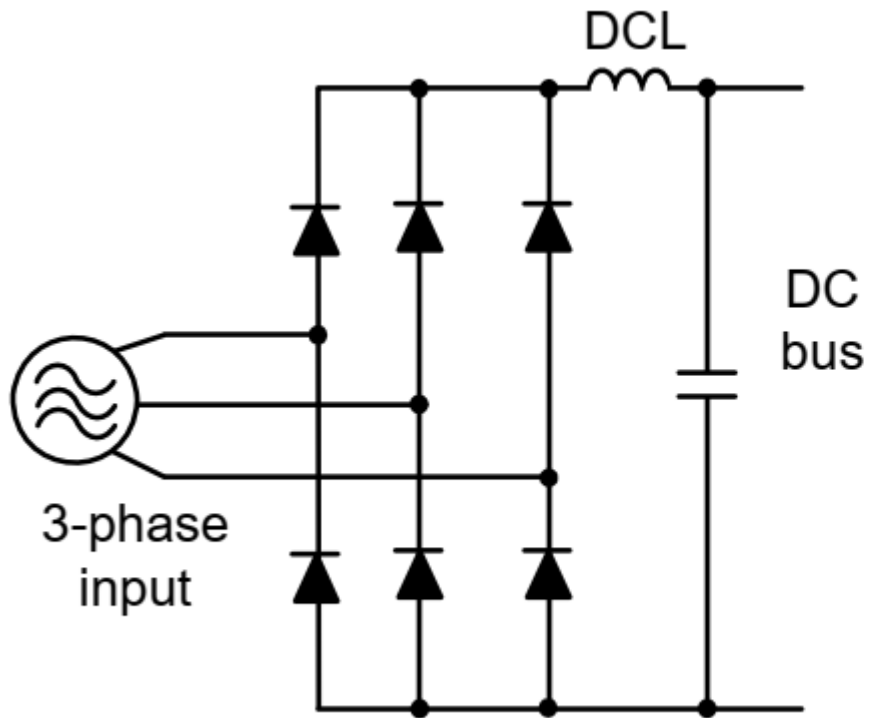
Aula	Conteúdo
Aula 1	Conceitos Básicos de Semicondutores
Aula 2	Diodos de potência
Aula 3	Associação de diodos e circuitos RLC chaveados
Aula 4	Retificadores a diodos
Aula 5	Transistores de potência - parte 1
Aula 6	Transistores de potência - parte 2
Aula 7	Conversores c.c./c.c.
Aula 8	Tiristores
Aula 9	Retificadores controlados
Aula 10	Conversores c.c./c.a.
Aula 11	Conversores c.a./c.a.
Aula 12	Conversores ressonantes



Retificadores de média tensão

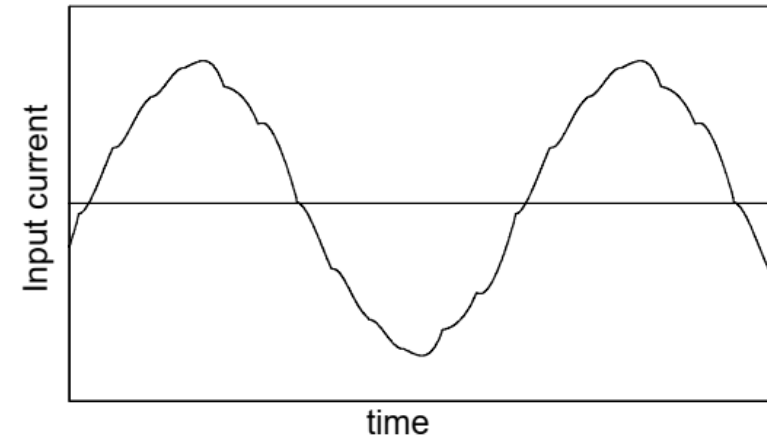
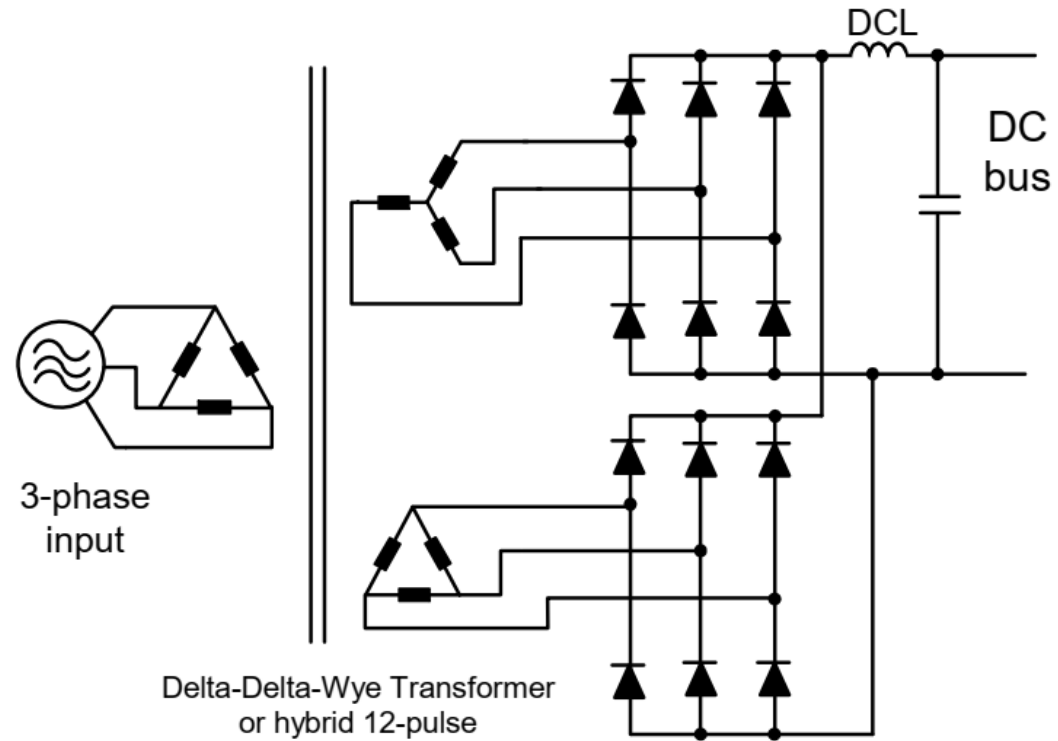


