



AGH



Euro - Centrum

Studia Podyplomowe

EFEKTYWNE UŻYTKOWANIE ENERGII ELEKTRYCZNEJ

w ramach projektu

**Śląsko-Małopolskie Centrum Kompetencji
Zarządzania Energią**

JAKOŚĆ ENERGII ELEKTRYCZNEJ - PROCES ŁĄCZENIA BATERII KONDENSATORÓW

dr hab. inż. Zbigniew Hanzelka, prof. AGH



AKADEMIA GÓRNICZO-HUTNICZA
IM. STANISŁAWA STASZICA W KRAKOWIE

JAKOŚĆ ENERGII ELEKTRYCZNEJ - PROCES ŁĄCZENIA BATERII KONDENSATORÓW

Zbigniew HANZELKA

**Wydział Elektrotechniki, Automatyki, Informatyki i
Inżynierii Biomedycznej**

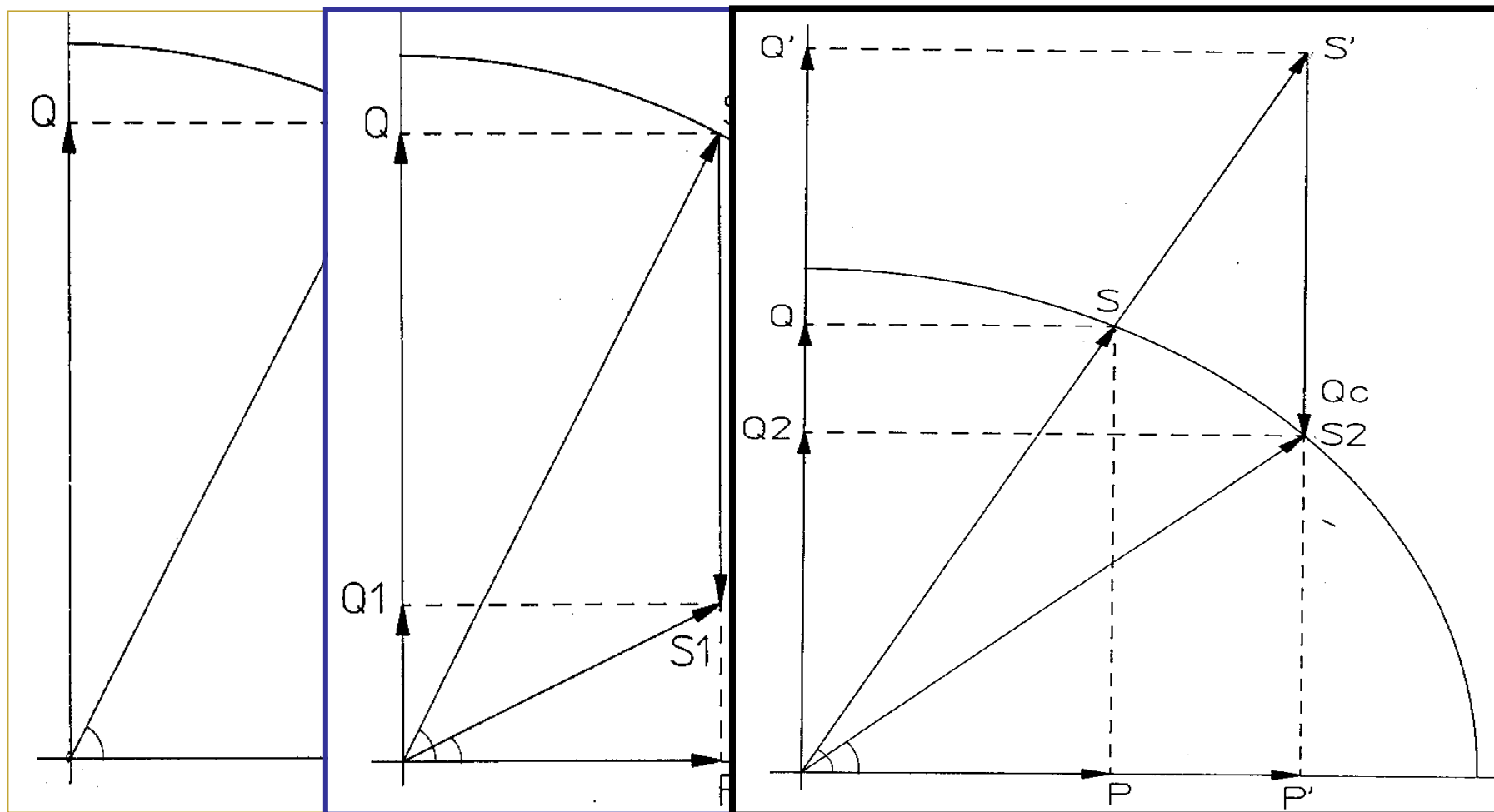
Katedra Automatyki Napędu i Urządzeń Przemysłowych

KGHM 2013



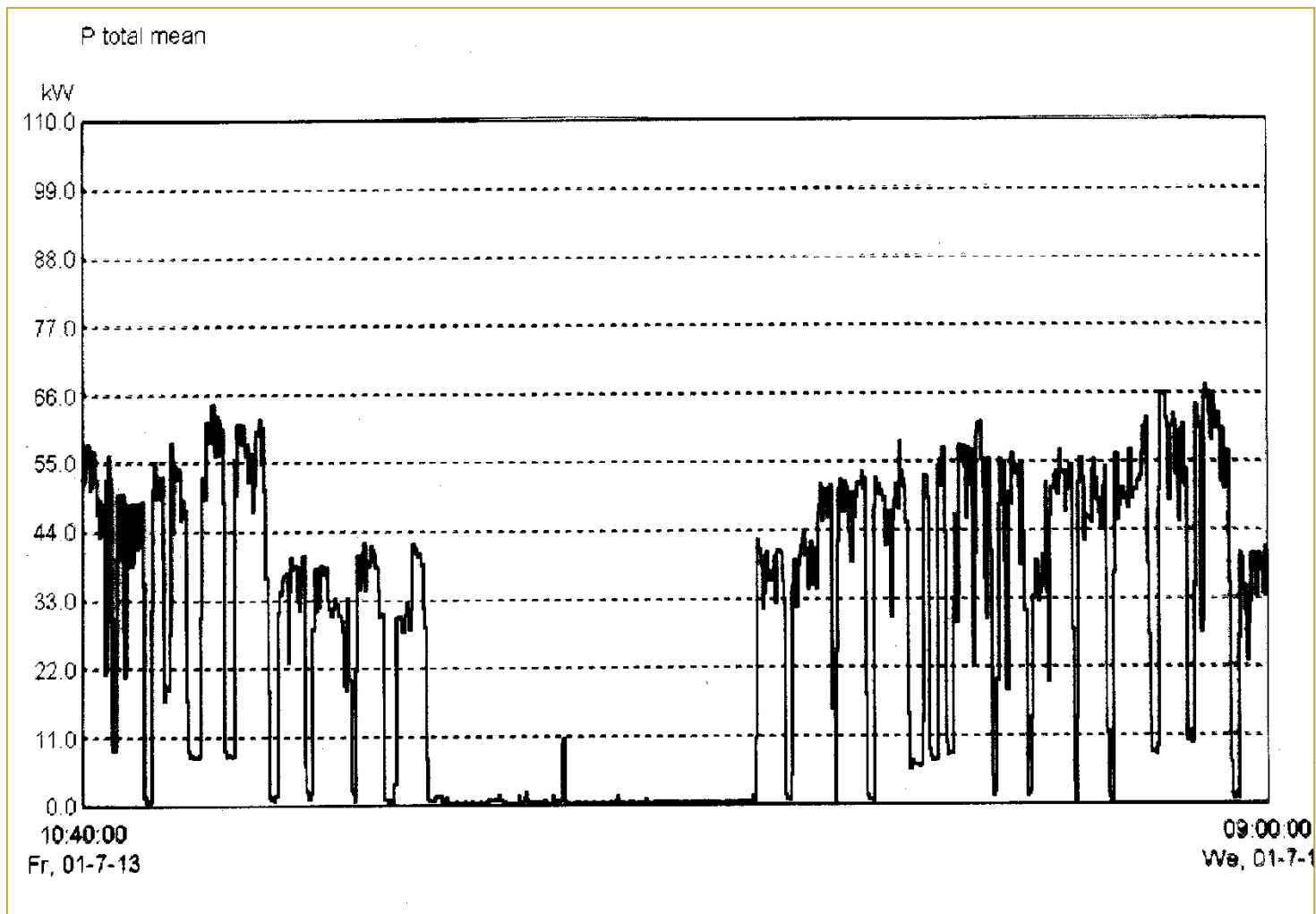
Kondensatory służą do realizacji trzech podstawowych celów:

- kompensacja mocy biernej



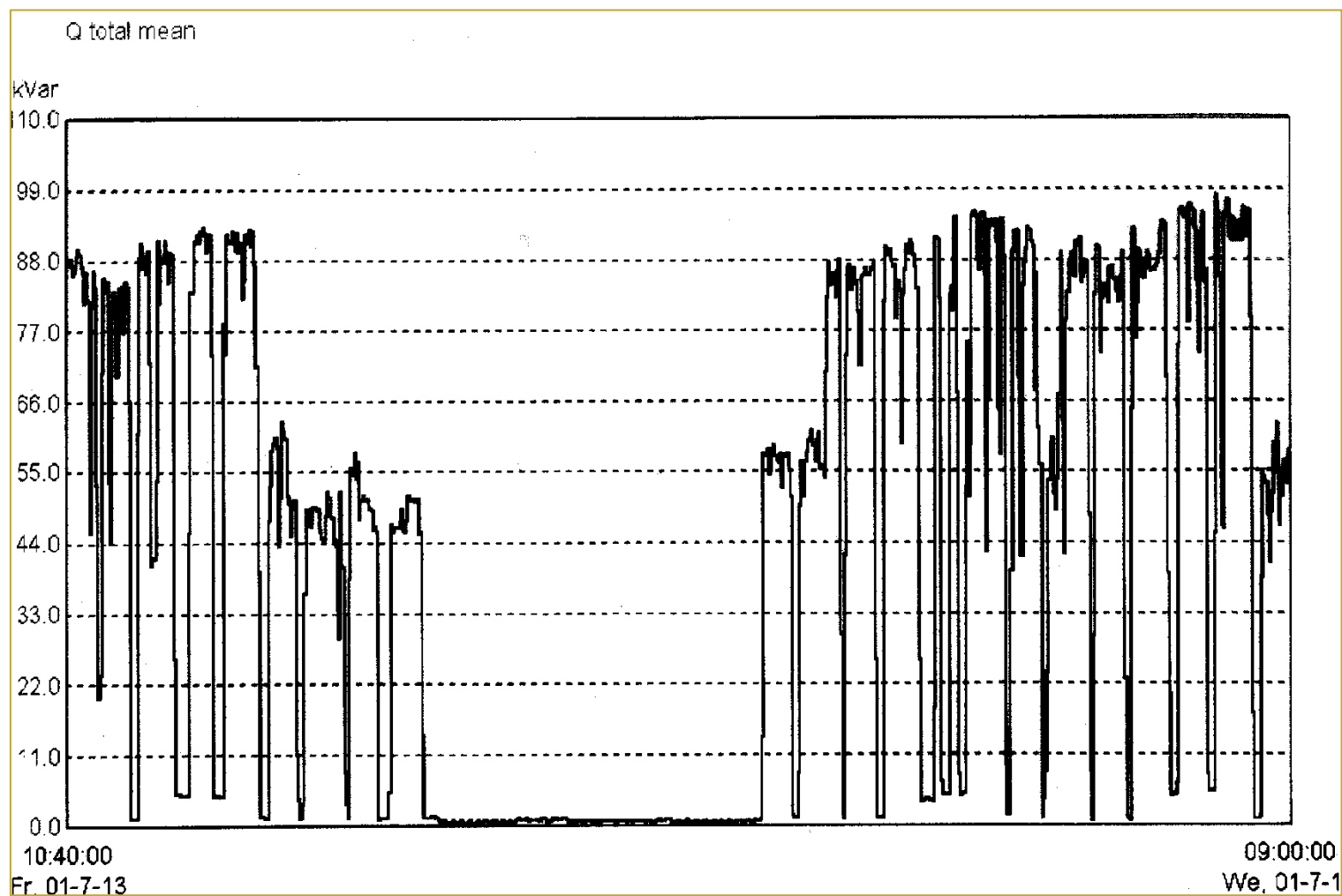


Moc czynna



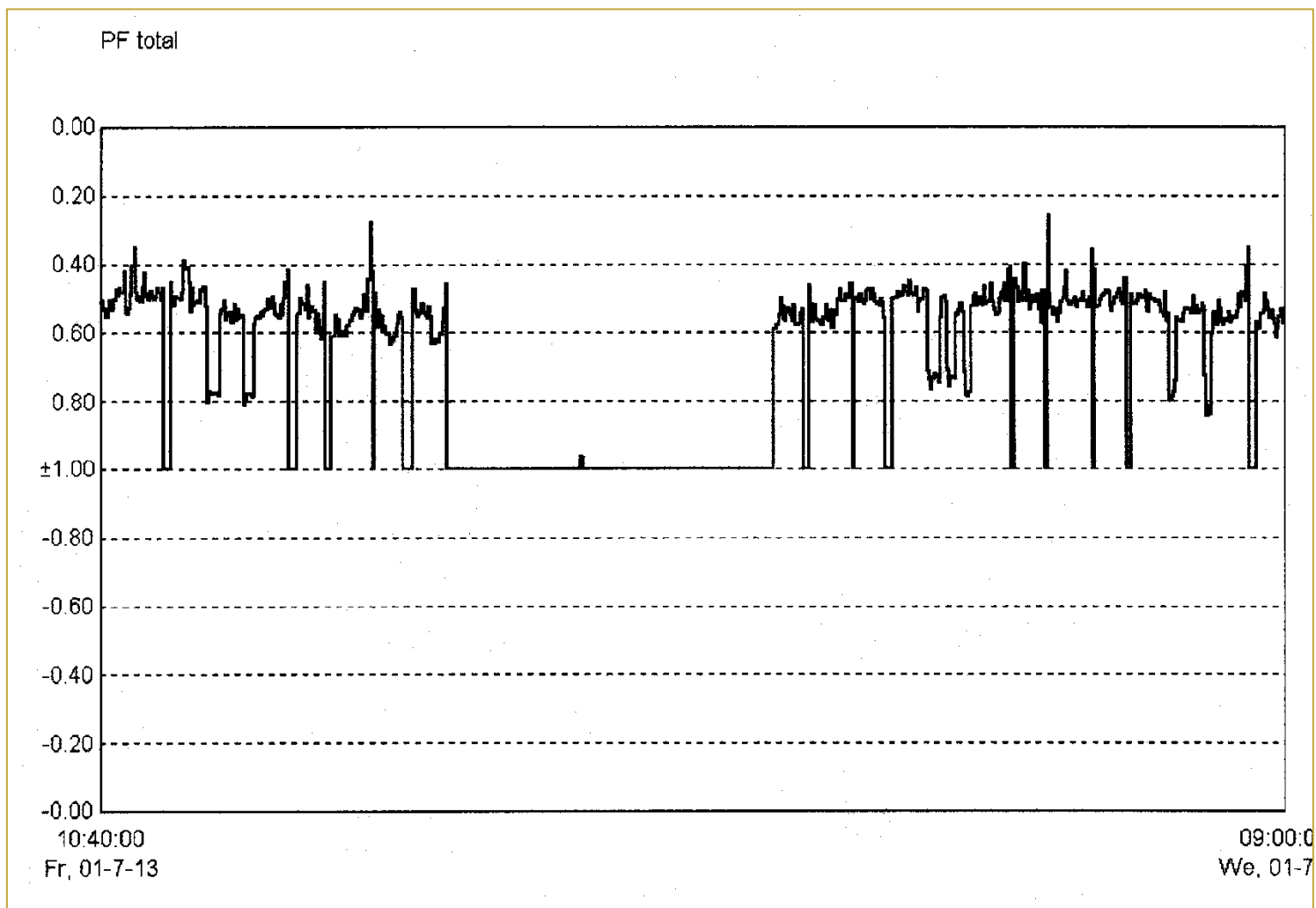


Moc bierna



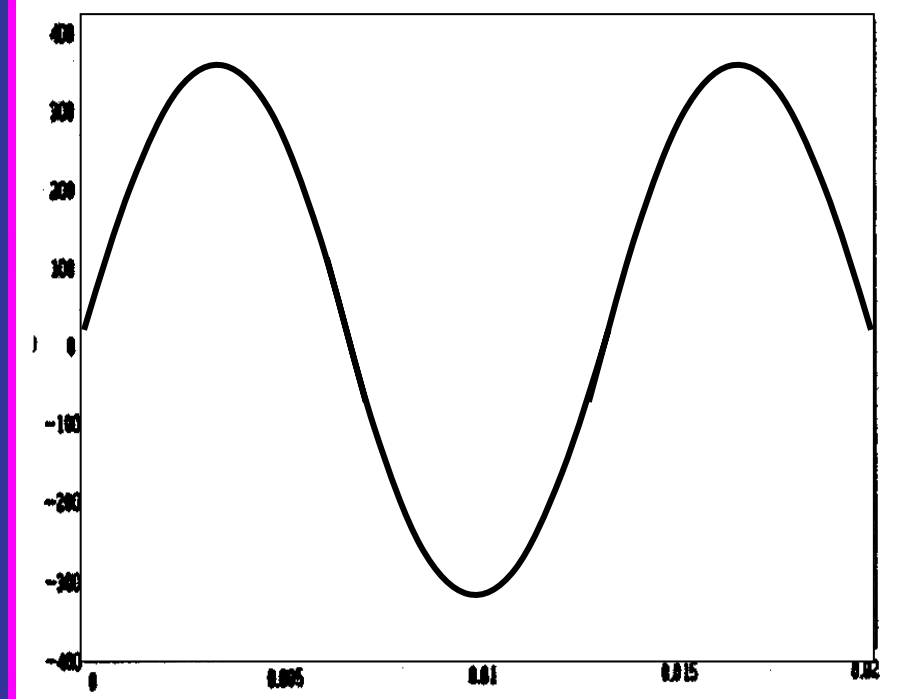
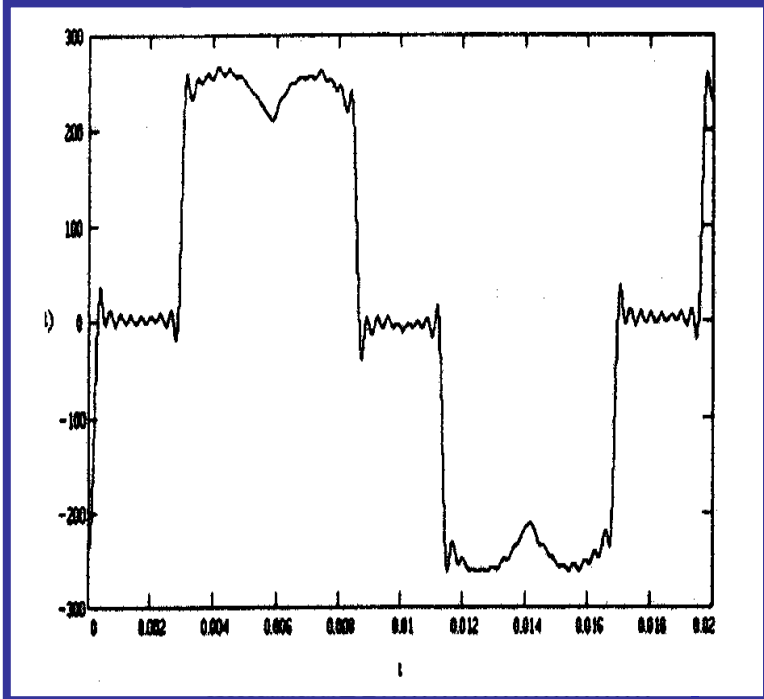