Retificador de 6 pulsos



Fonte: Yasaka. Multi-Pulse Rectifier Solutions for Input Harmonics Mitigation

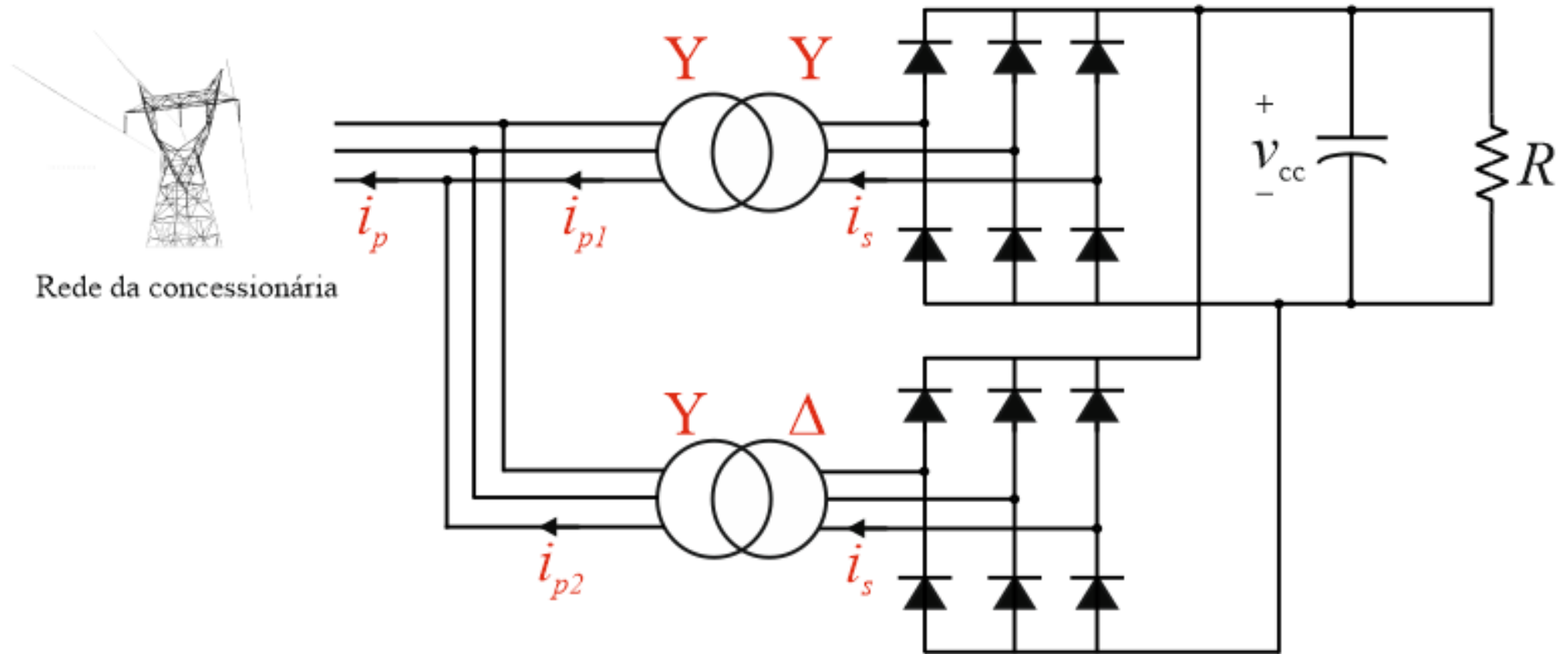
Retificador de 12 pulsos



Fonte: Yasaka. Multi-Pulse Rectifier Solutions for Input Harmonics Mitigation

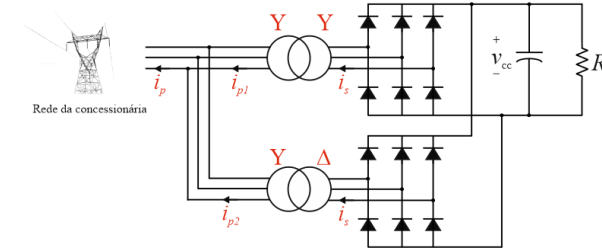
Retificador de 12 pulsos

- Exemplo didático com dois transformadores

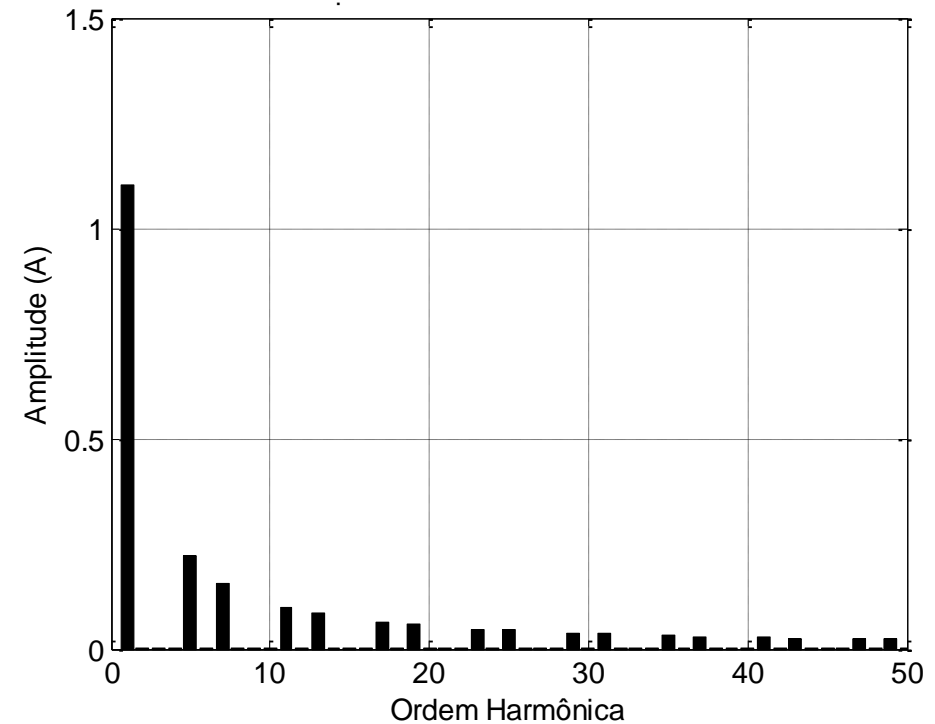
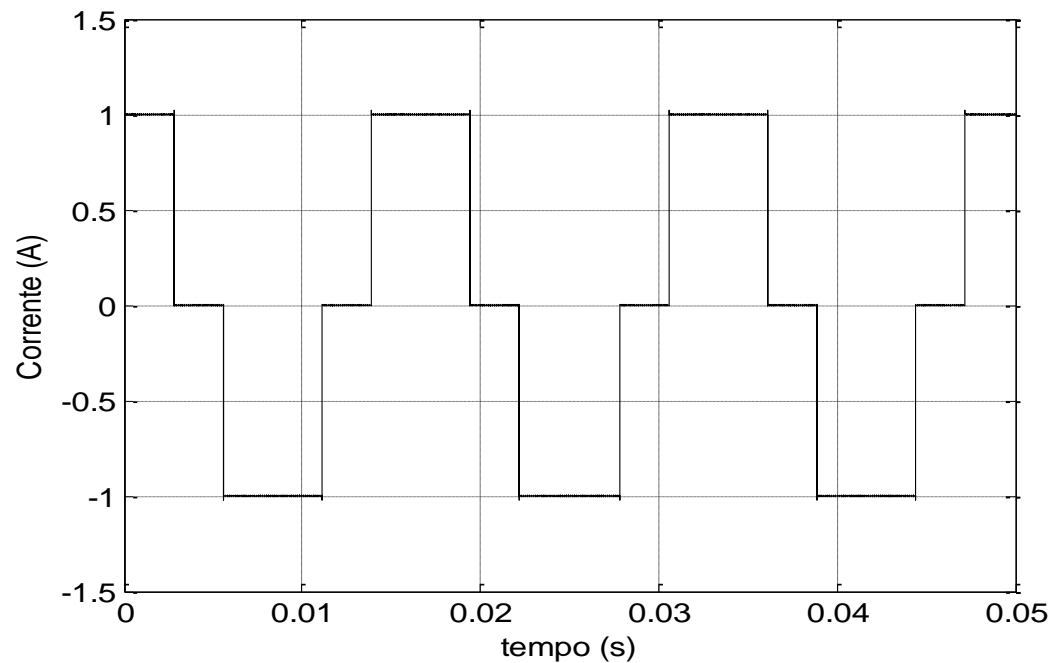