Współczynnik mocy

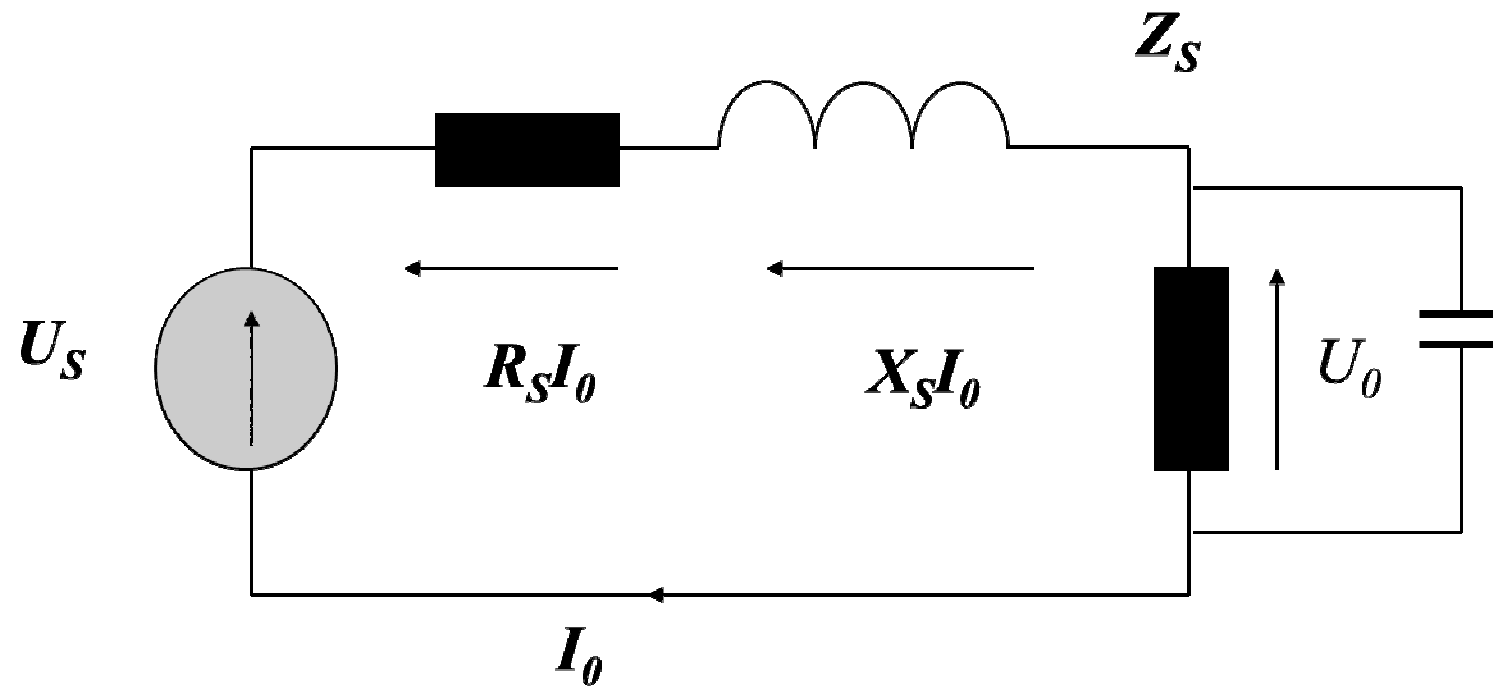




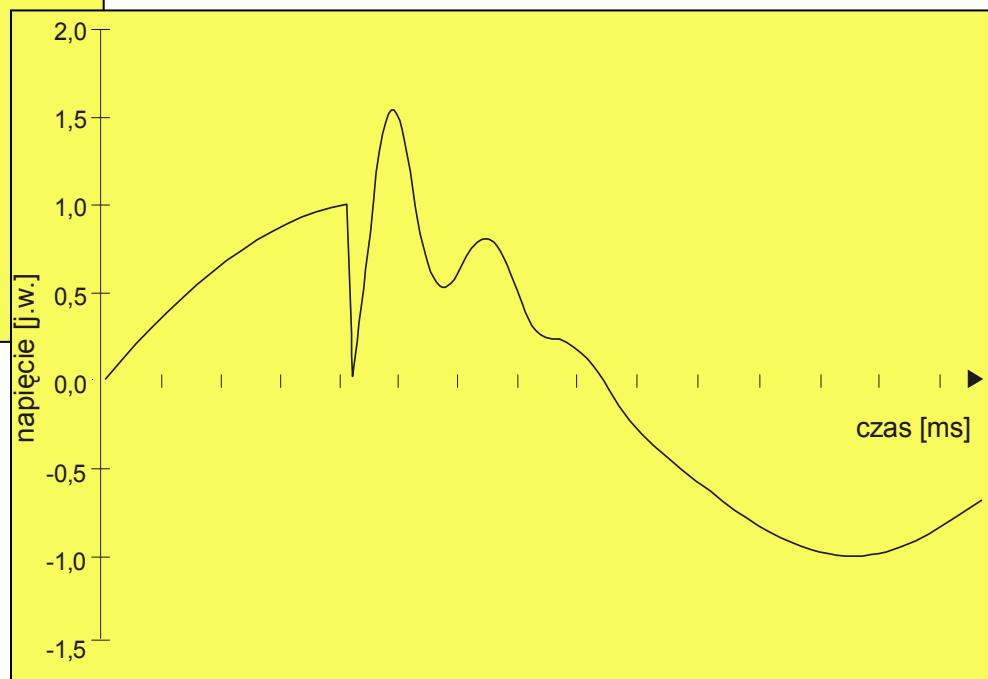
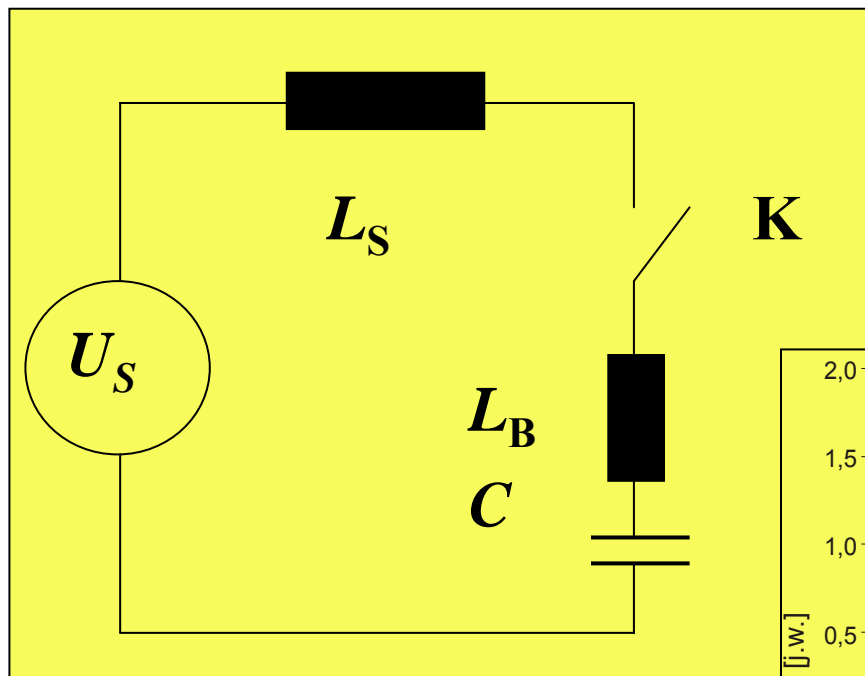
Pasywna filtracja wyższych harmonicznych



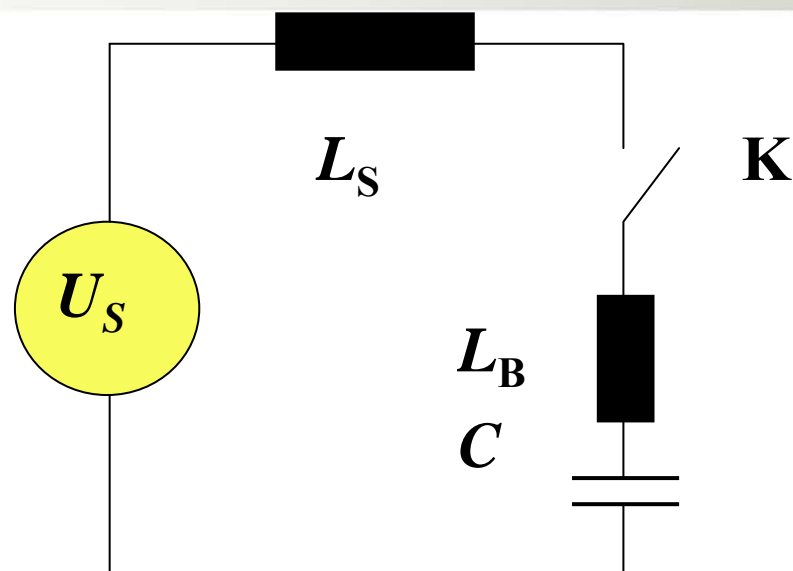
Regulacja napięcia



Łączenie pojedynczej baterii kondensatorów



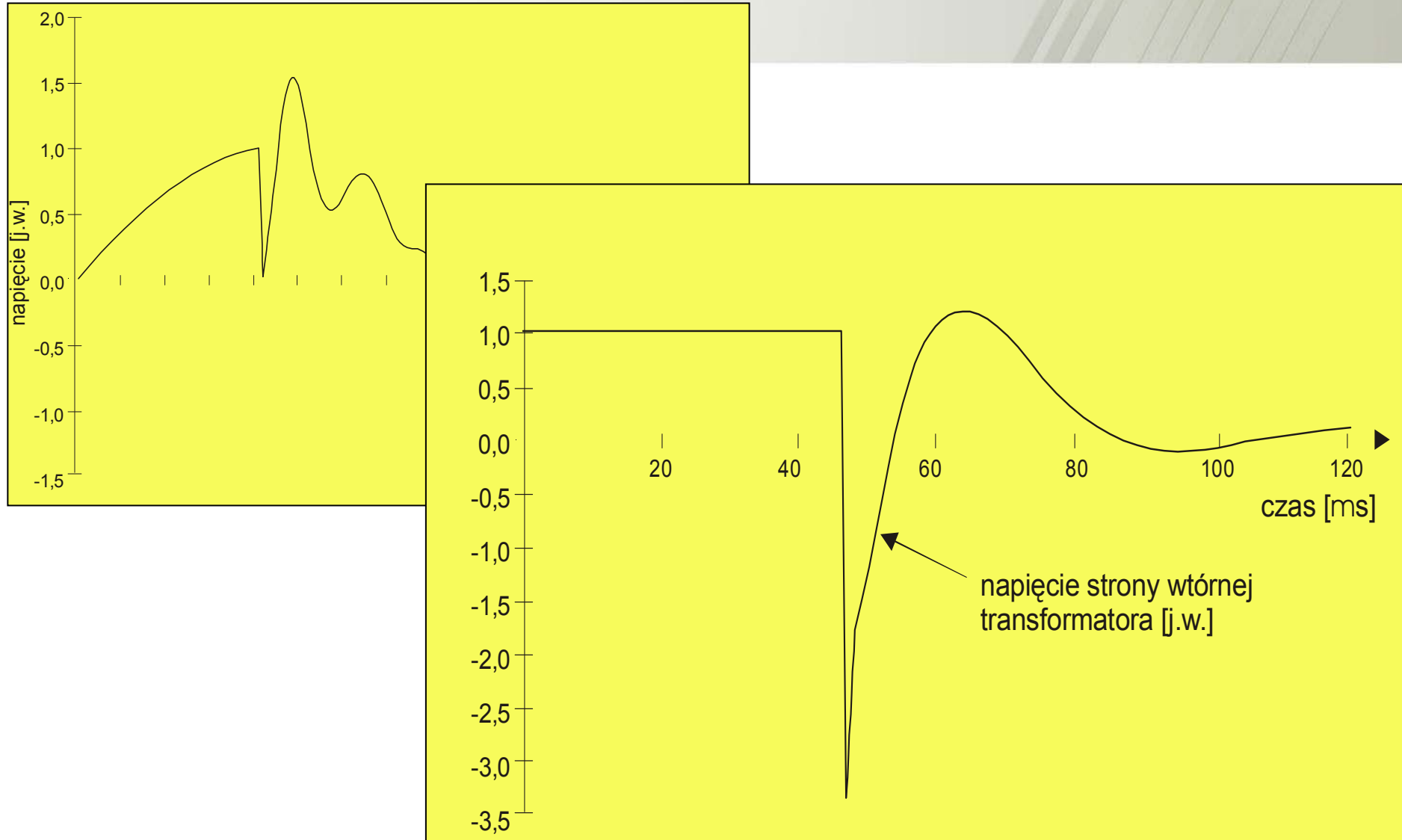
Łączenie pojedynczej baterii kondensatorów



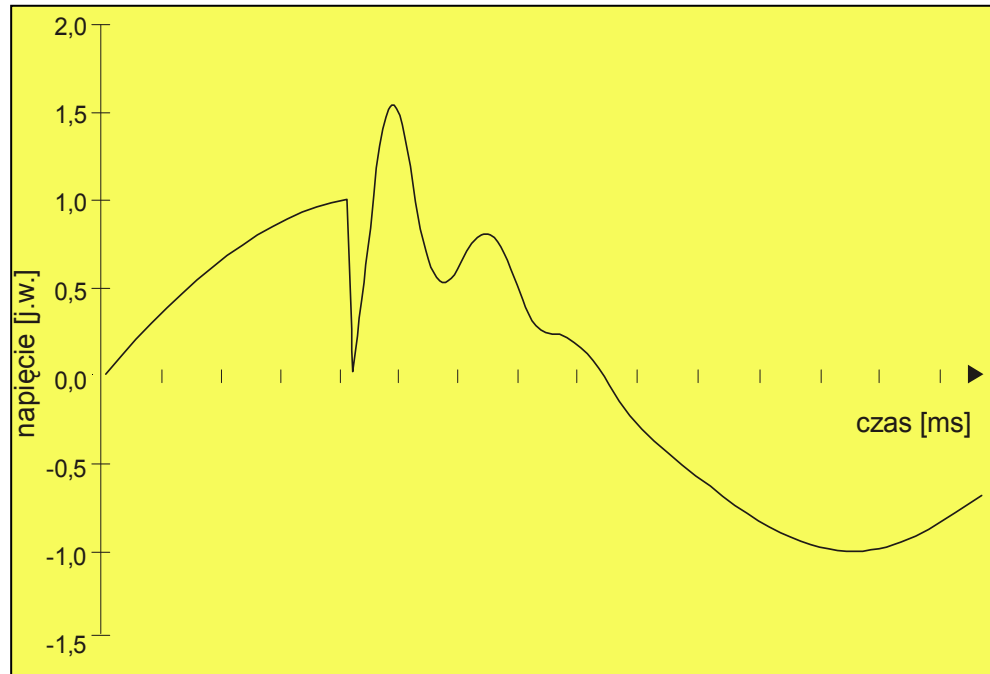
$$I_{\max.} = \frac{\sqrt{2}U_S}{Z_C} = \sqrt{2}U_S \sqrt{\frac{C_B(\mu F)}{(L_S + L_B)(\mu H)}} = \sqrt{2} \sqrt{I_{ZW} \cdot I_{CN}}$$



Łączenie pojedynczej baterii kondensatorów



Łączenie pojedynczej baterii kondensatorów

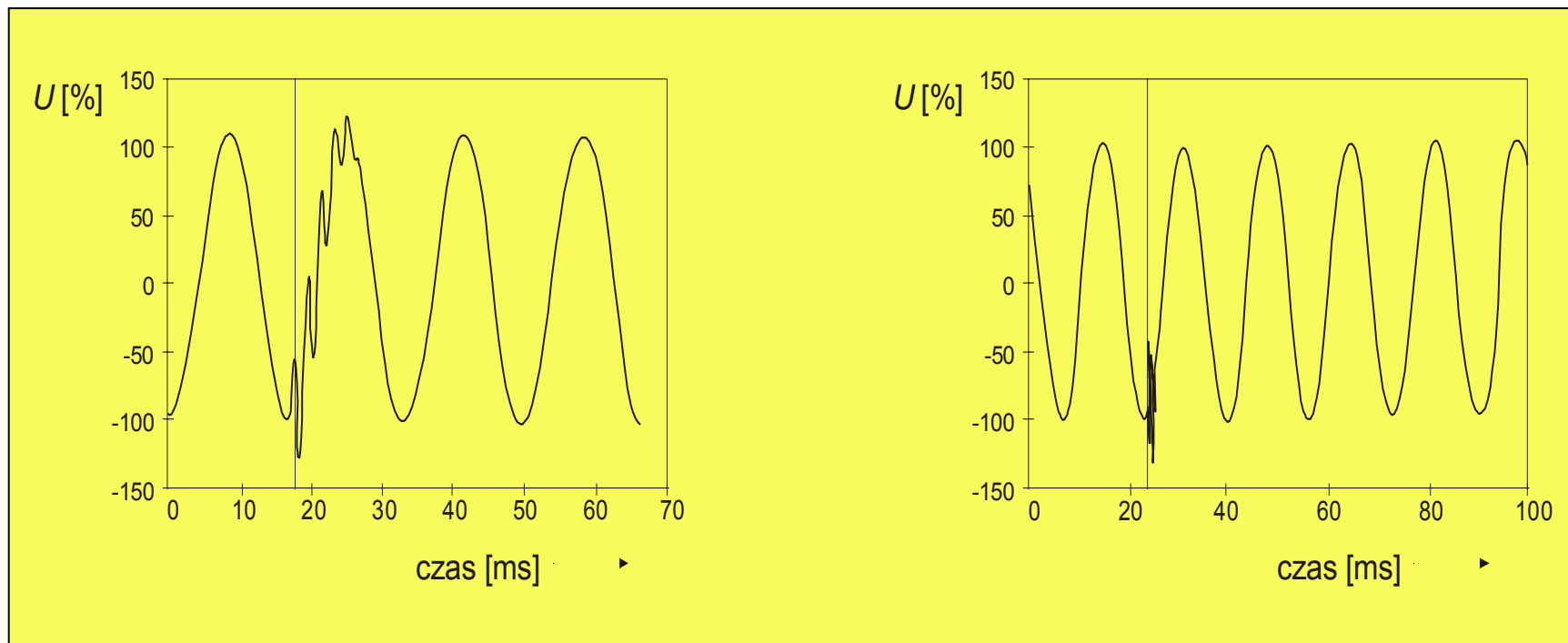


$$f = f_S \sqrt{\frac{I_{ZW.}}{I_{CN}}}$$

$$f = \frac{1}{2\pi \sqrt{(L_S + L_B)C}}$$

300 - 600 Hz (900 Hz)

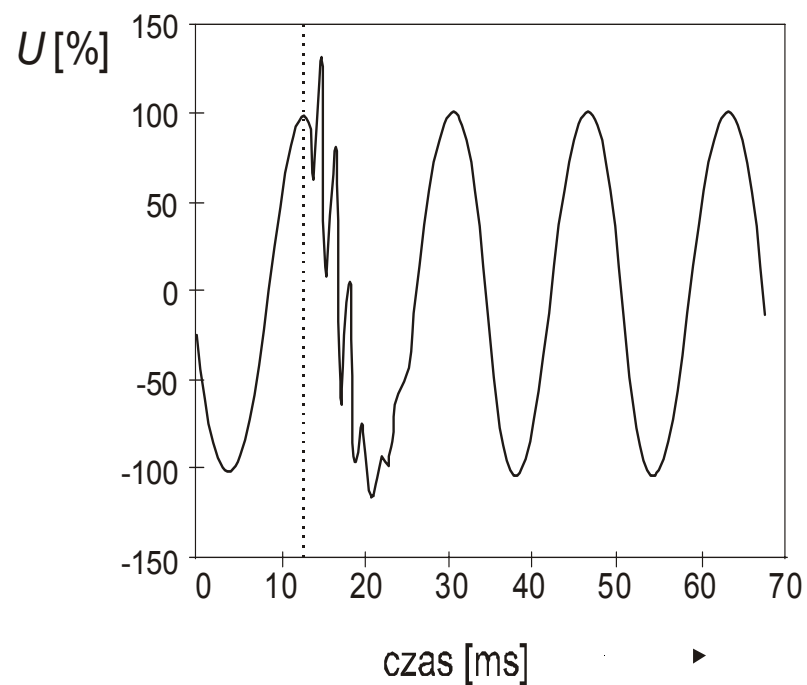
Łączenie pojedynczej baterii kondensatorów



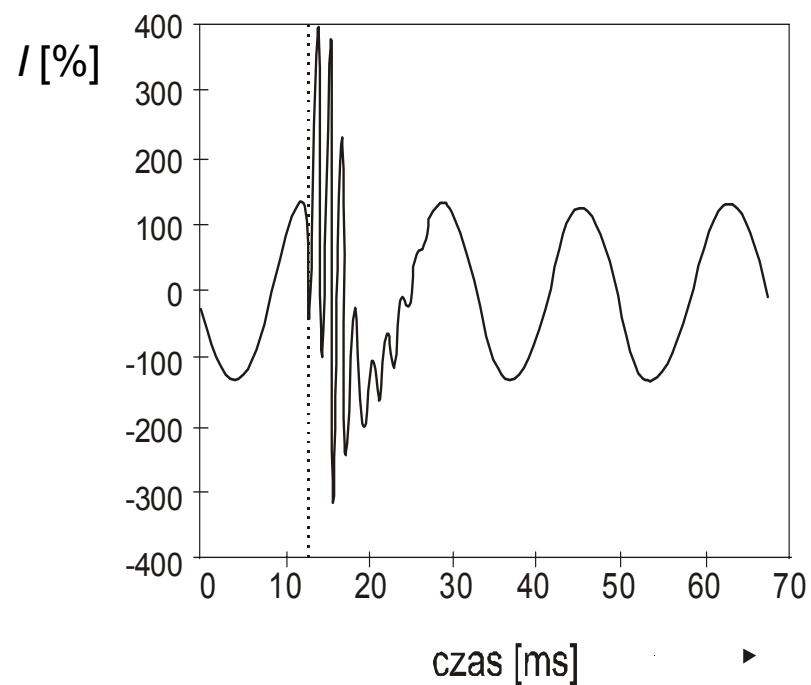
$U_{max} = 110 - 160 \% (200 \%)$

Czas trwania: 0,5 – 3 okresów

Łączenie pojedynczej baterii kondensatorów

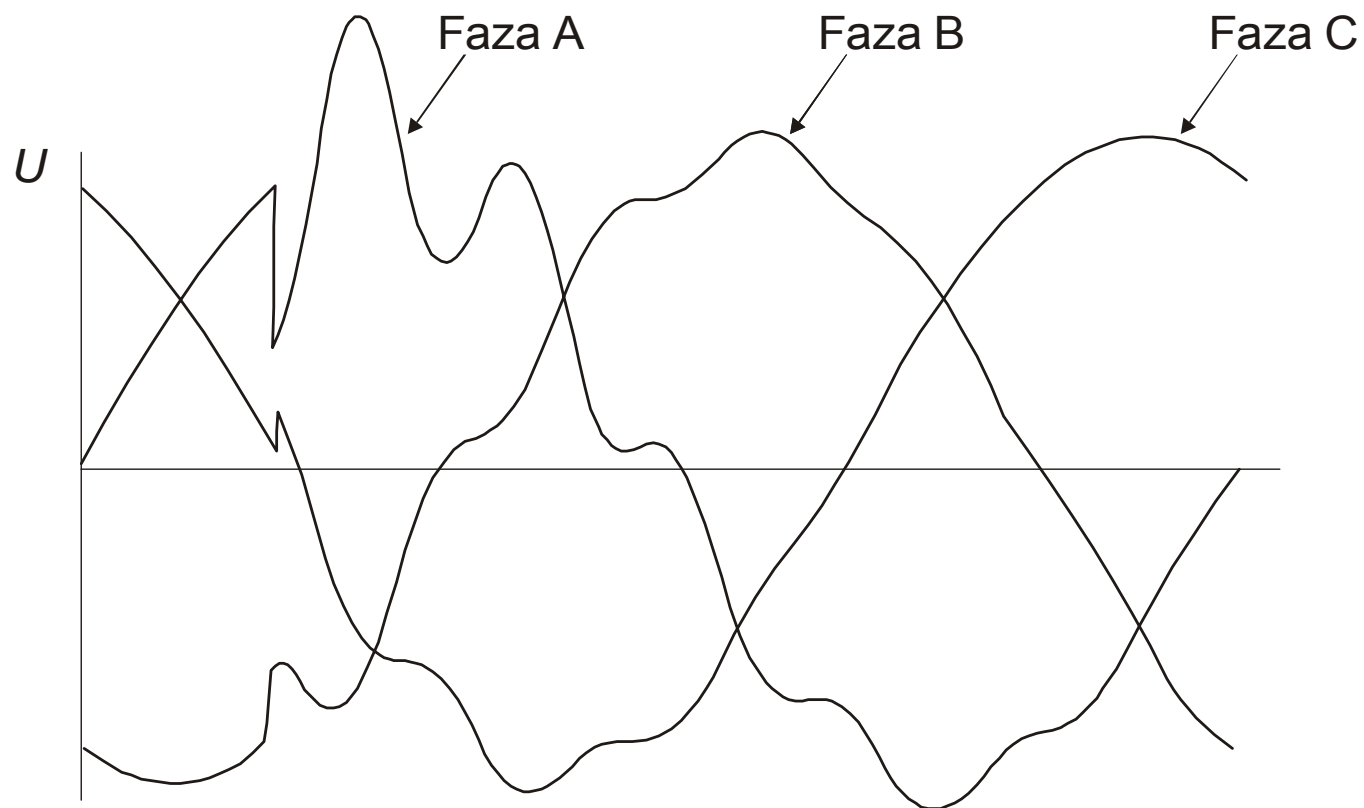


(a)



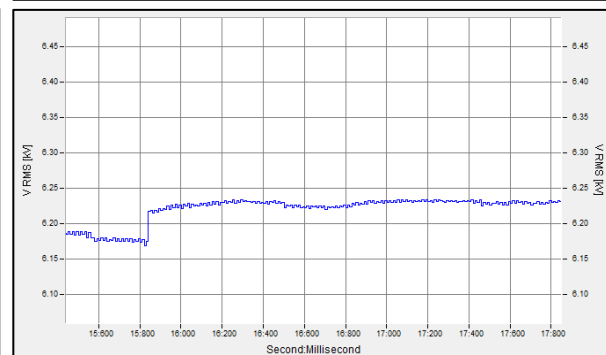
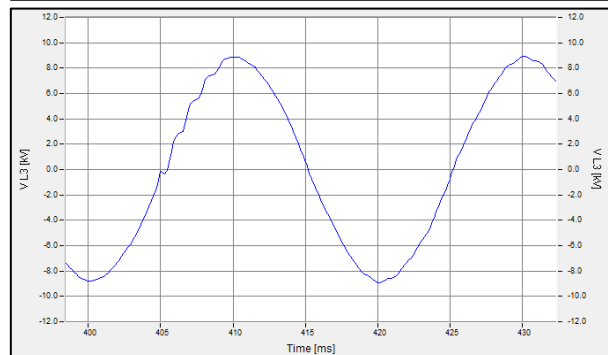
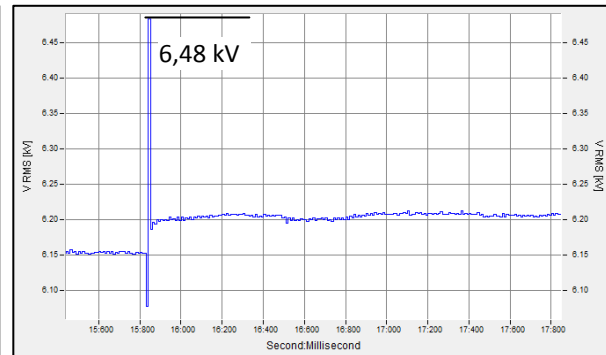
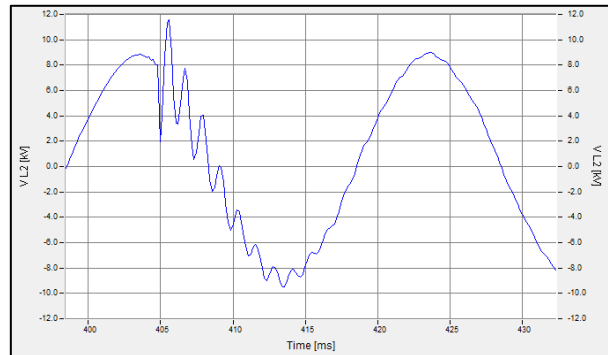
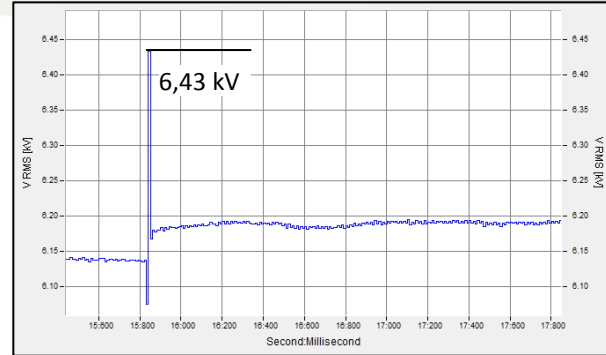
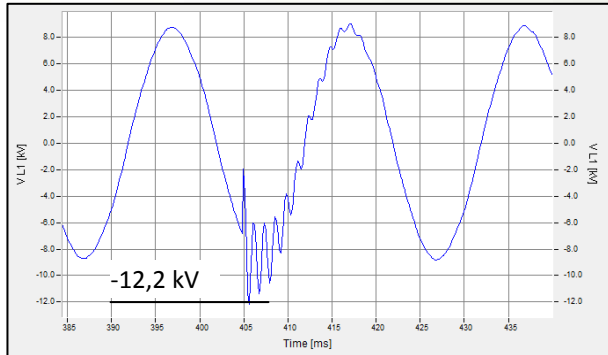
(b)

Łączenie pojedynczej baterii kondensatorów





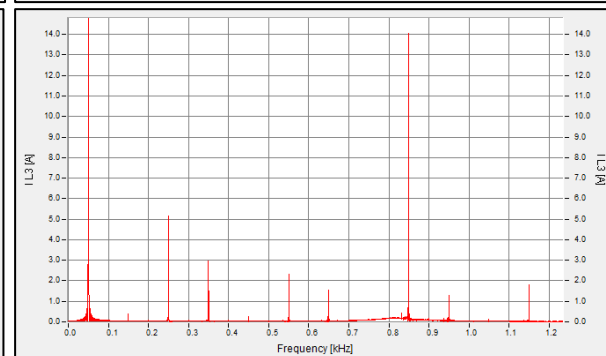
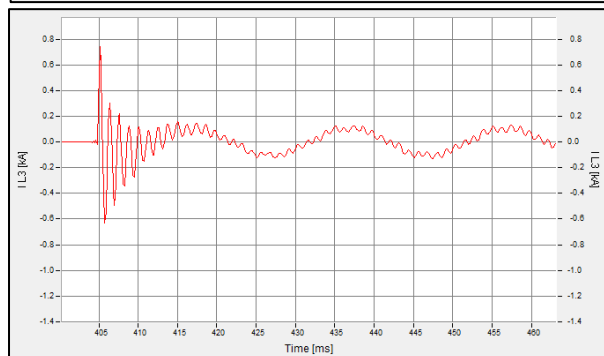
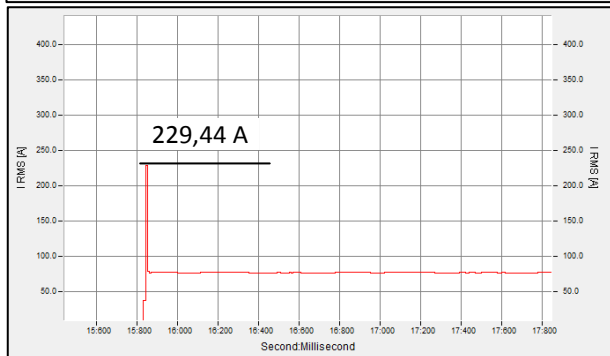
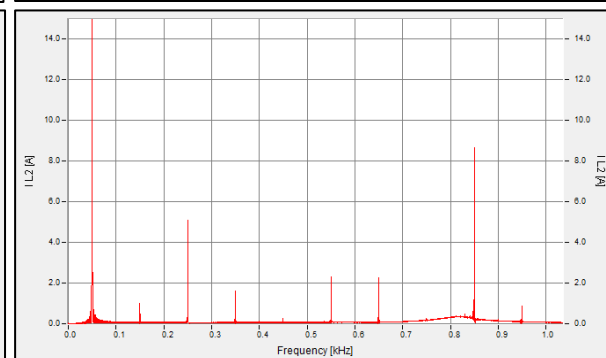
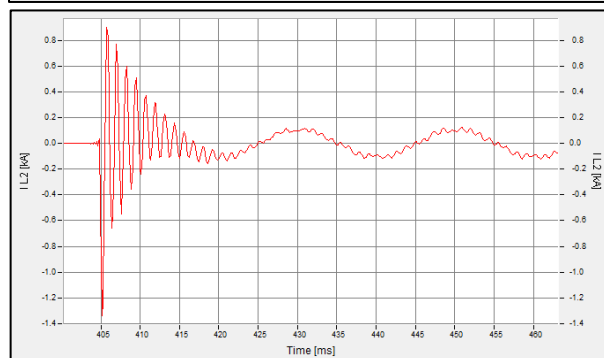
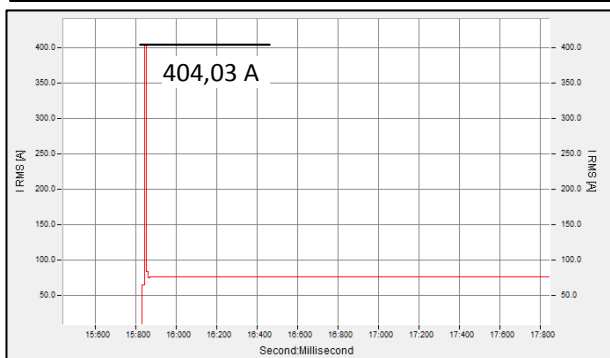
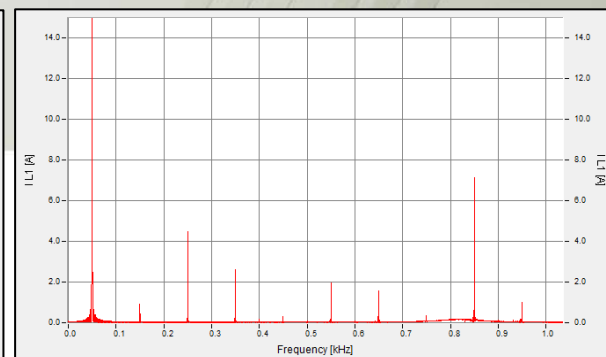
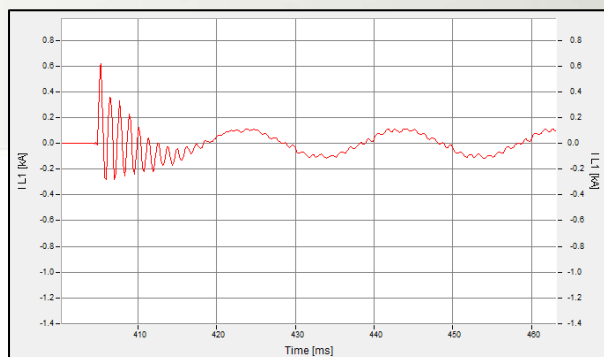
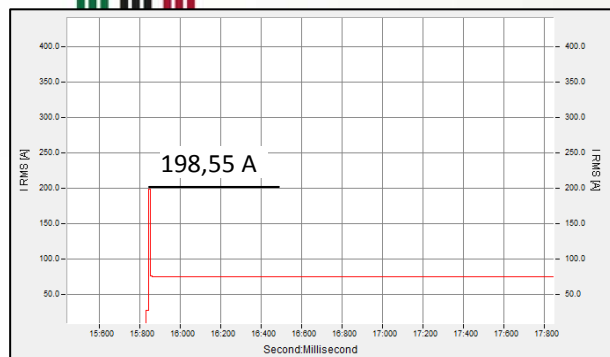
Łączenie pojedynczej baterii kondensatorów



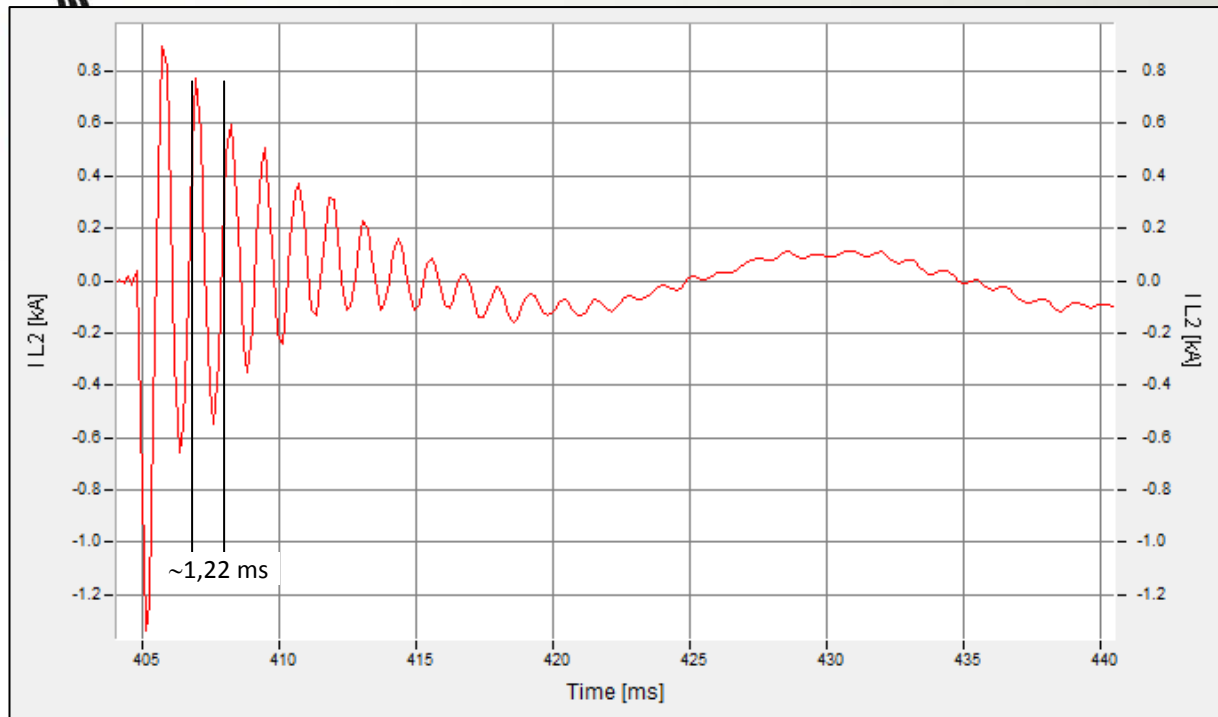
Proces załączania
baterii kondensatorów
– napięcia
międzyfazowe
(wartości chwilowe,
wartości RMS 10 ms)



Łączenie pojedynczej baterii kondensatorów

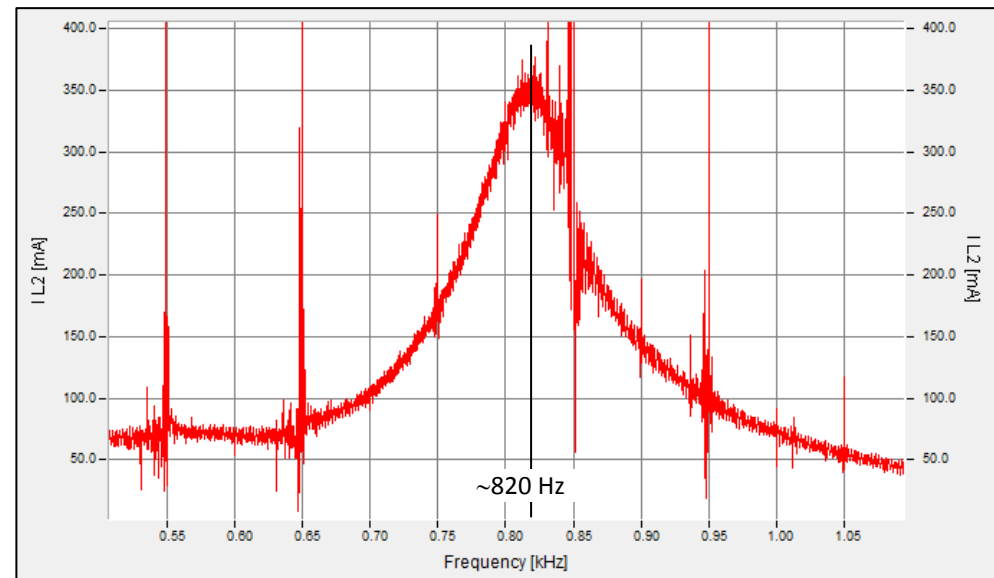


Dominującą wyższą harmoniczną w przebiegu prądu jest 17. i jej maksymalna wartość wynosi 14,05 A (zmierzone w fazie 3) podczas procesu załączenia.