Cancelamento dos harmônicos – carga altamente indutiva

Espectro harmônico – retificador de 6 pulsos com carga indutiva



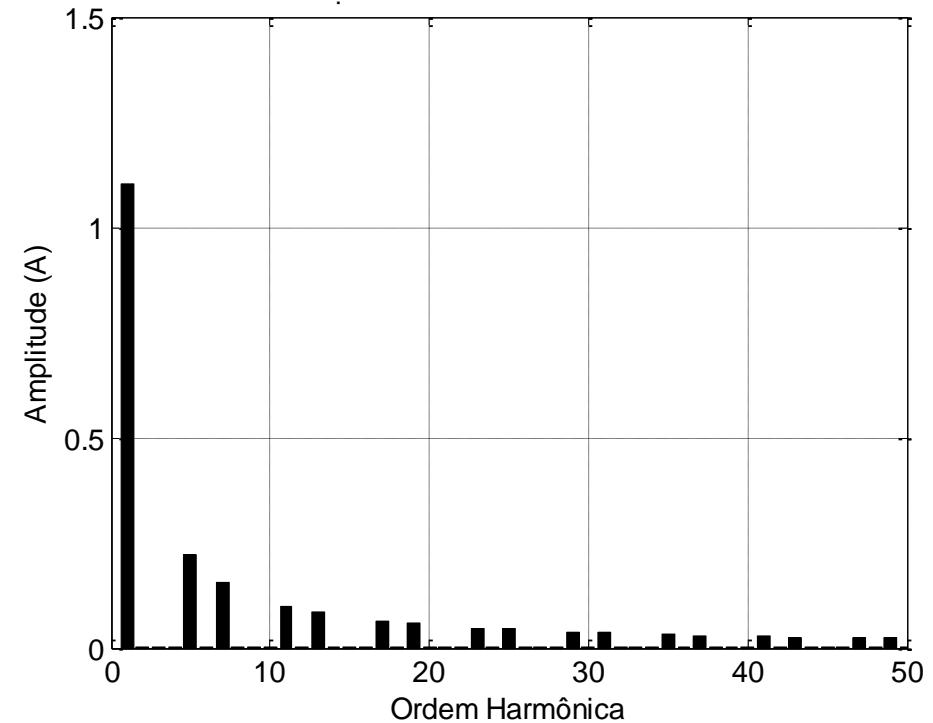
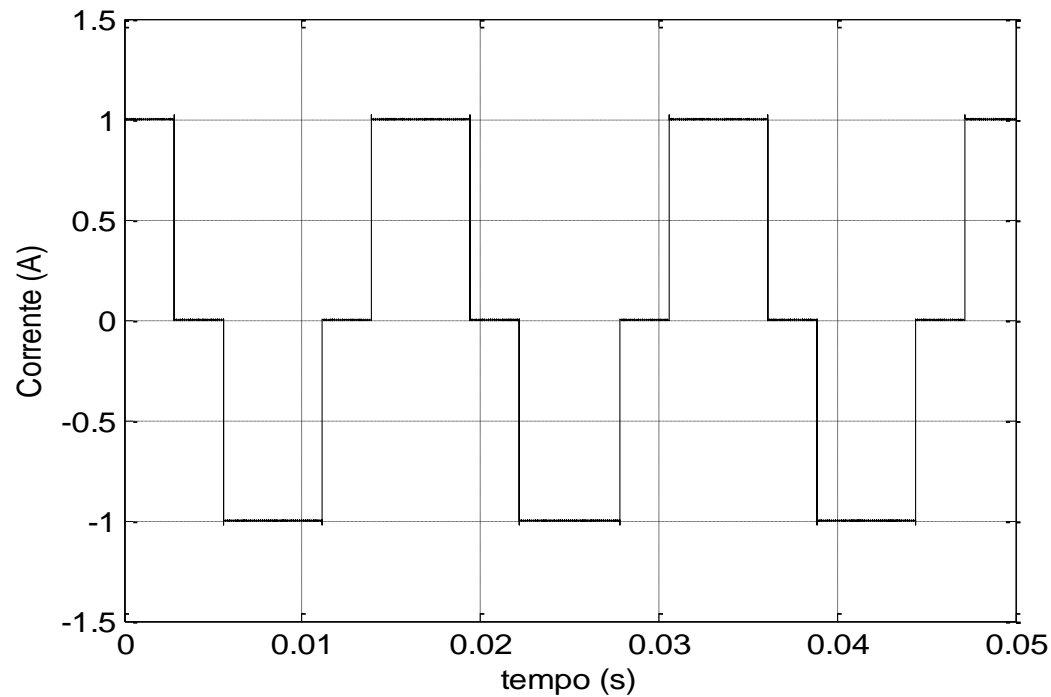
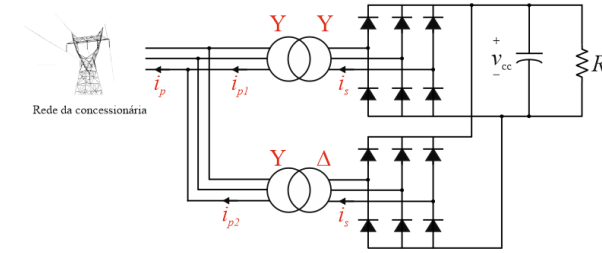
$$i_s = \frac{2\sqrt{3}}{\pi} \left(\cos \omega t - \frac{1}{5} \cos 5\omega t + \frac{1}{7} \cos 7\omega t - \frac{1}{11} \cos 11\omega t + \dots \right)$$