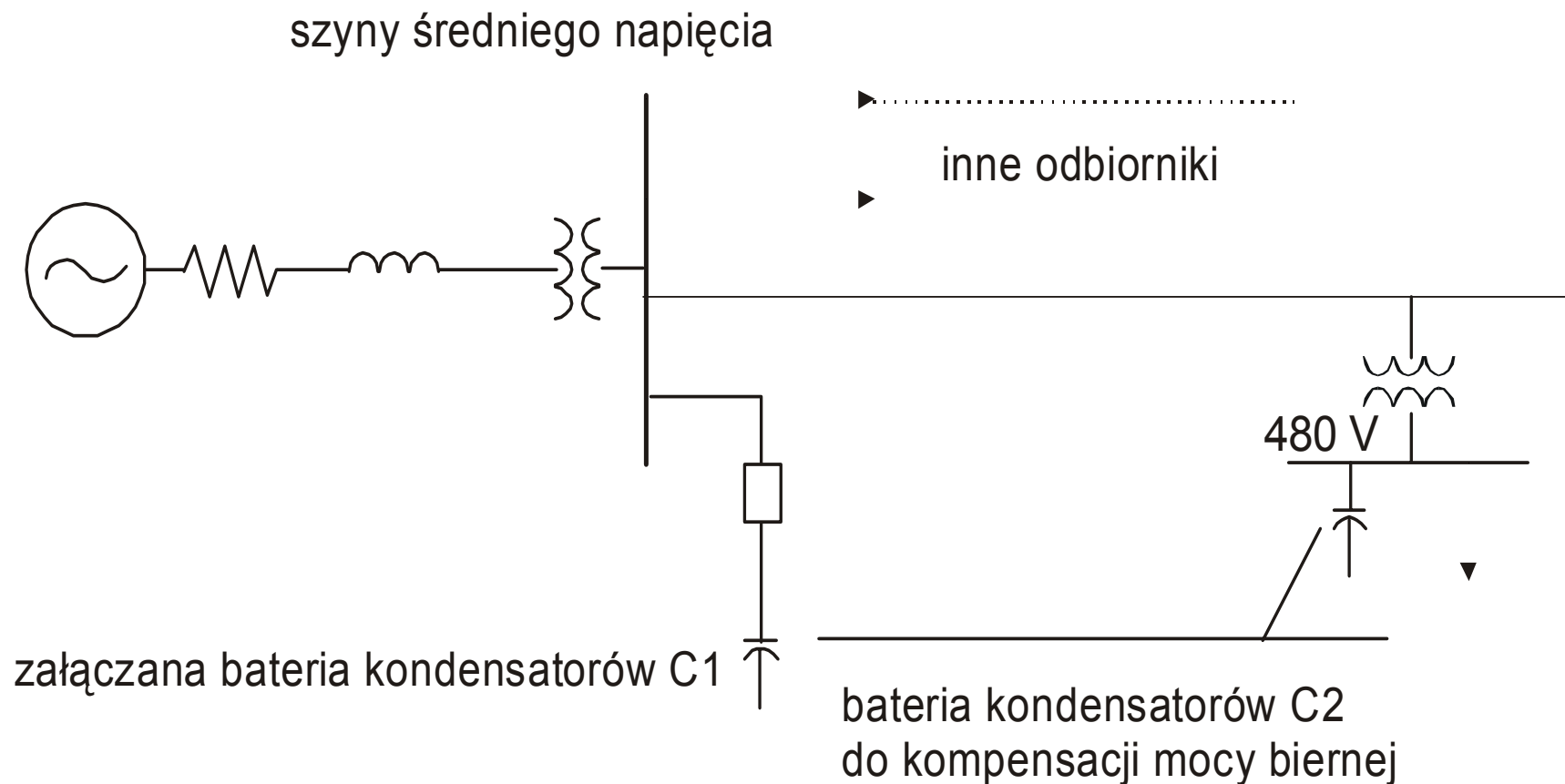


Łączenie pojedynczej baterii kondensatorów

Oscylacje tłumione wskazują na występowanie częstotliwości rezonansowej ok. 820 Hz ($16,4 f_1$).

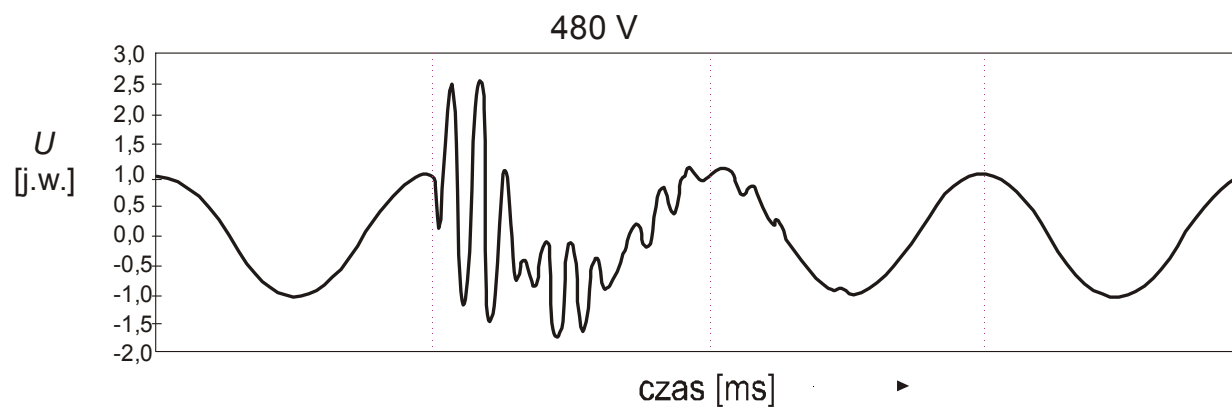
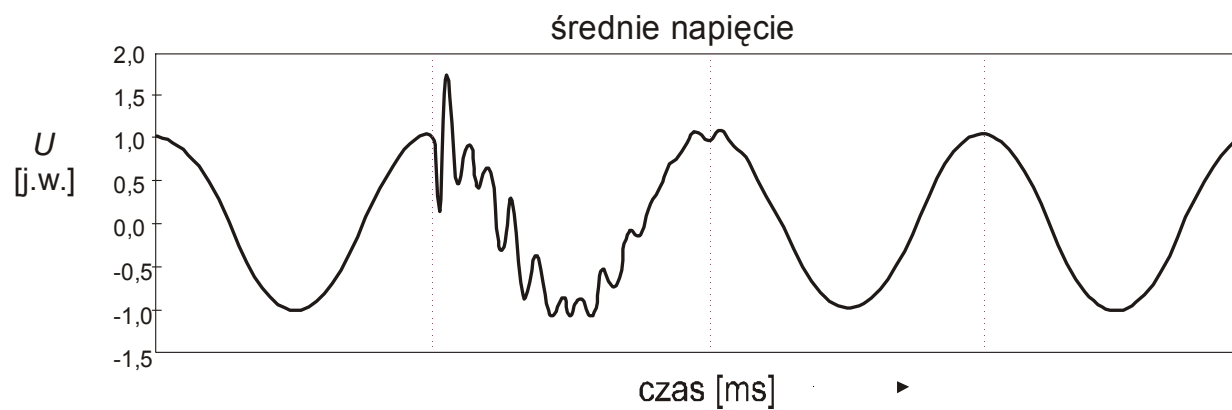


Proces wzmacniania oscylacji

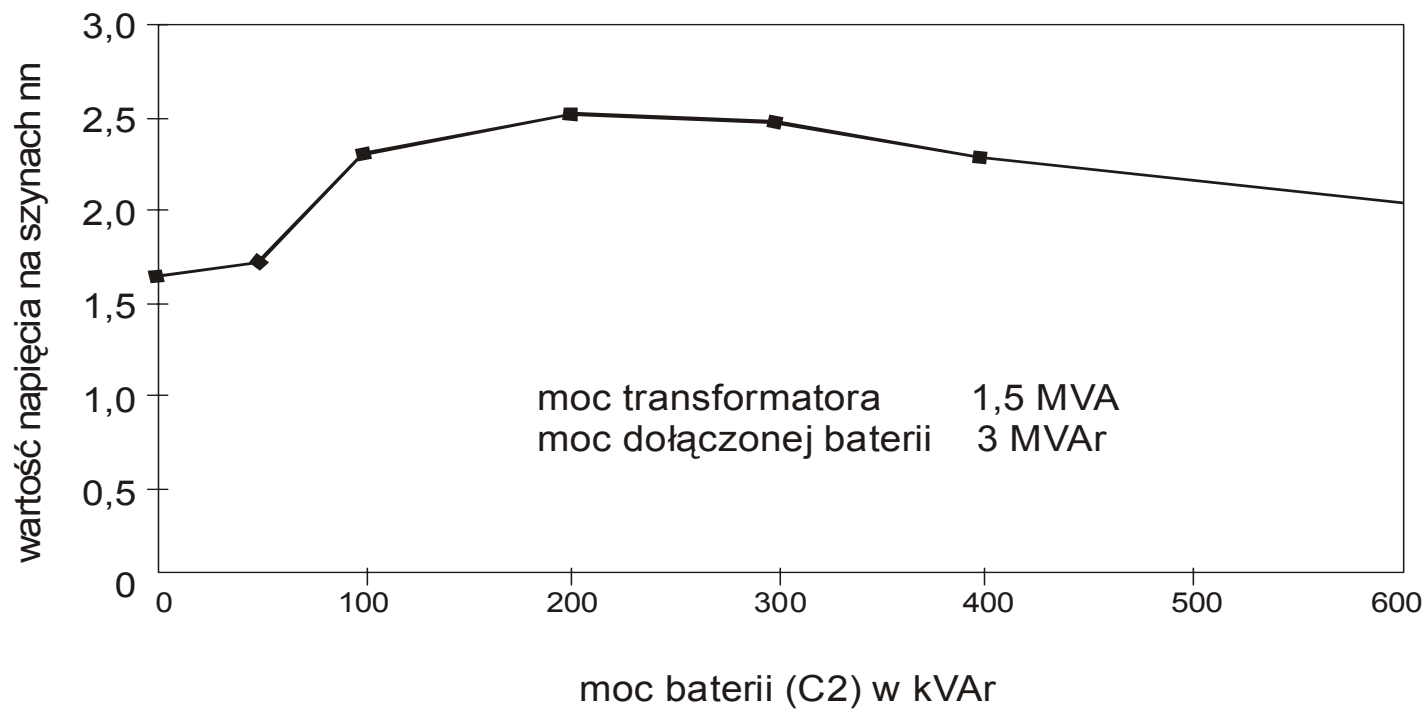


$$C1 = 3 \text{ MVar} \quad C2 = 200 \text{ kVar}$$

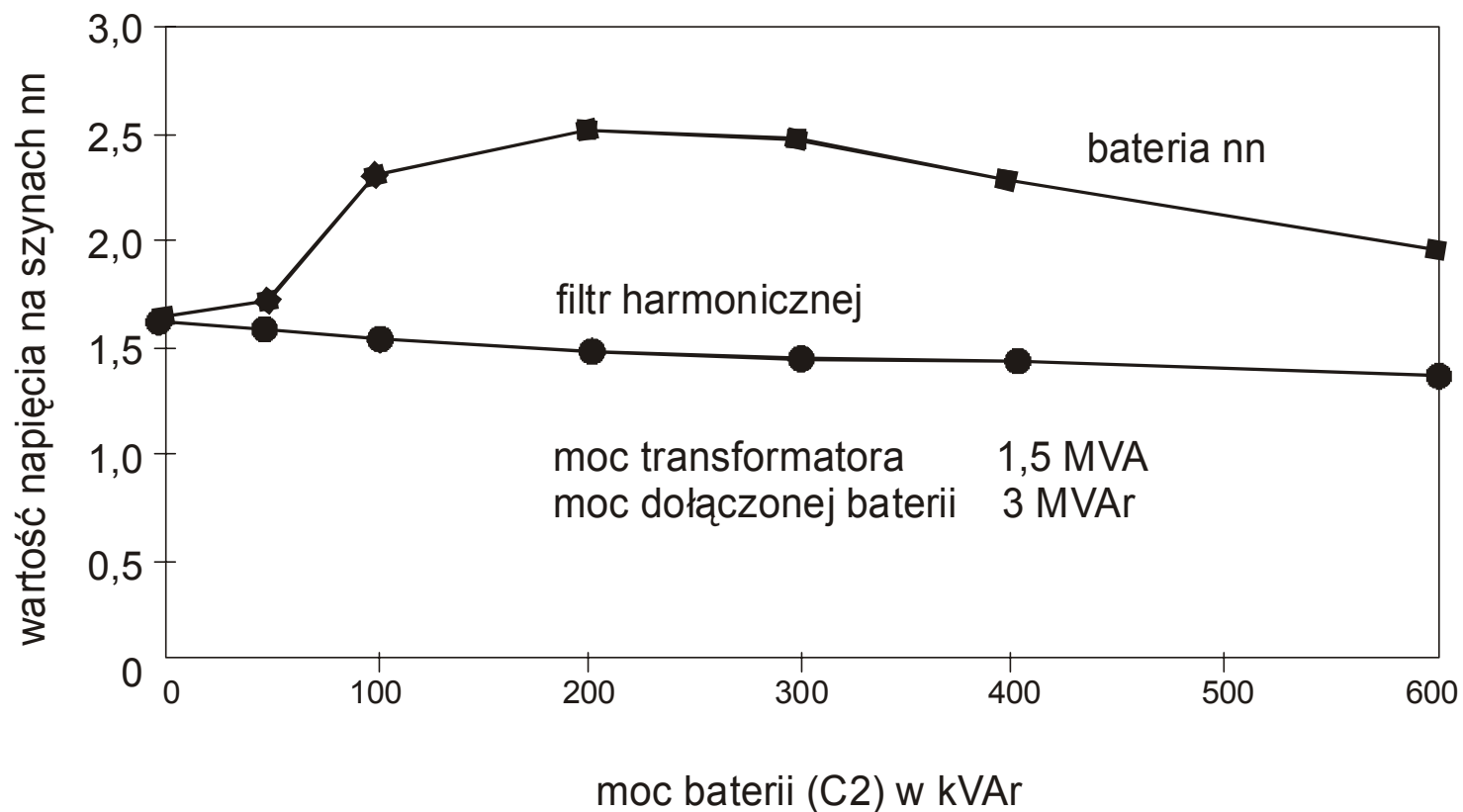
Proces wzmacniania oscylacji

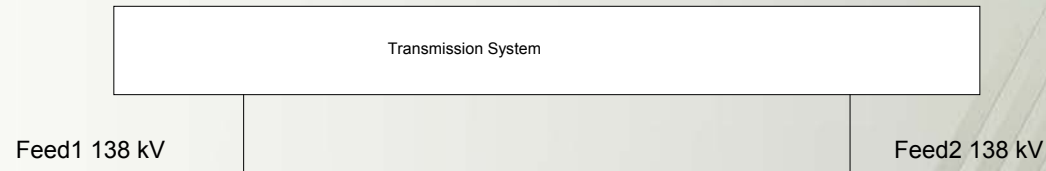


Proces wzmacniania oscylacji



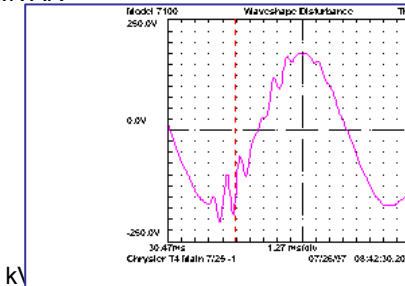
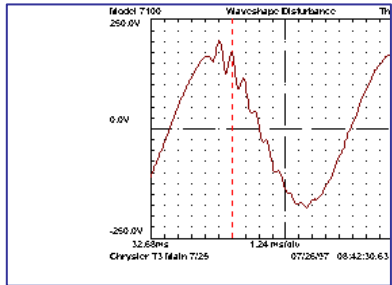
Proces wzmacniania oscylacji





36 MVAR

36 MVAR



T3
18 MVA

AutoPlant 138 kV

T4
18 MVA

12 kV

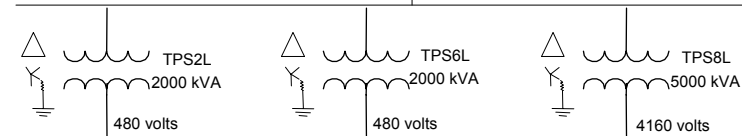
12 kV

2100 kvar
7200 volts

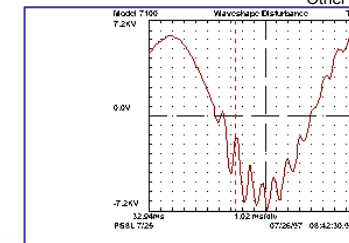
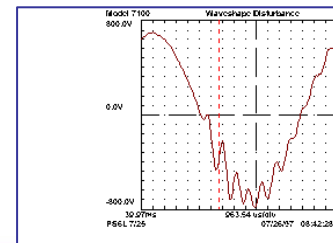
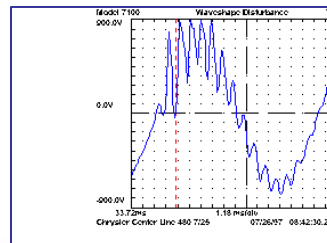
2100 kvar
7200 volts
(1200 kvar in service)

Feeder 301 Loads

Feeder 401 Loads

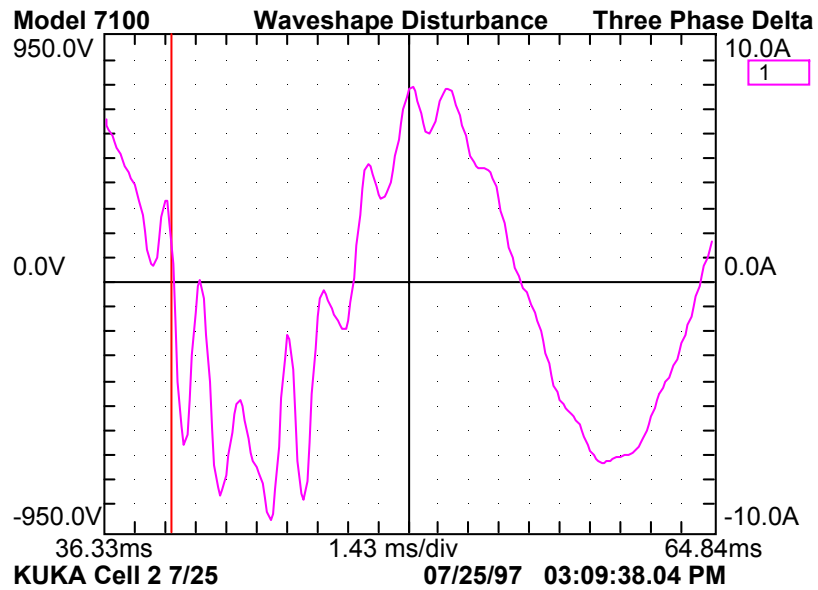


Other Load
ions

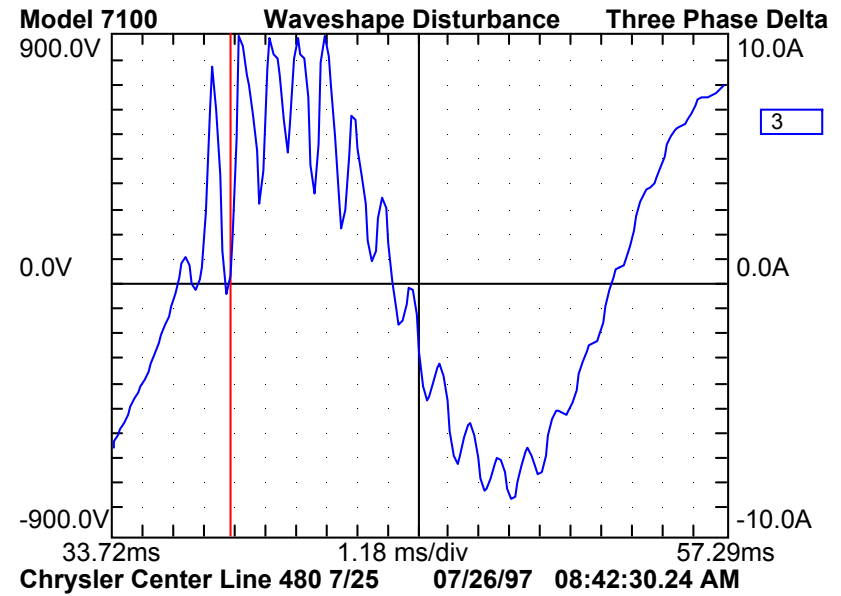




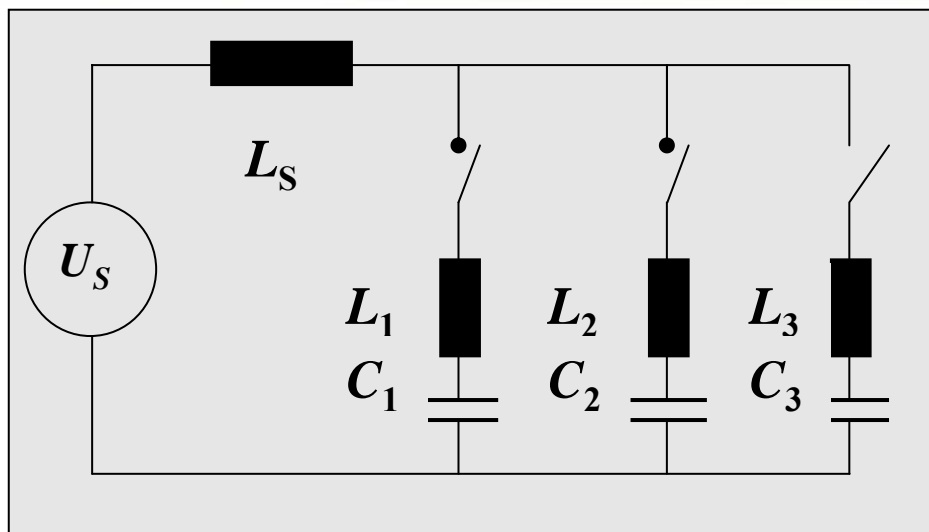
Robot Cell



Paint Line



Dołączanie kolejnej baterii

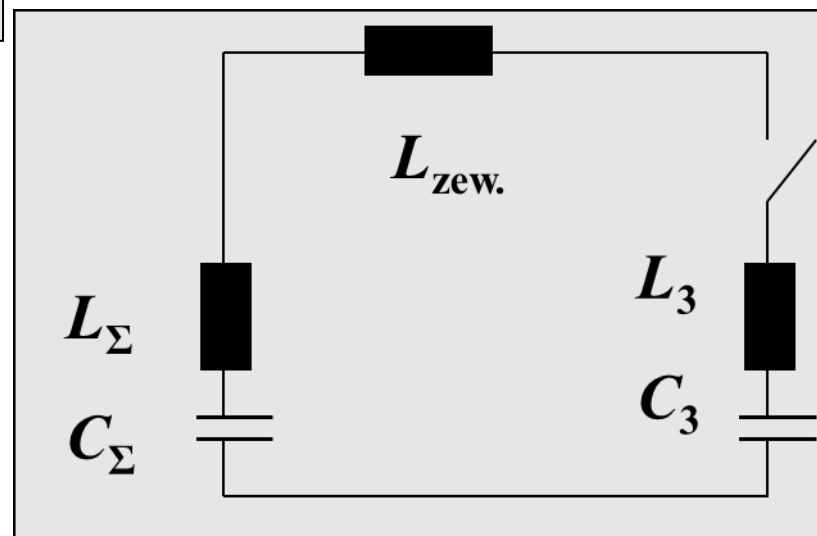


$$L_{\Sigma} = \frac{L_1 L_2}{L_1 + L_2}$$

$$C_{\Sigma} = C_1 + C_2$$

$$L = L_{\Sigma} + L_{zew.} + L_3$$

$$C = \frac{C_{\Sigma} C_3}{C_{\Sigma} + C_3}$$

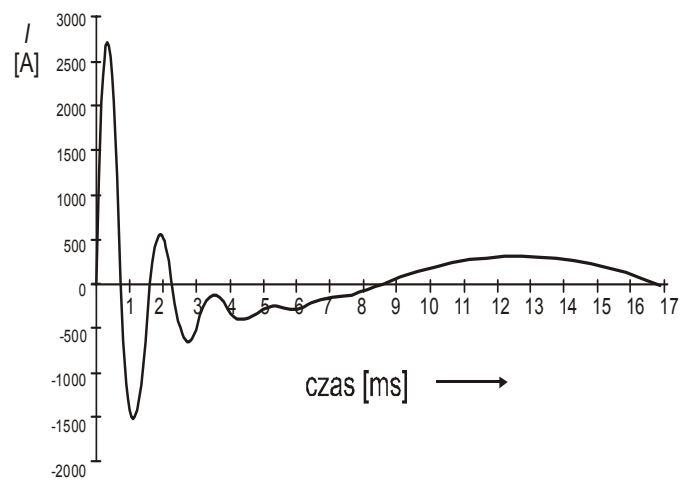


Dołączanie kolejnej baterii

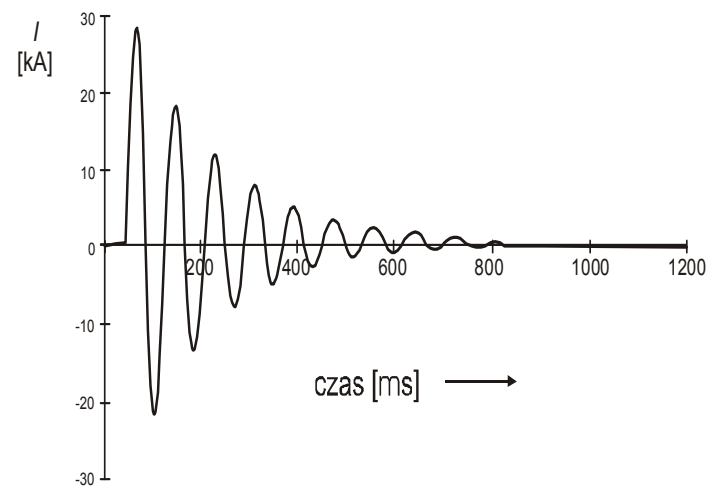
$$I_{\max.} = \frac{\sqrt{2}U_s}{Z_C} = \sqrt{2}U_s \sqrt{\frac{C}{L}} = \sqrt{\frac{2U_s I_{CN1} I_{CN2}}{\omega L_{zew.} (I_{CN1} + I_{CN2})}}$$

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \mathbf{1 - 8,5 \text{ kHz}}$$

Dołączanie kolejnej baterii

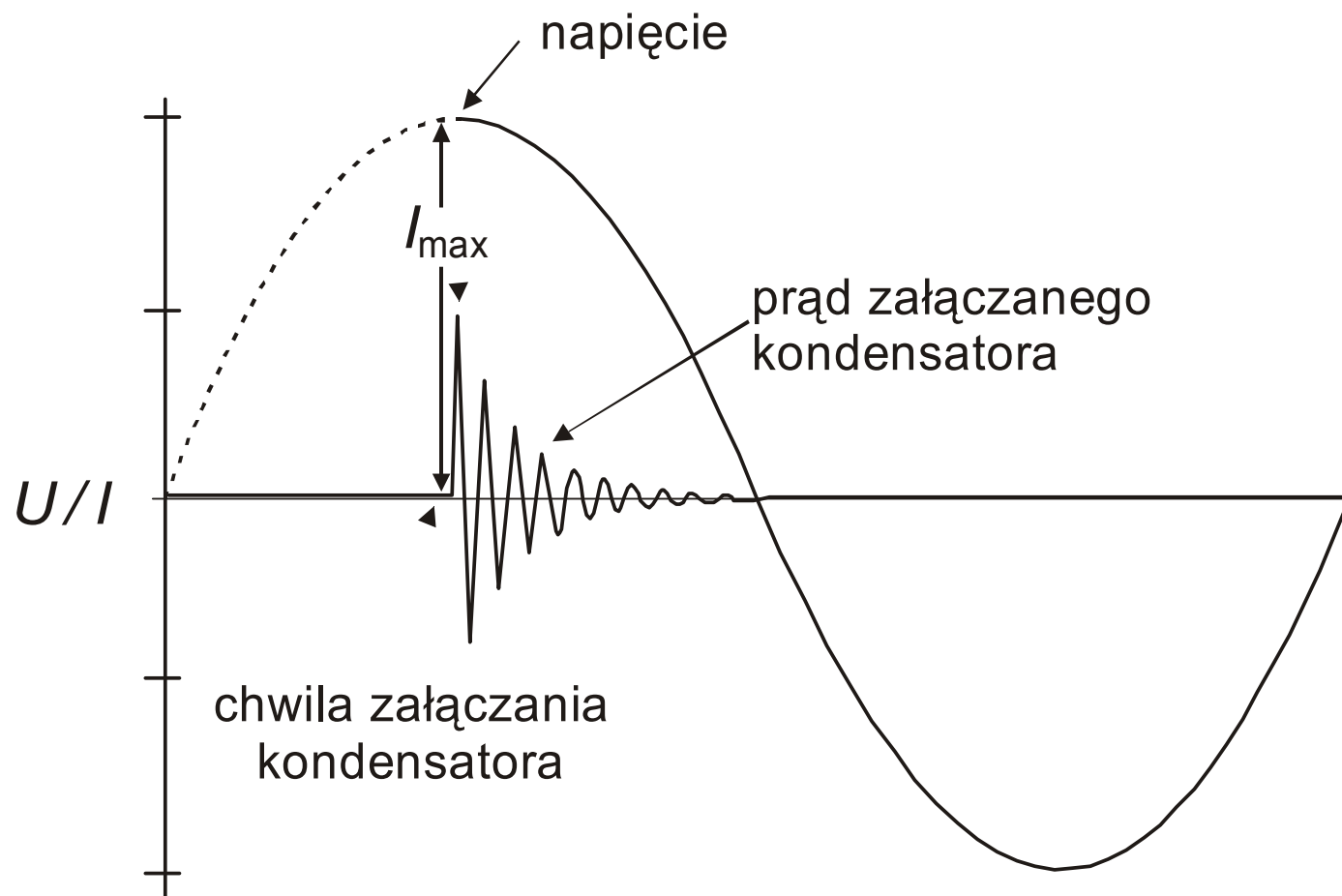


(a)

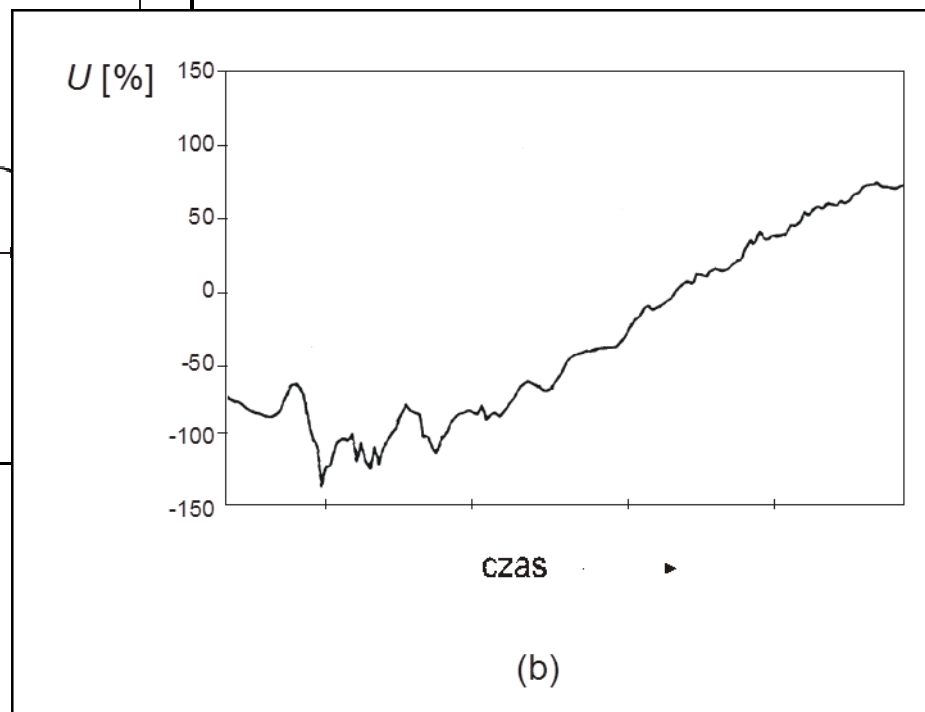
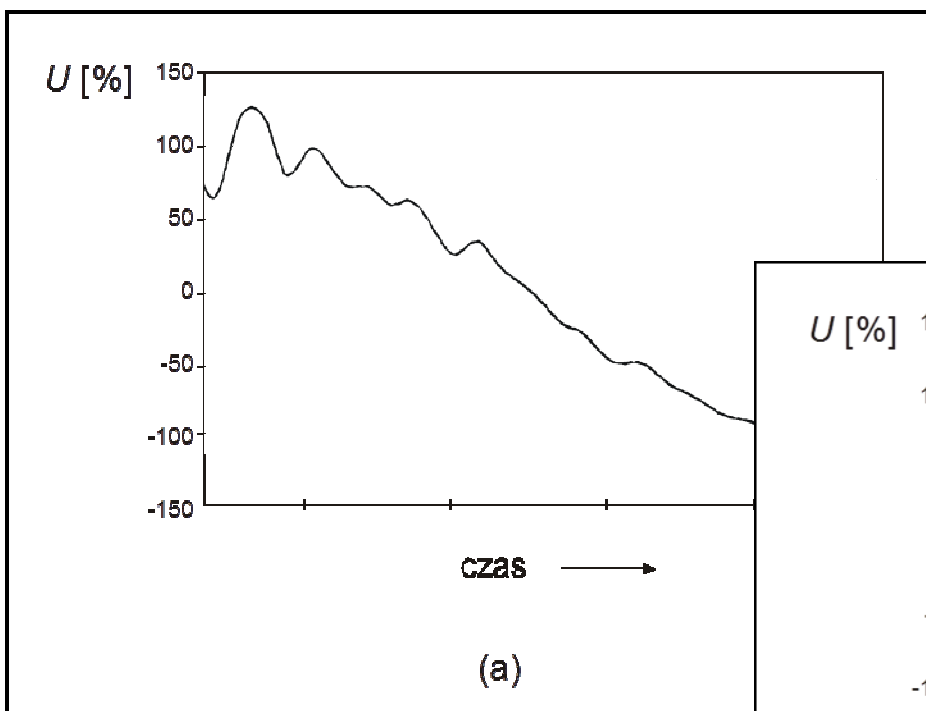


(b)

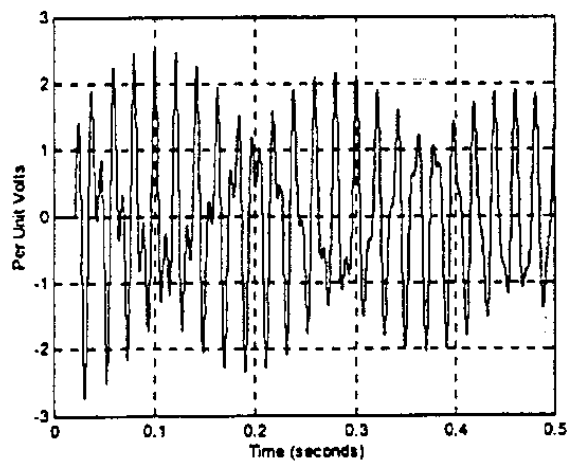
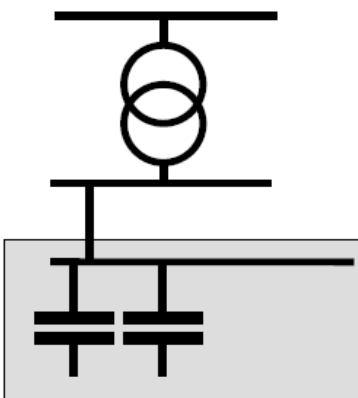
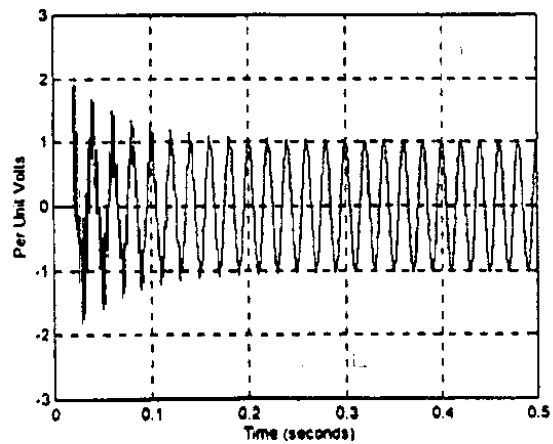
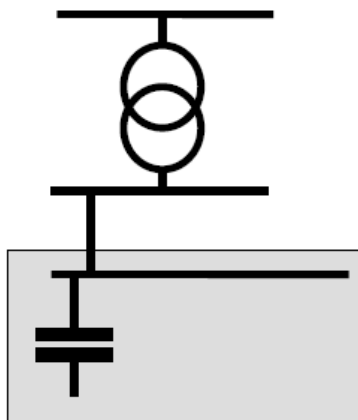
Dołączanie kolejnej baterii