Cancelamento dos harmônicos – carga altamente indutiva

□ Transformador YY:

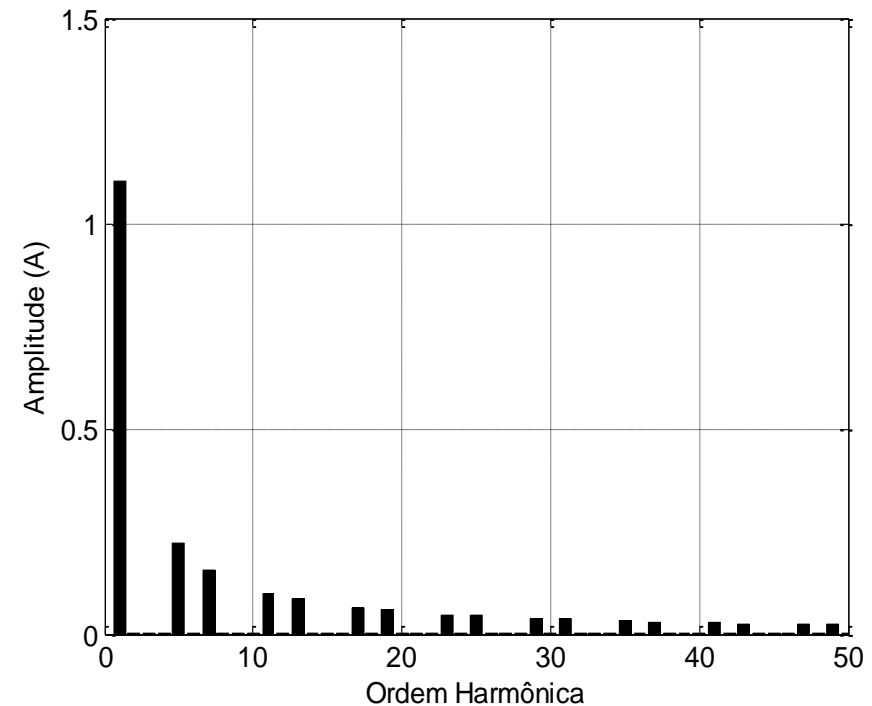
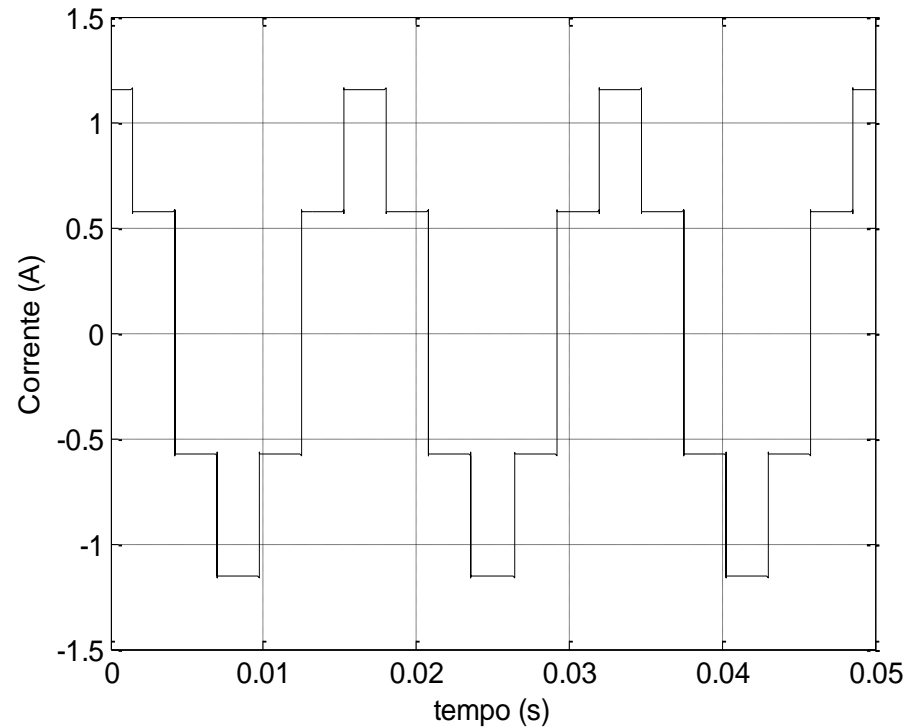
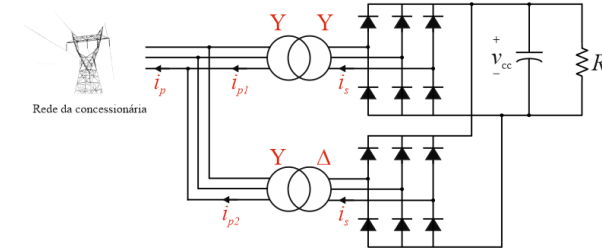
$$i_{p1} = \frac{N_{2,YY}}{N_{1,YY}} \frac{2\sqrt{3}}{\pi} \left(\cos \omega t - \frac{1}{5} \cos 5\omega t + \frac{1}{7} \cos 7\omega t - \frac{1}{11} \cos 11\omega t + \dots \right)$$



Cancelamento dos harmônicos – carga altamente indutiva

Transformador $Y\Delta$:

$$i_{p2} = \frac{1}{\sqrt{3}} \frac{N_{2,Y\Delta}}{N_{1,Y\Delta}} \frac{2\sqrt{3}}{\pi} \left(\cos \omega t + \frac{1}{5} \cos 5\omega t - \frac{1}{7} \cos 7\omega t - \frac{1}{11} \cos 11\omega t + \dots \right)$$