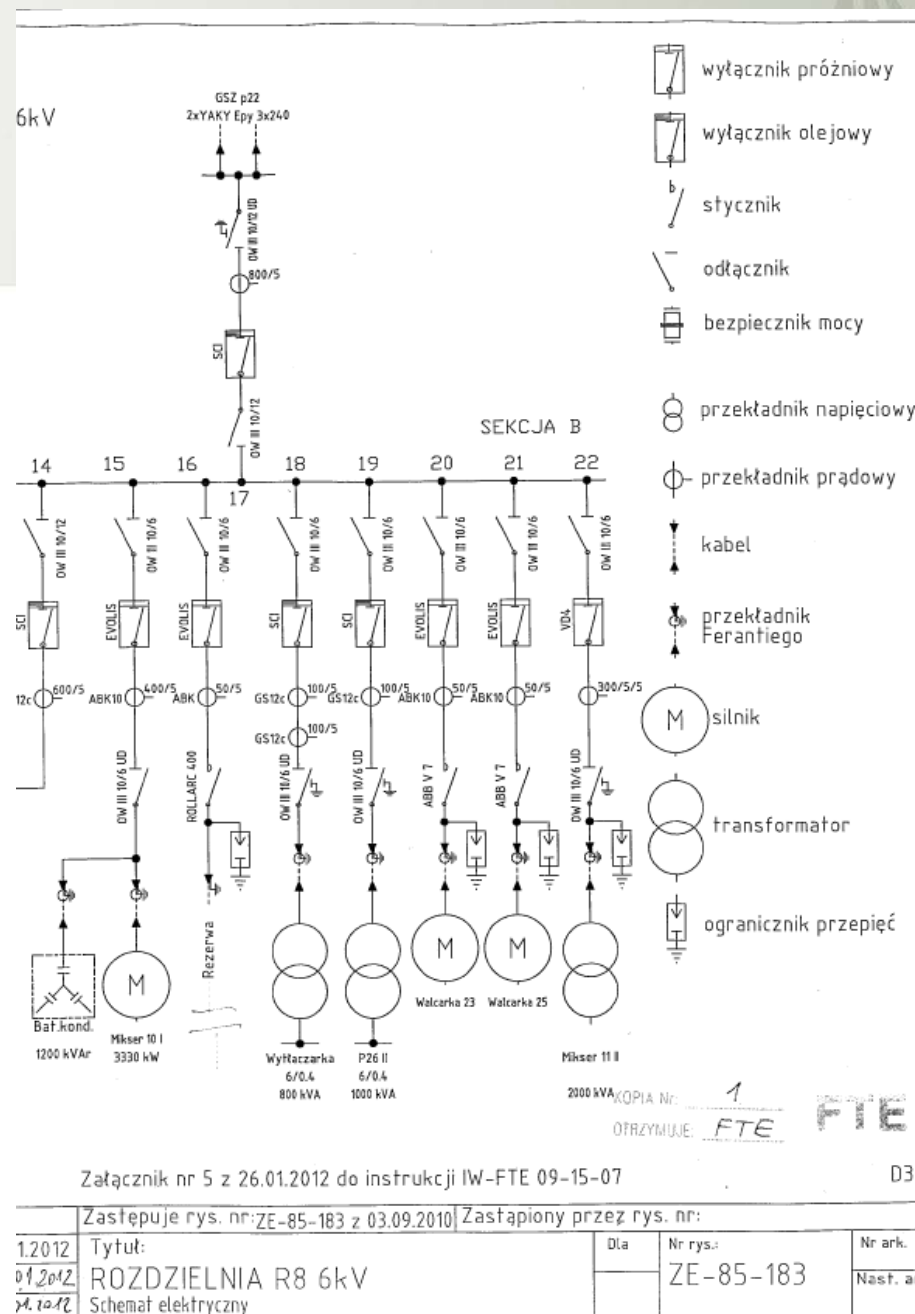
Dołączanie kolejnej baterii



Dołączanie kolejnej baterii

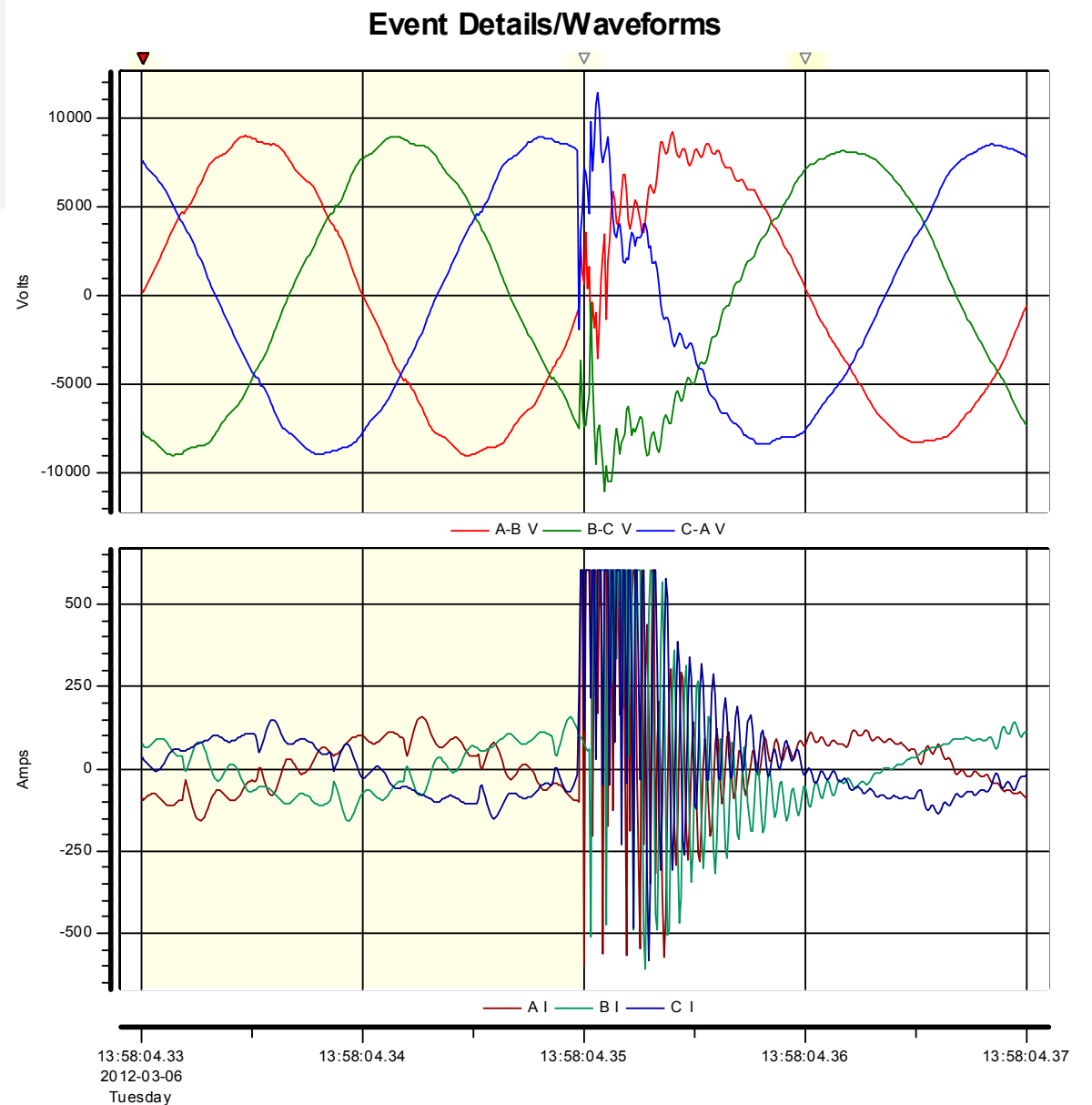


Dołączanie kolejnej baterii





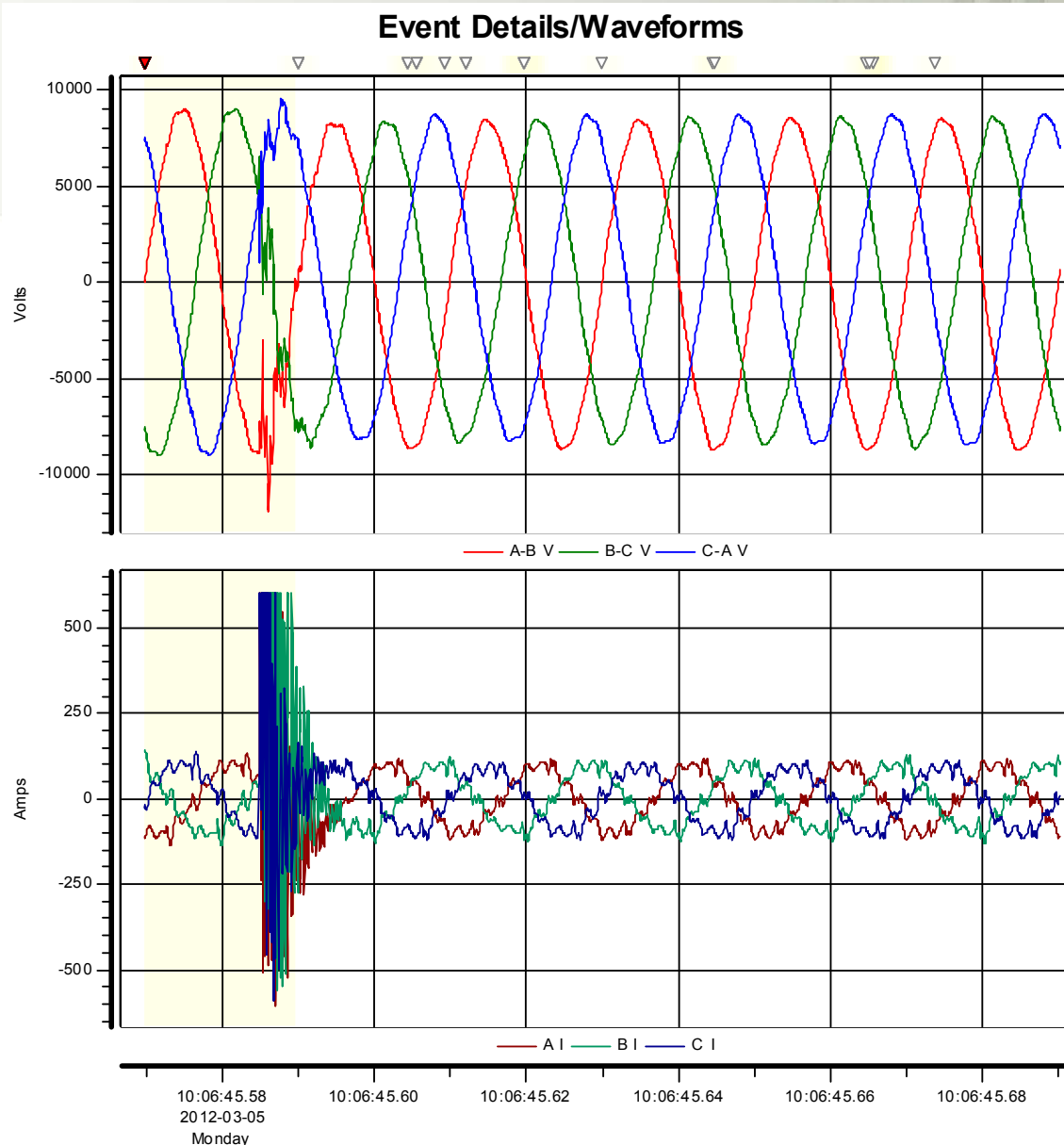
Dołączanie kolejnej baterii



Event #79 at 2012-03-06 13:58:04.330
Pre-trigger



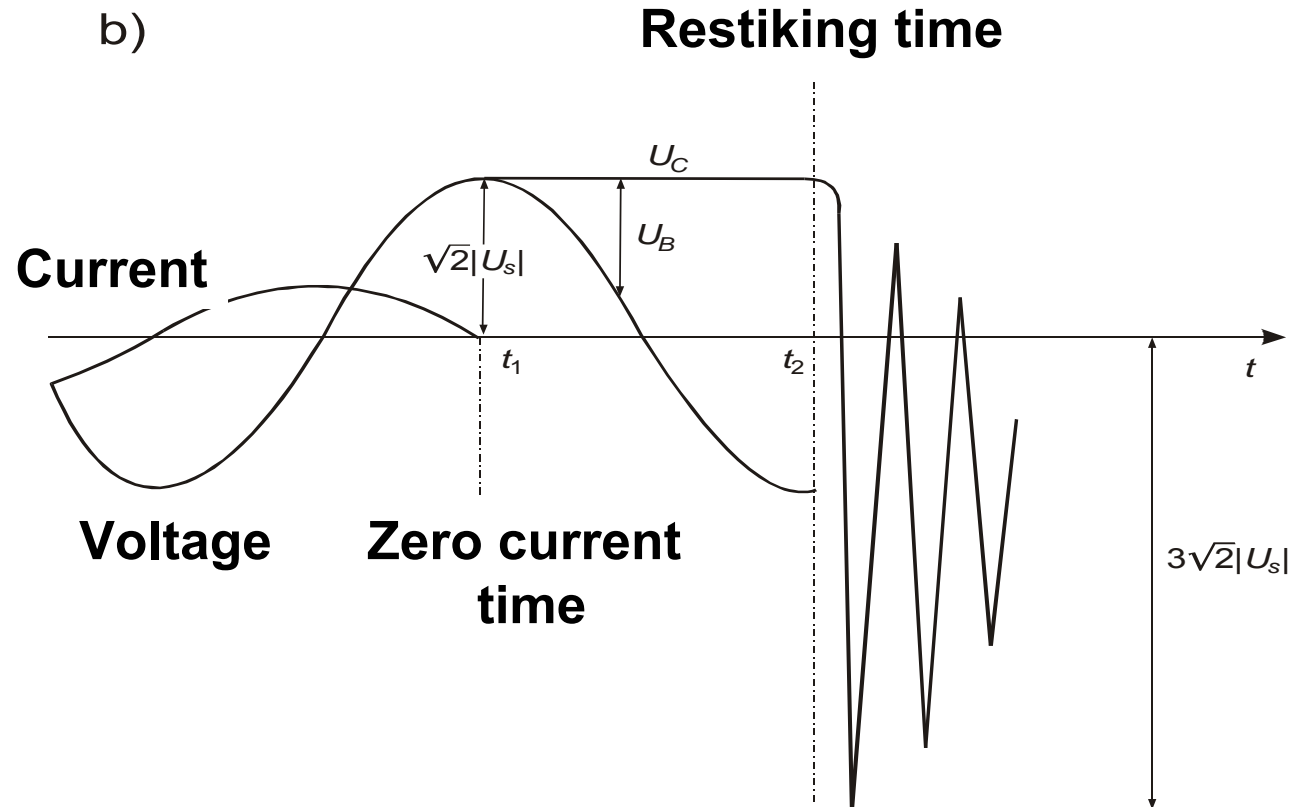
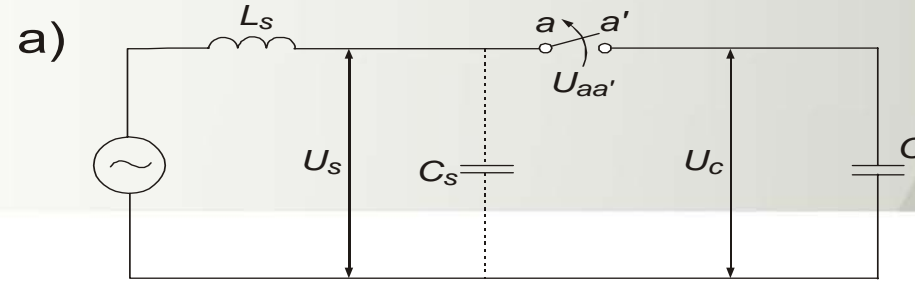
Dołączanie kolejnej baterii



Event #59 at 2012-03-05 10:06:45.569
Pre-trigger

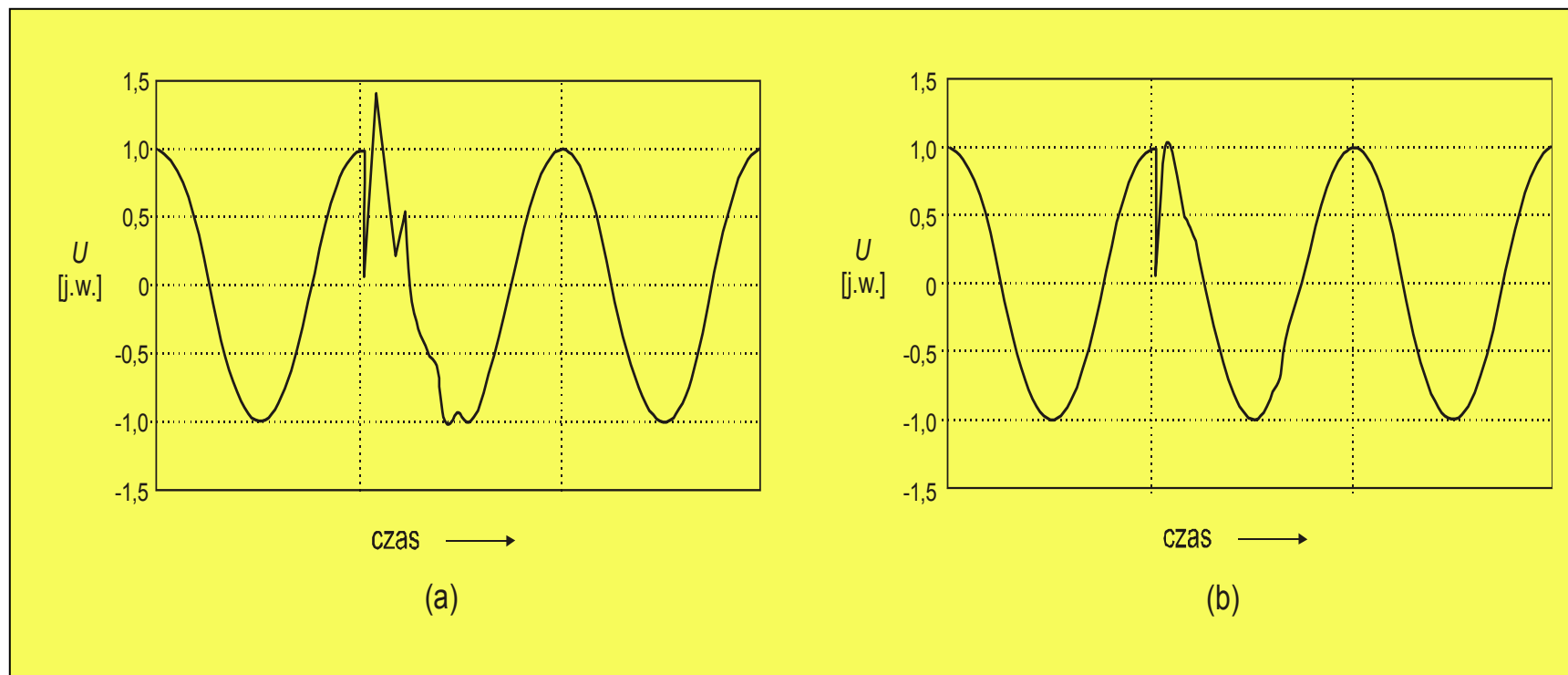
Szczególne warunki łączenia baterii:

- **załączanie baterii wstępnie naładowanej**
- **zapłon łuku podczas procesu wyłączania baterii.**



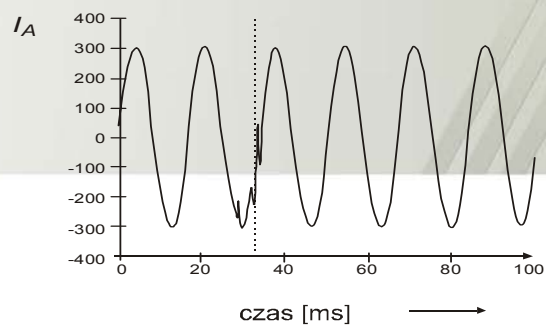
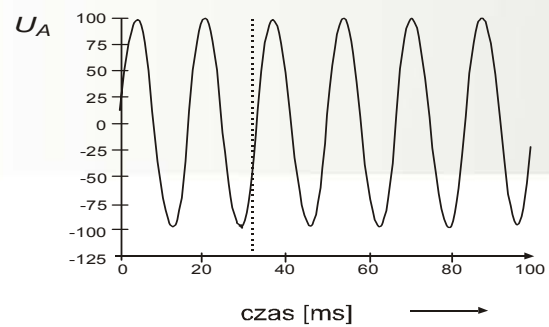
Sposoby redukcji przepięć i przetężeń:

- ochrona przecięciowa
- szeregowo rezystancja

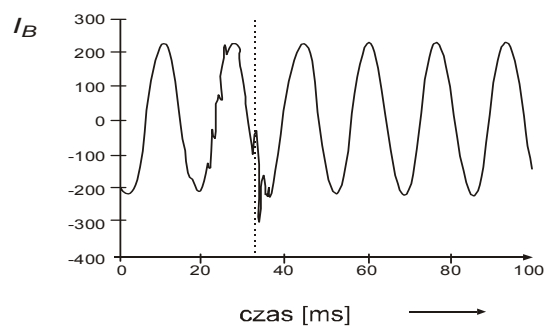
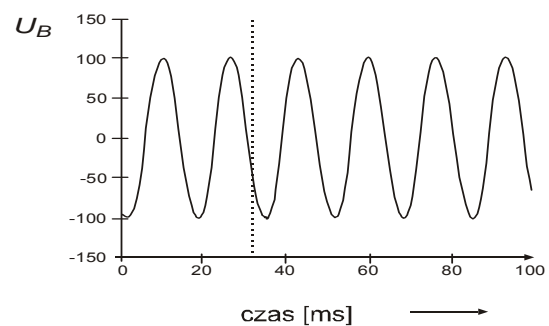


Szeregowy dławik

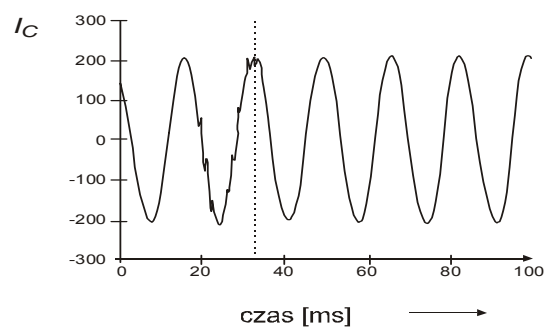
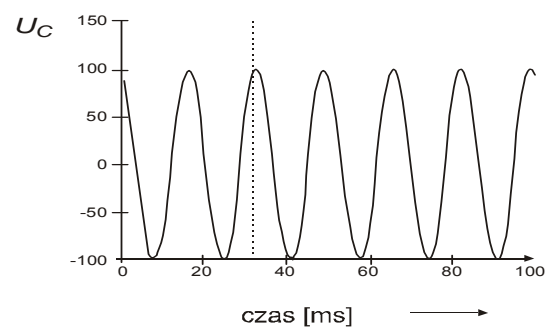
FAZA A



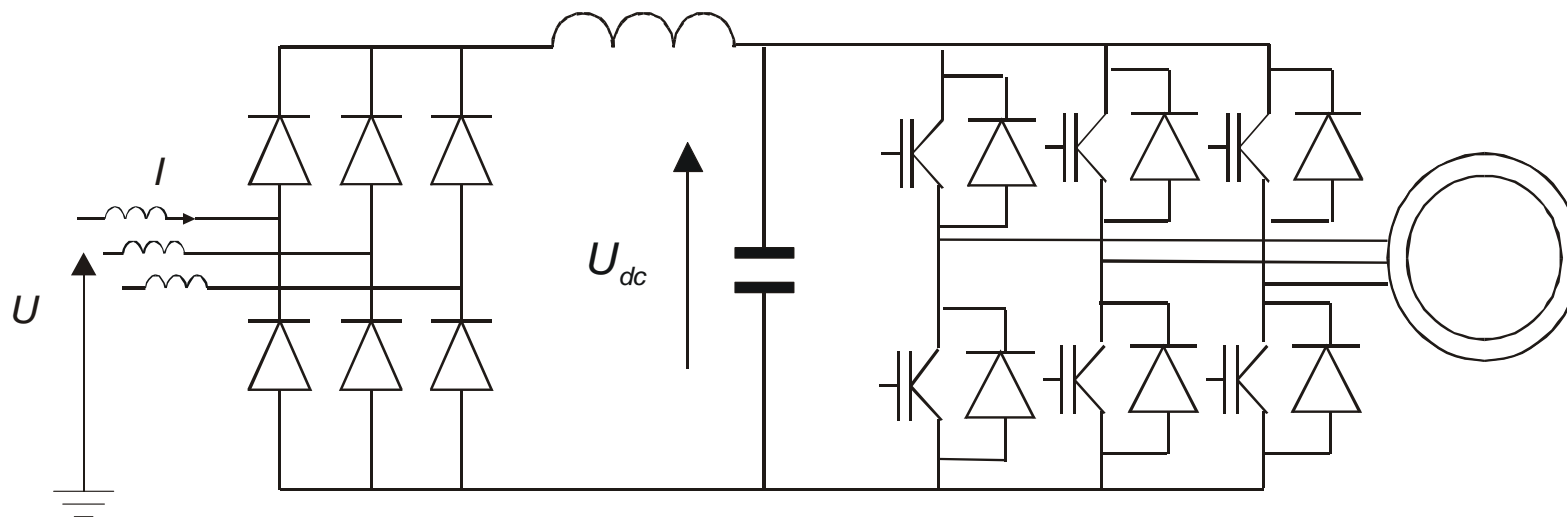
FAZA B



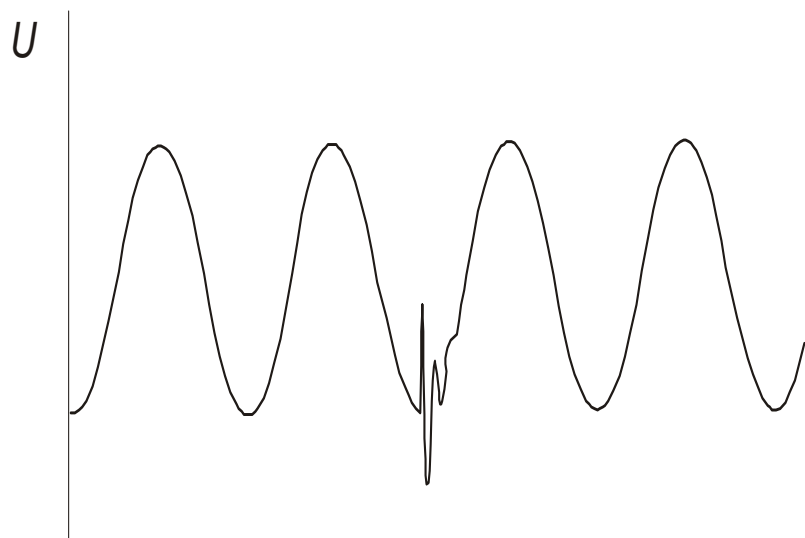
FAZA C



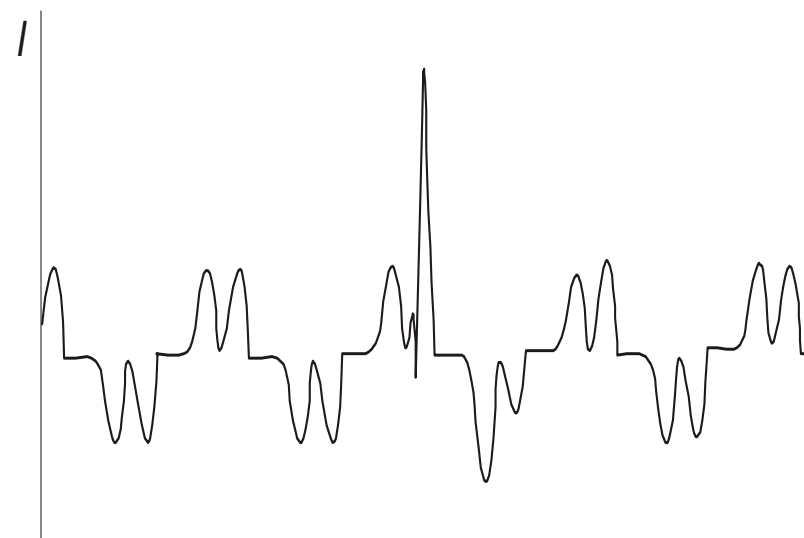
Awaryjne wyłączenia czułych odbiorników



Awaryjne wyłączenia czułych odbiorników

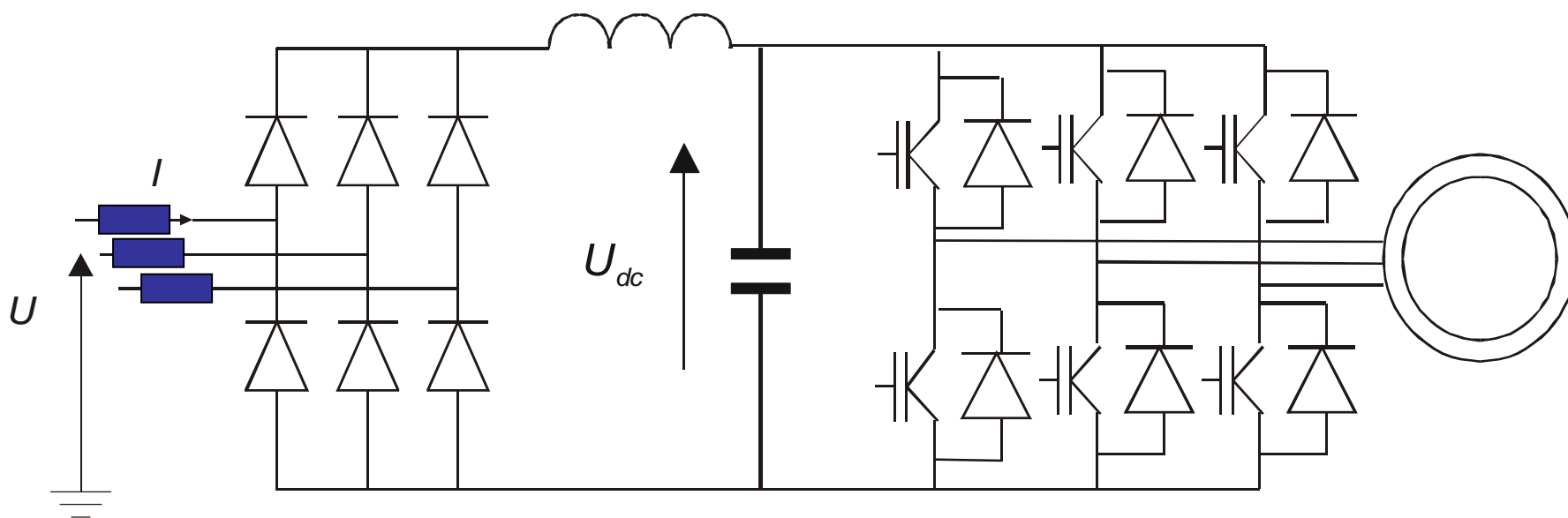


czas [ms] →

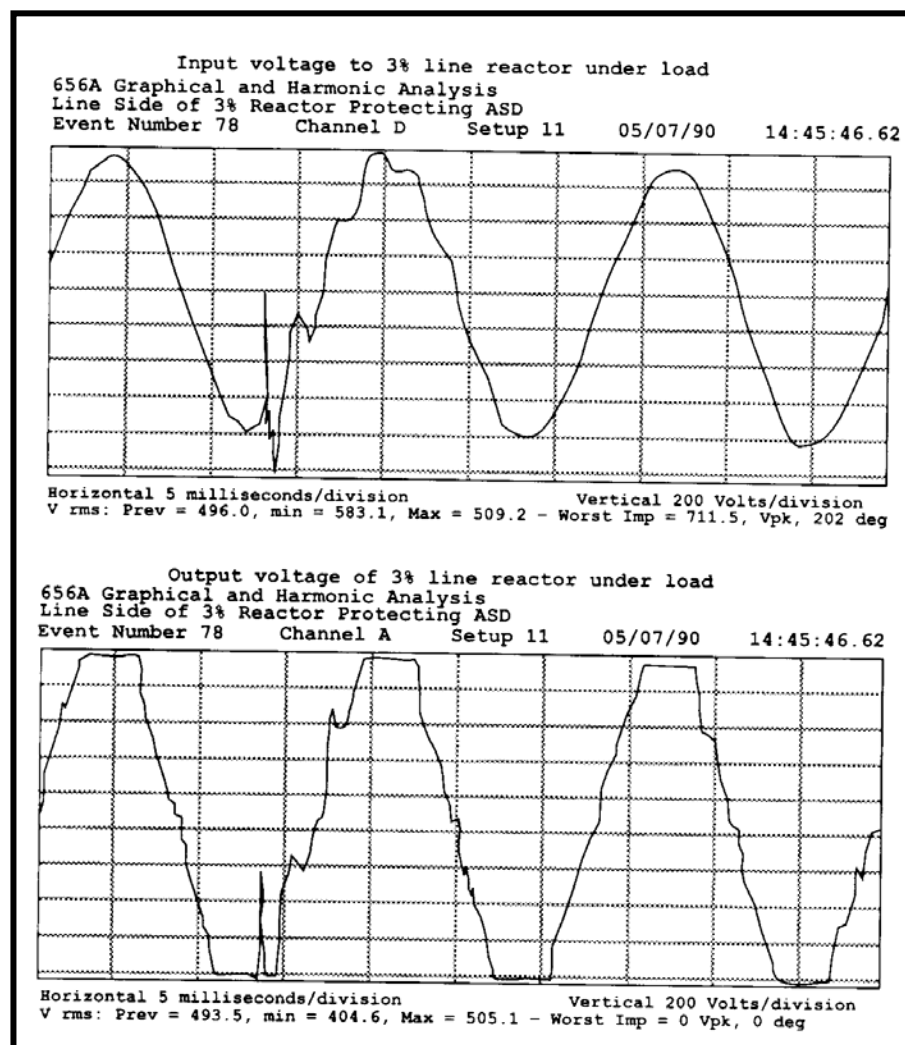


czas [ms] →

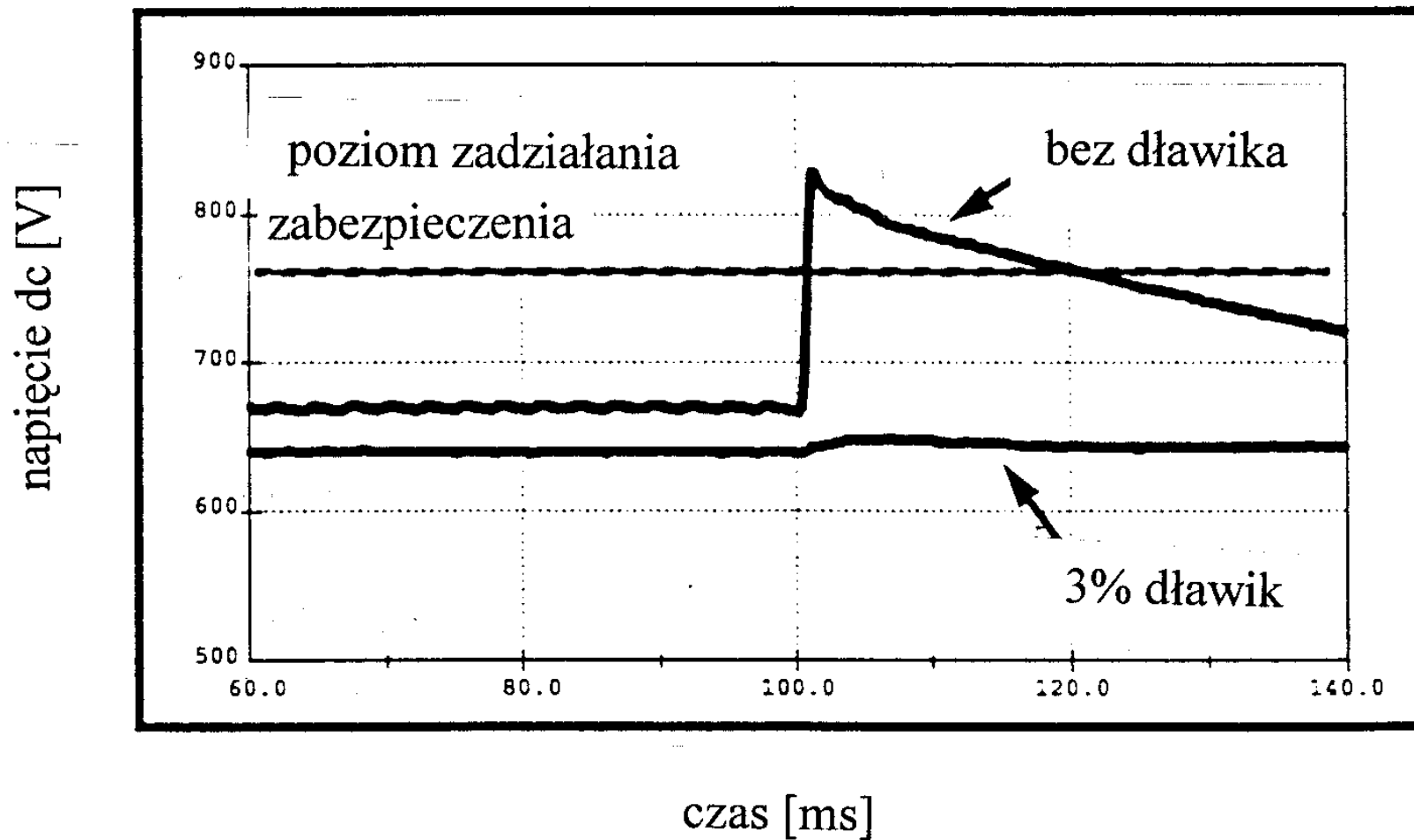
Awaryjne wyłączenia czułych odbiorników



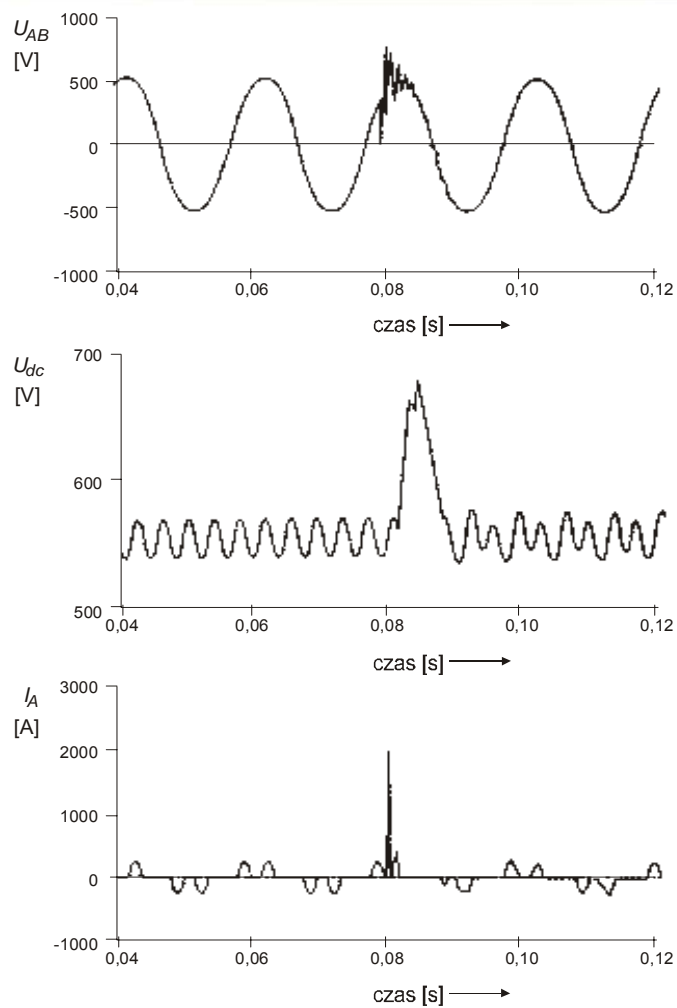
Awaryjne wyłączenia czułych odbiorników



Awaryjne wyłączenia czułych odbiorników



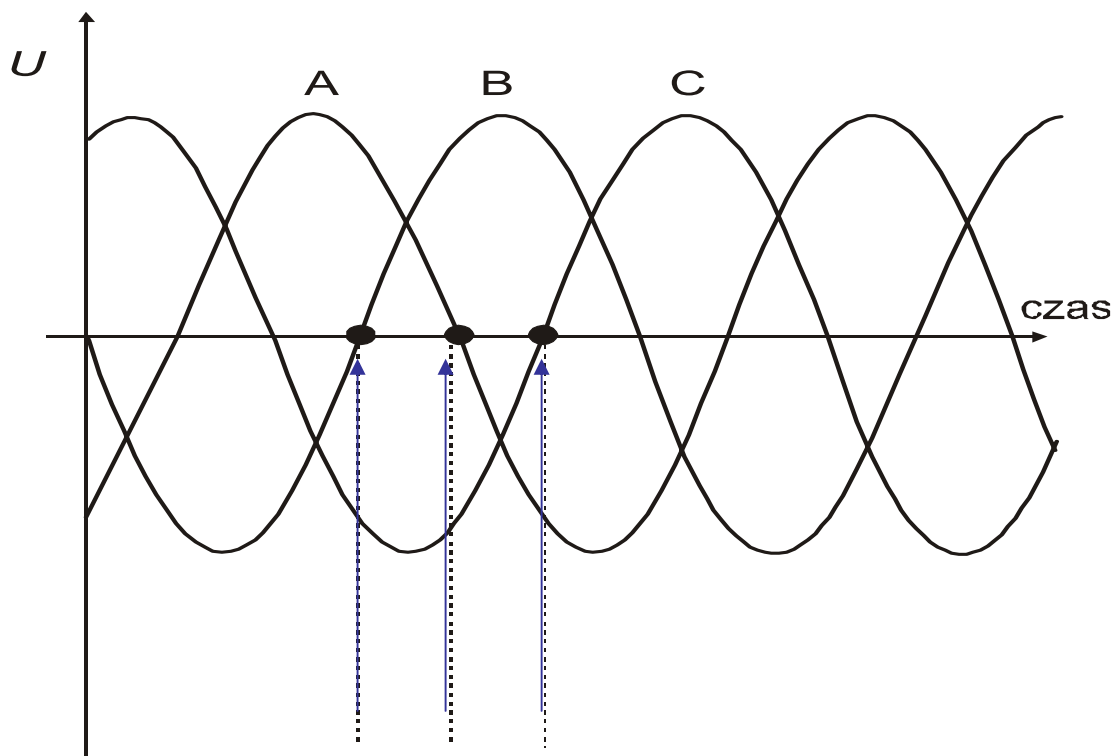
Awaryjne wyłączenia czułych odbiorników



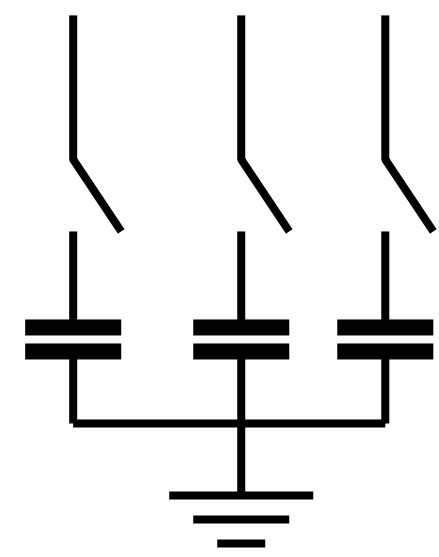
(a)

Filtry pasywne

Łączenie synchroniczne

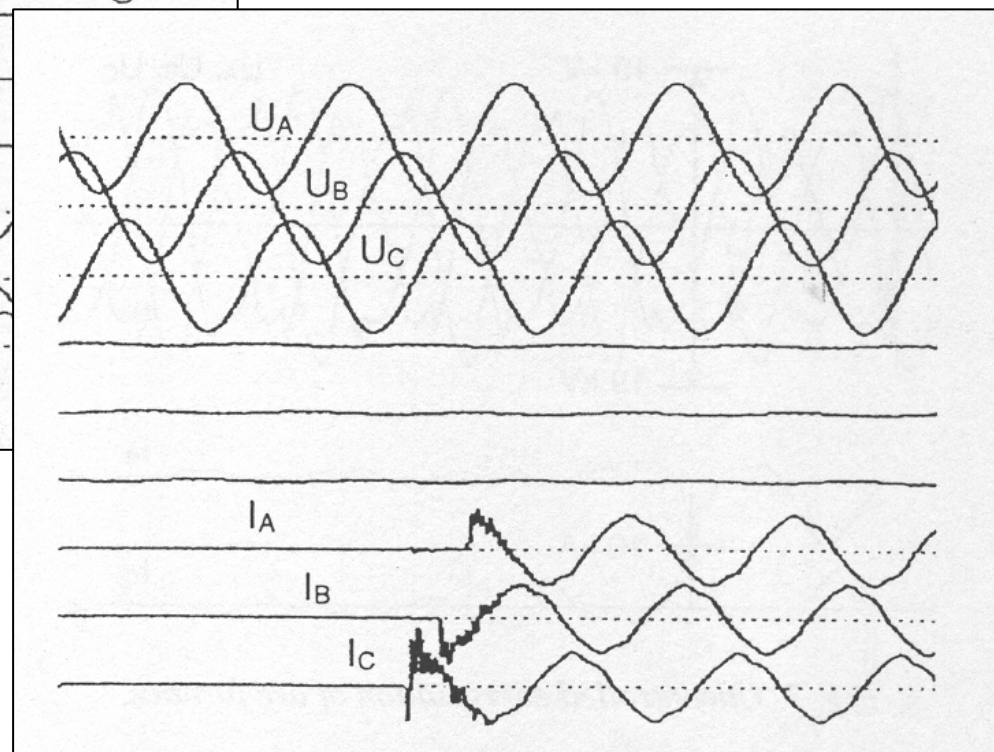
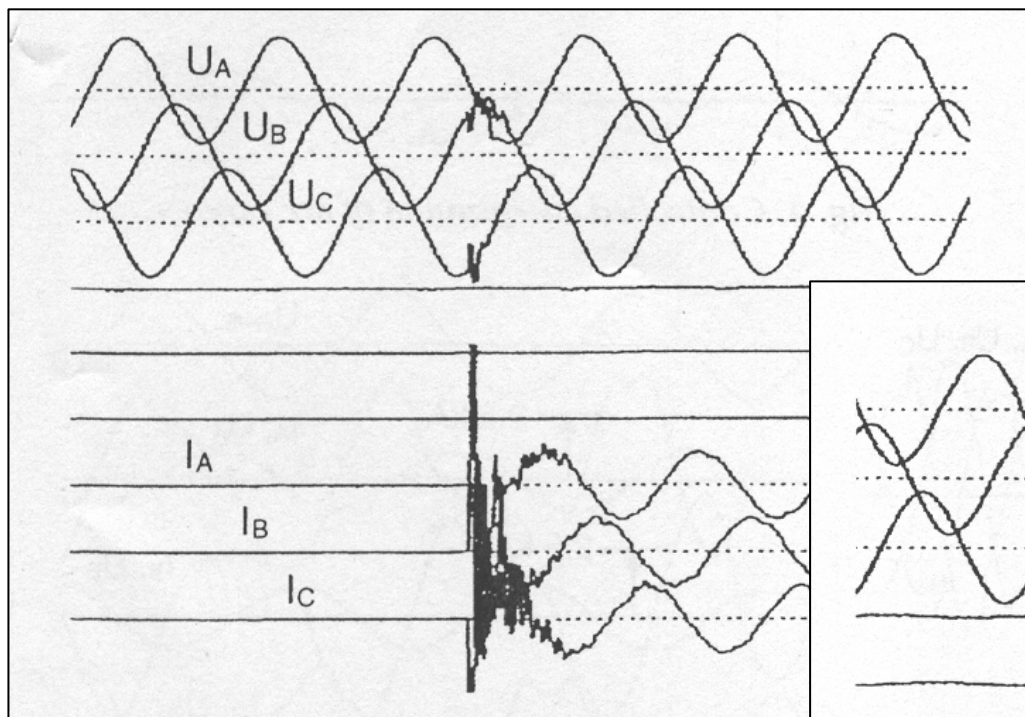