Cancelamento dos harmônicos – carga altamente indutiva

- Relação de espiras para cancelamento de harmônicos

$$\frac{1}{\sqrt{3}} \frac{N_{2,Y\Delta}}{N_{1,Y\Delta}} = \frac{N_{2,YY}}{N_{1,YY}}$$

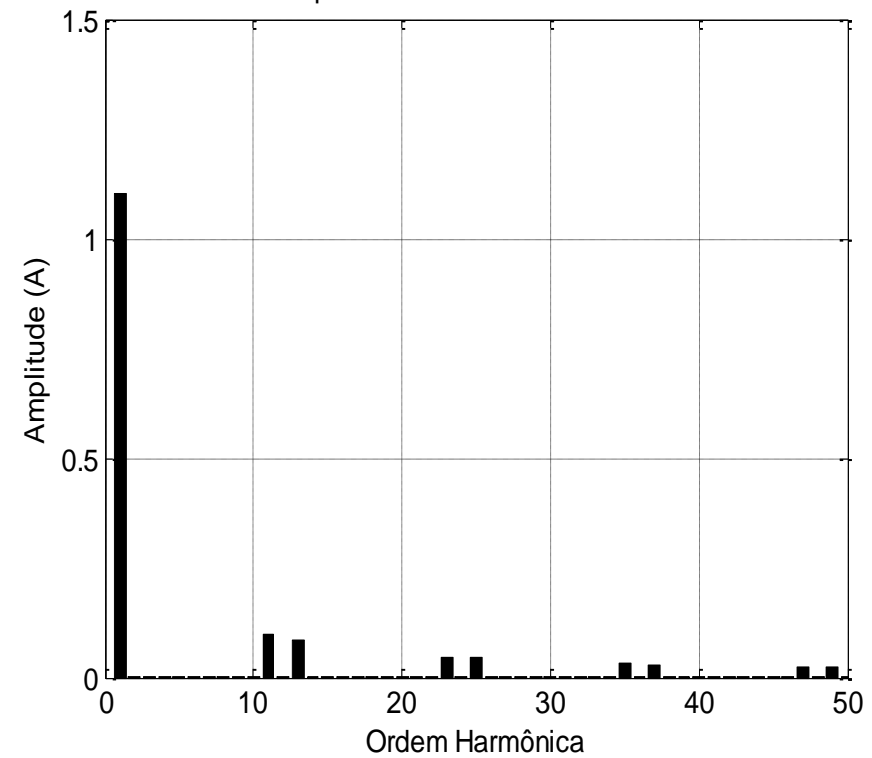
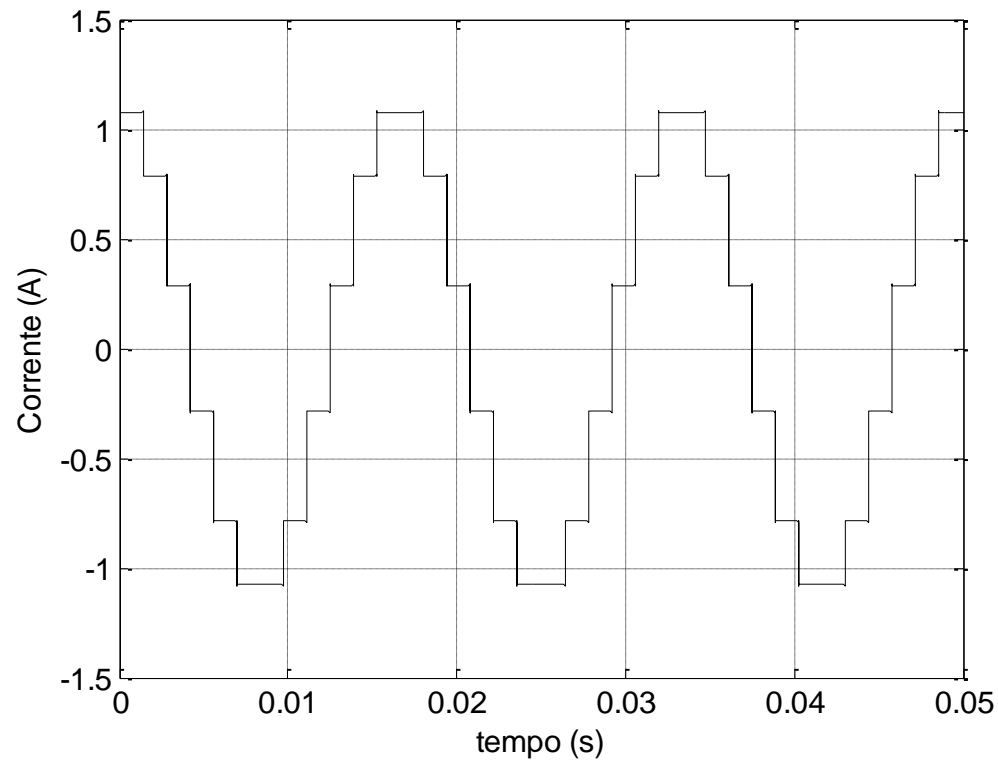
que é equivalente a:

$$a_{Y\Delta} = \frac{a_{YY}}{\sqrt{3}}$$

onde a é a relação de transformação de cada enrolamento.

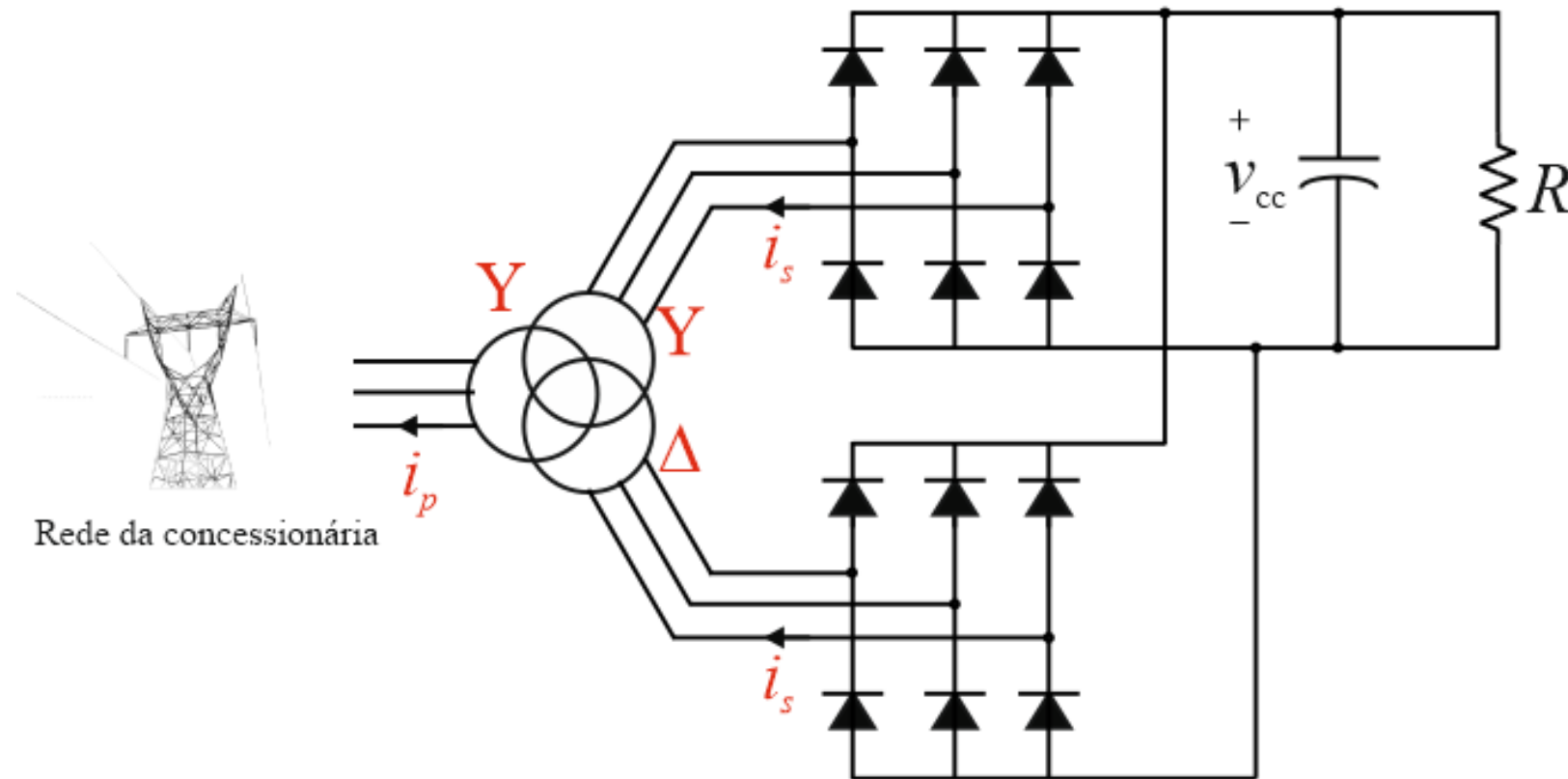
Cancelamento dos harmônicos – carga altamente indutiva

$$i_p = i_{p1} + i_{p2} = \frac{2\sqrt{3}}{\pi} \left(\cos \omega t - \frac{1}{11} \cos 11\omega t + \frac{1}{13} \cos 13\omega t - \frac{1}{23} \cos 23\omega t \dots \right)$$

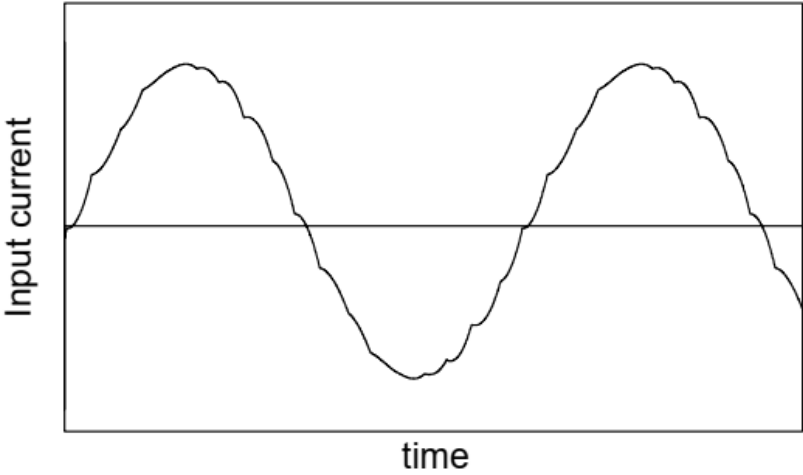
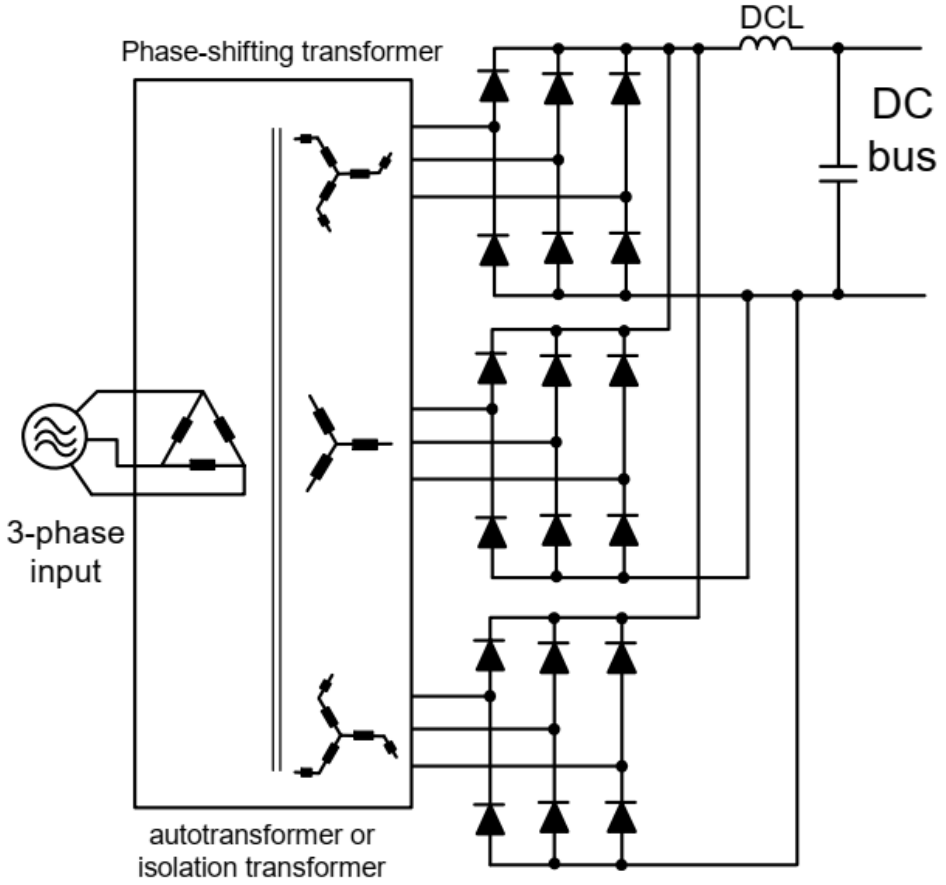


Implementação prática – retificador de 12 pulsos

- ❑ Um único transformador com dois secundários;
- ❑ Cancelamento por fluxo magnético!

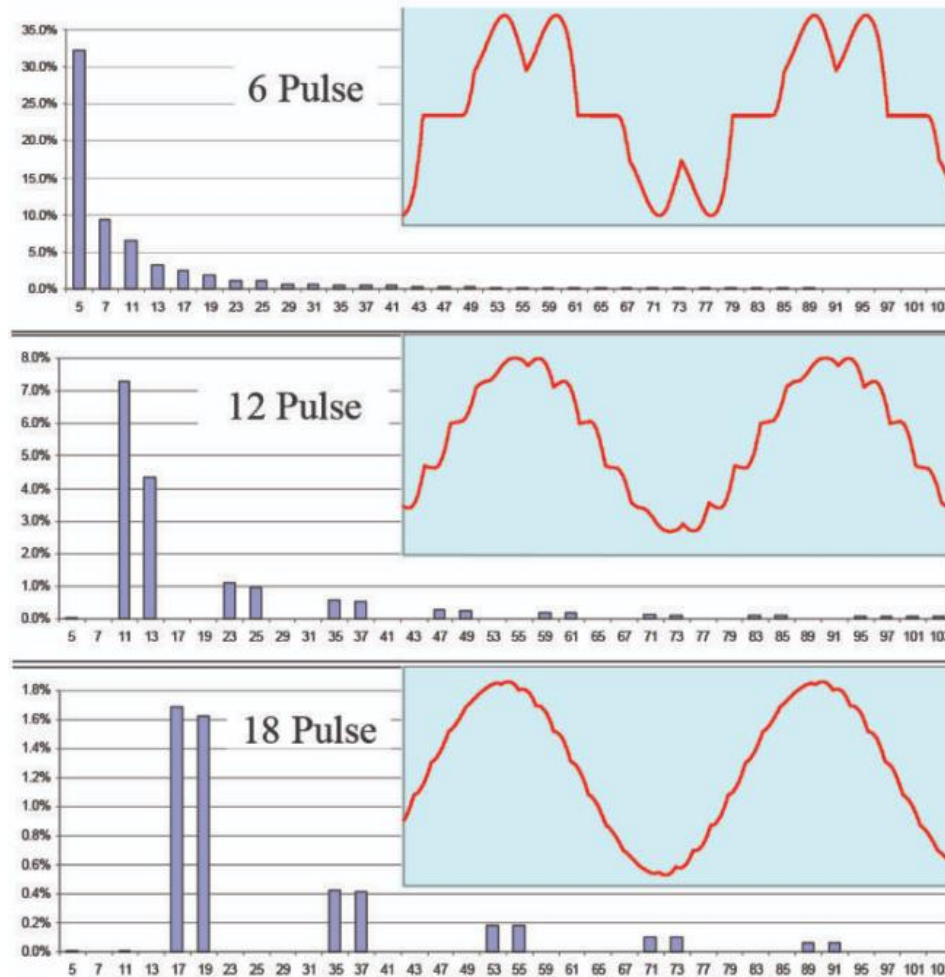


Retificador de 18 pulsos



<https://www.ee.co.za/article/medium-voltage-industrial-variable-speed-drives.html>

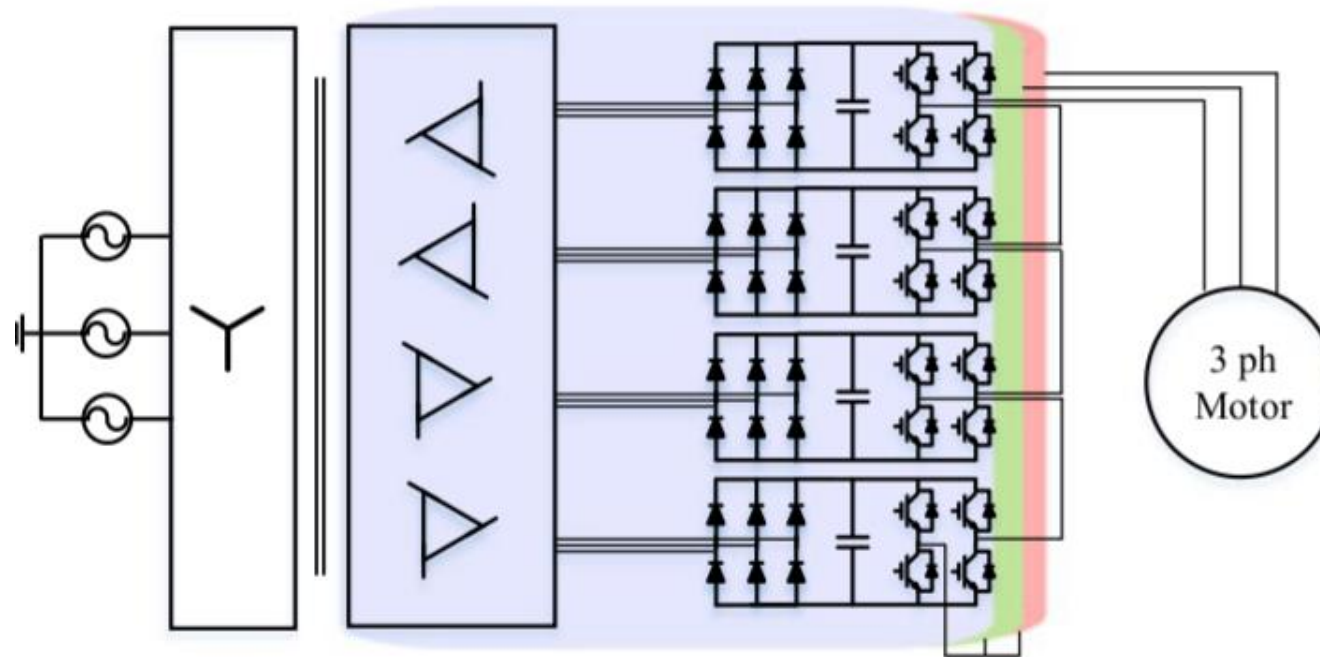
Efeito do aumento do número de pulsos



<https://www.ee.co.za/article/medium-voltage-industrial-variable-speed-drives.html>

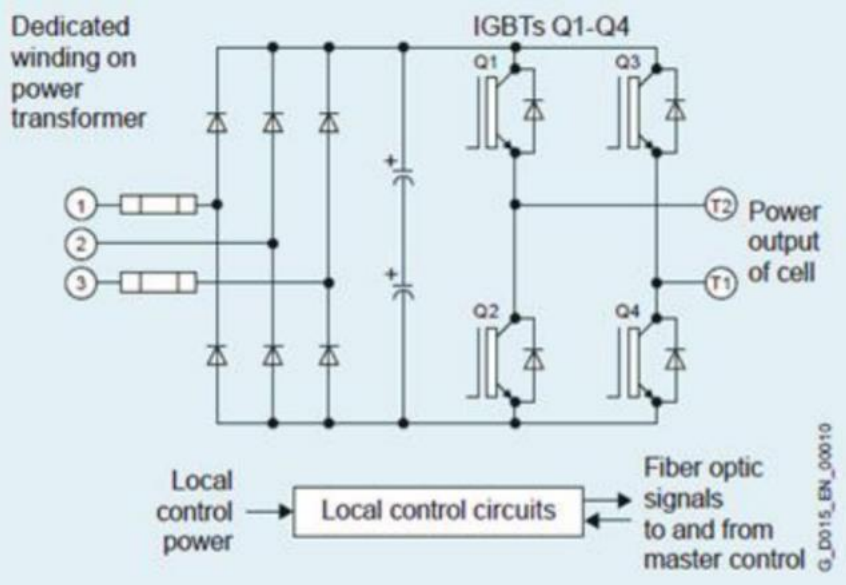
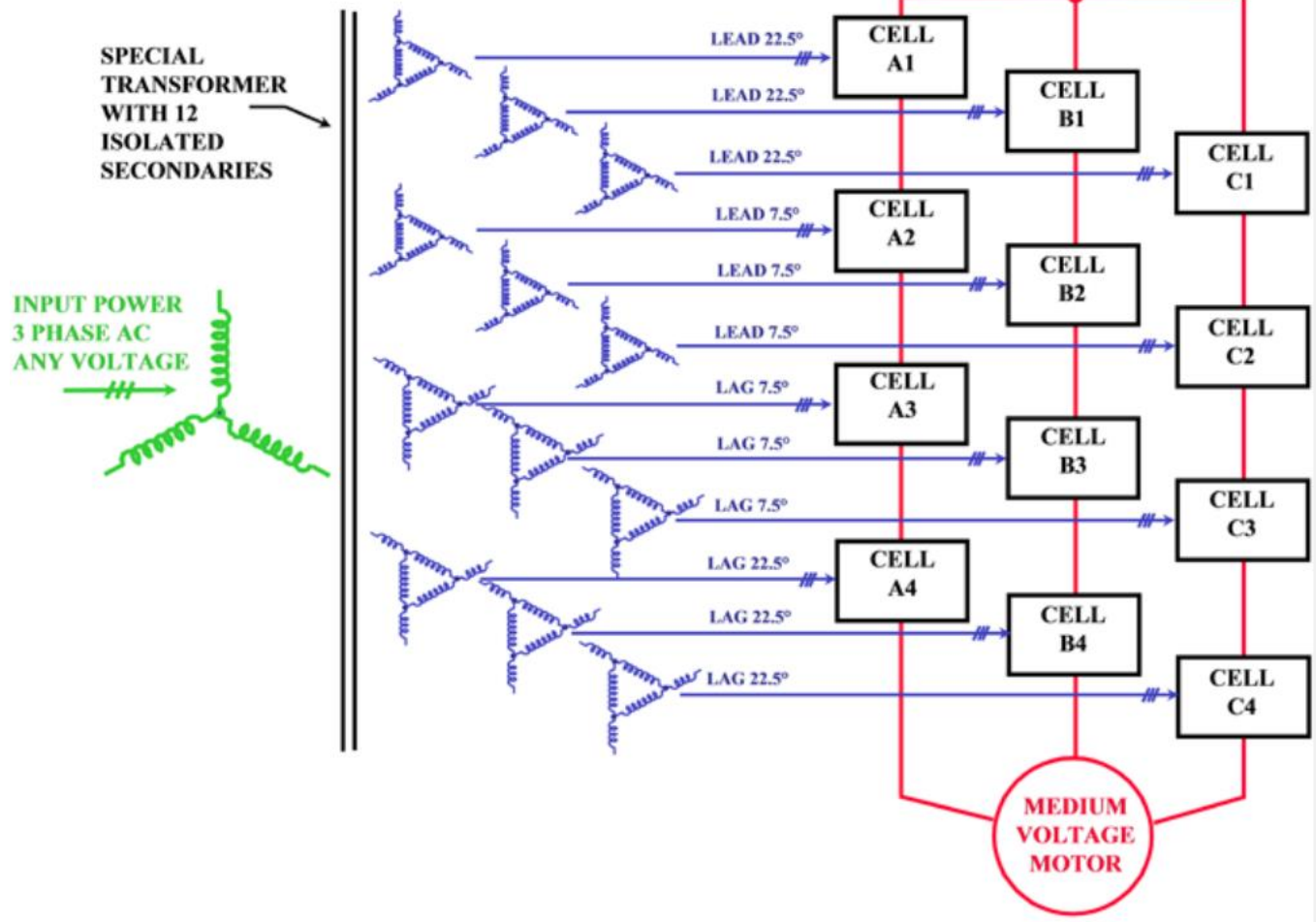
Exemplo de aplicação

- ❑ Cascaded H-Bridge Converter (CHB) com transformador zig-zag
 - Siemens Robicon perfect harmony
 - Delta Electronics MVD 2000 series



A. Marzoughi, R. Burgos, D. Boroyevich and Y. Xue, "Design and Comparison of Cascaded H-Bridge, Modular Multilevel Converter, and 5-L Active Neutral Point Clamped Topologies for Motor Drive Applications," in *IEEE Transactions on Industry Applications*, vol. 54, no. 2, pp. 1404-1413, March-April 2018.

Exemplo de aplicação



<https://www.controldesign.com/articles/2016/peter-hammond-recalls-the-birth-of-the-medium-voltage-drive/>

<https://www.lda-portal.siemens.com/>

Robicon Perfect Harmony



<https://www.controldesign.com/articles/2016/peter-hammond-recalls-the-birth-of-the-medium-voltage-drive/>

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