Chwile łączenia



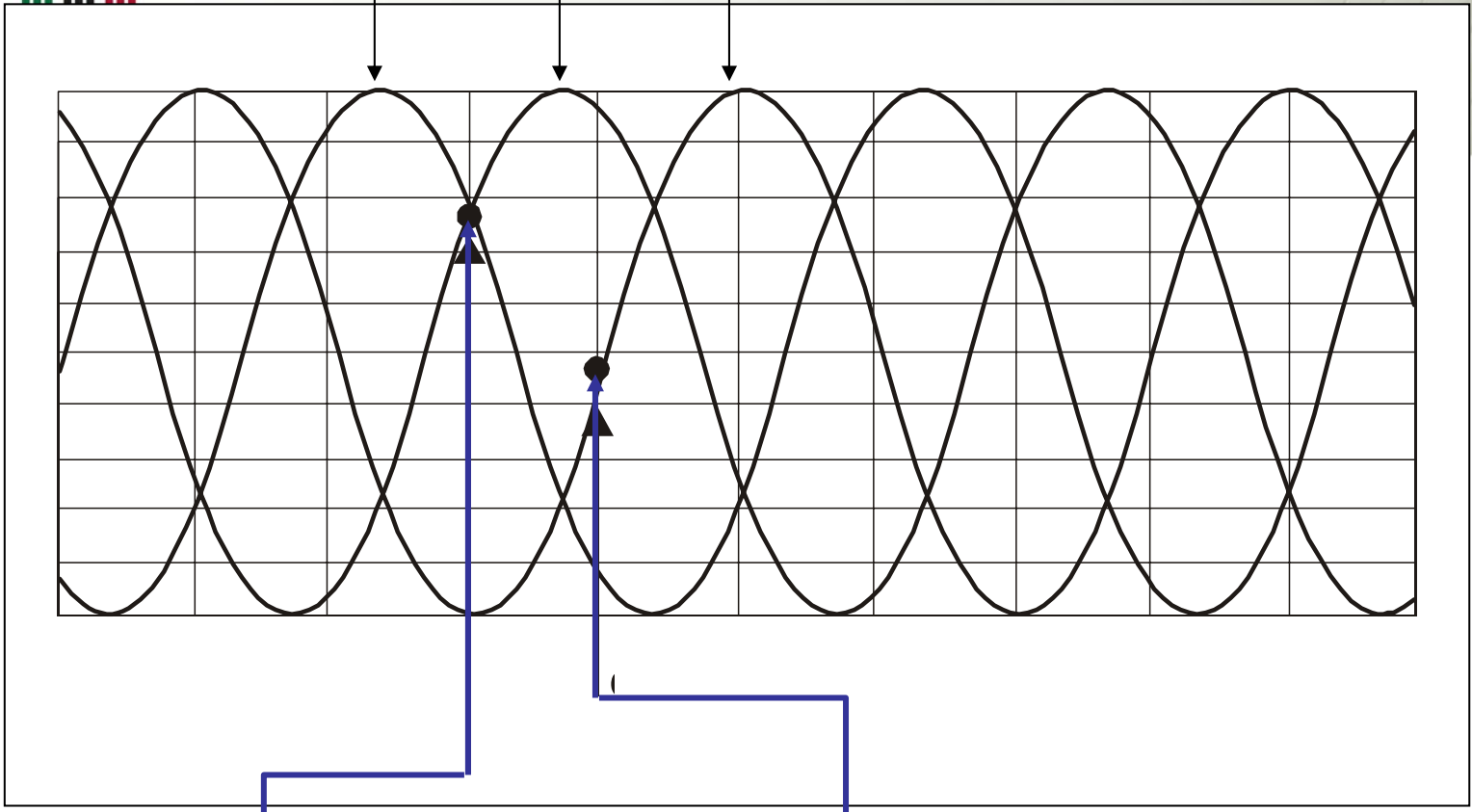
Uziemiona gwiazda

Łączenie synchroniczne

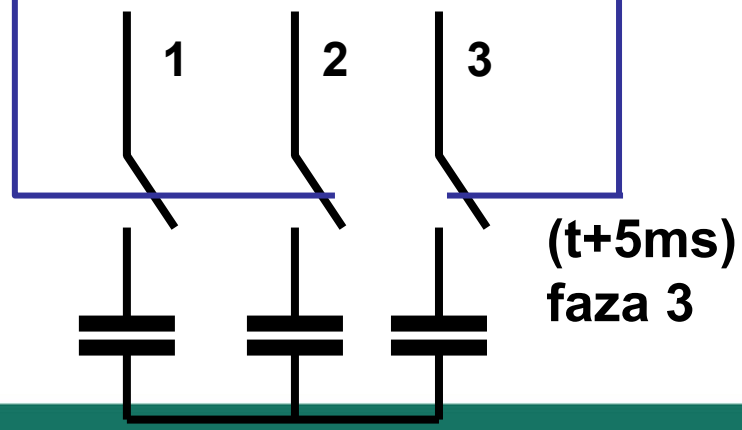




U1 U2 U3



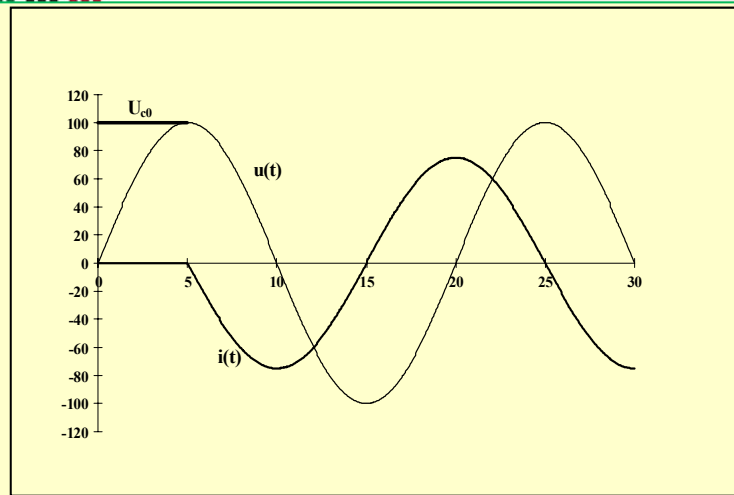
(t) faza
1 + 2



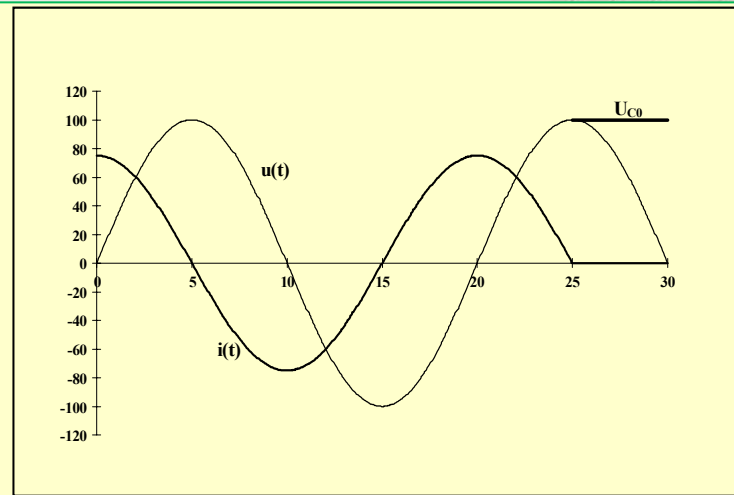
Nie uziemiona
gwiazda



Łączenie synchroniczne



a)



b)

$$u = U_m \sin(\omega t + \varphi_u)$$

$$i(t) = I_m \cos(\omega t + \varphi_u) - nB_C \left(U_{C0} - \frac{n^2}{n^2 - 1} U_m \sin\varphi_u \right) \sin\omega_n t - I_m \cos\varphi_u \cos\omega_n t$$

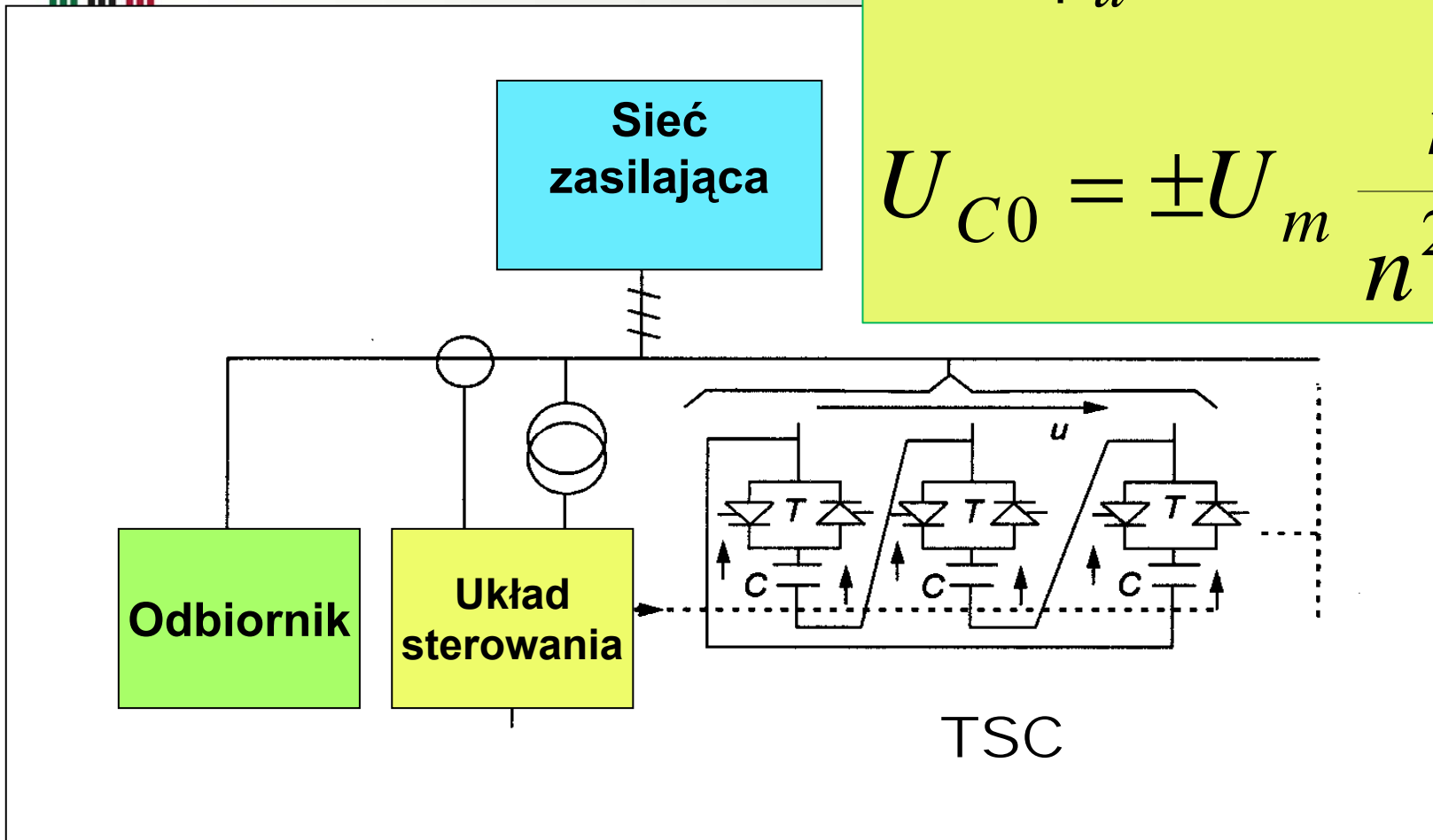
$$n = \sqrt{X_C / X_L}$$

$$\omega_n = 1 / \sqrt{LC} = n\omega$$



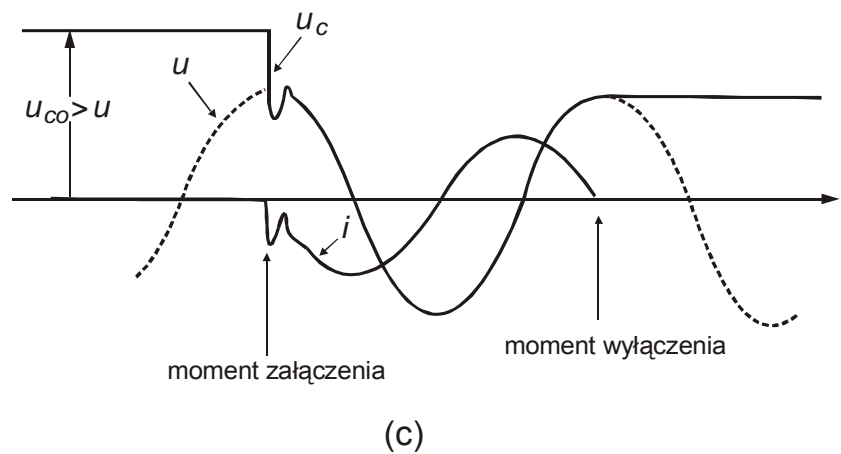
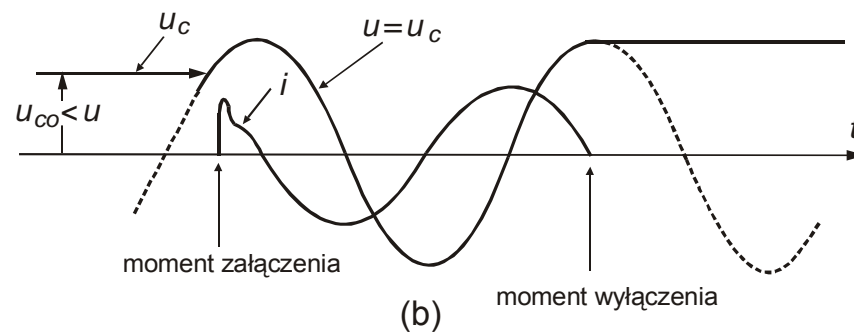
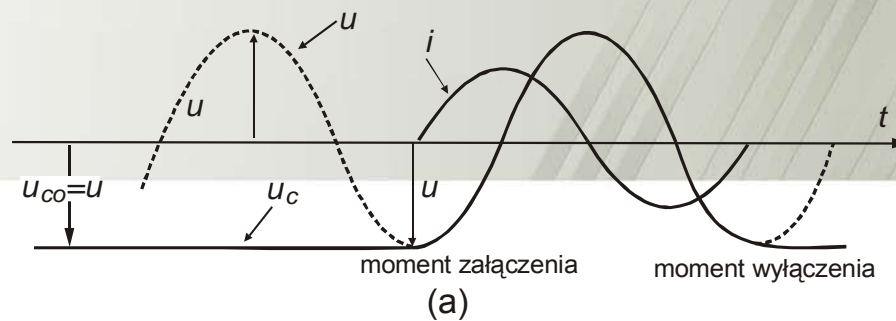
$$\cos \varphi_u = 0$$

$$U_{C0} = \pm U_m \frac{n^2}{n^2 - 1}$$

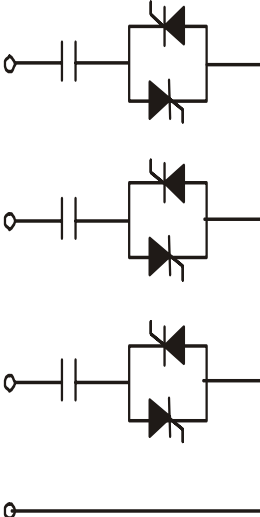
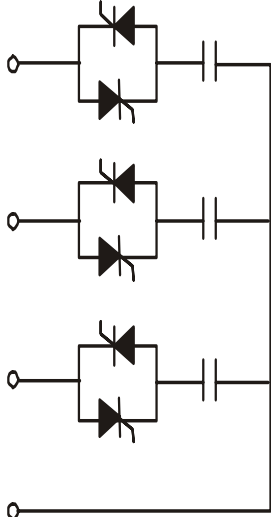
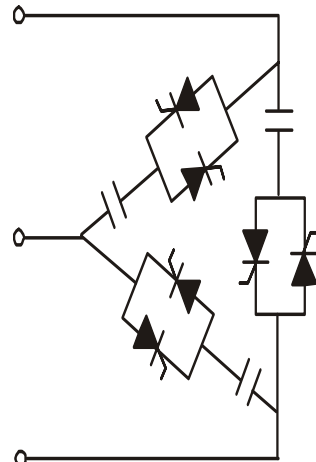


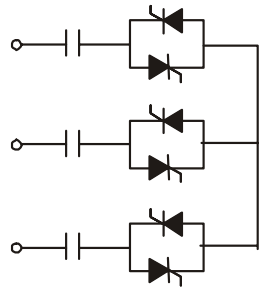
$$i(t) = I_m \cos(\omega t + \varphi_u) - nB_C \left(U_{C0} - \frac{n^2}{n^2 - 1} U_m \sin \varphi_u \right) \sin \omega_n t - I_m \cos \varphi_u \cos \omega_n t$$

Łączenie synchroniczne

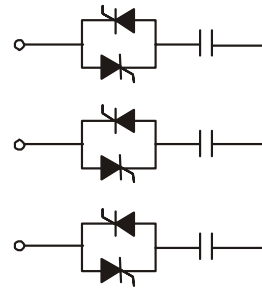


Thyristor switched capacitors (TSC)

 <p>W3NA</p>	 <p>W33AN</p> <p> $I_T = 0,71 I$ $I_C = I$ $U_T = 1,63 U$ $U_C = 0,82 U$ $U_{dc} = \pm 0,82 U$ $\pm 0,82 U$ $\pm 0,82 U$ </p>	<p> $I_T = 0,41 I$ $I_C = 0,58 I$ $U_T = 2,83 U$ $U_C = 1,41 U$ $U_{dc} = \pm 1,41 U$ $\pm 1,41 U$ $\pm 1,41 U$ </p>  <p>W33AA</p>	<p> $T_{on} = \frac{1}{2} T$ $T_{off} = \frac{1}{2} T$ $T_{rec} = T$ </p>
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W33YA



W33AY

$$I_T = 0,71 I$$

$$I_C = I$$

$$U_T = 1,93 U$$

$$U_c = 1,12 U$$

$$U_{dc} = \pm 1,12 U$$

$$\pm 0,82 U$$

$$\pm 0,30 U$$

$$I_T = 0,71 I$$

$$I_C = 0,58 I$$

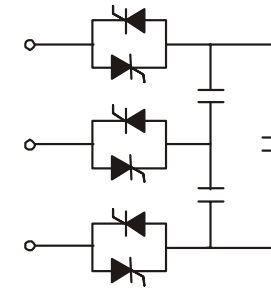
$$U_T = 1,93 U$$

$$U_c = 1,93 U$$

$$U_{dc} = \pm 1,93 U$$

$$\pm 0,52 U$$

$$\pm 1,41 U$$

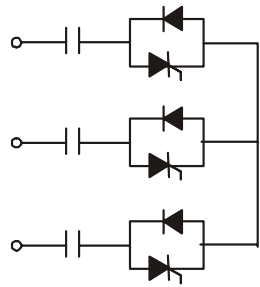


W33AD

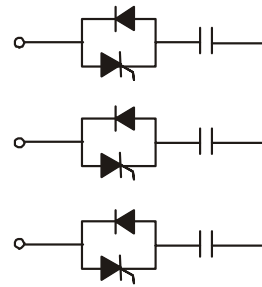
$$T_{on} = \frac{5}{12} T$$

$$T_{off} = \frac{5}{12} T$$

$$T_{rec} = \frac{21}{12} T$$



W33YA



W33AY

$$I_T = 0,71 I$$

$$I_C = I$$

$$U_T = 1,93 U$$

$$U_c = 1,12 U$$

$$U_{dc} = \pm 1,12 U$$

$$\pm 0,82 U$$

$$\pm 0,30 U$$

$$I_T = 0,71 I$$

$$I_C = 0,58 I$$

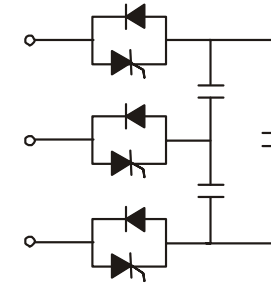
$$U_T = 1,93 U$$

$$U_c = 1,93 U$$

$$U_{dc} = \pm 1,93 U$$

$$\pm 0,52 U$$

$$\pm 1,41 U$$

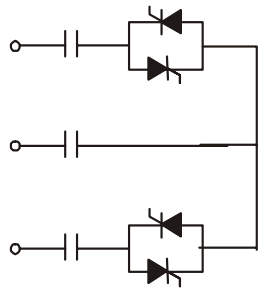


W33AD

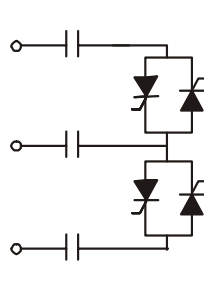
$$T_{on} = \frac{7}{12} T$$

$$T_{off} = \frac{7}{12} T$$

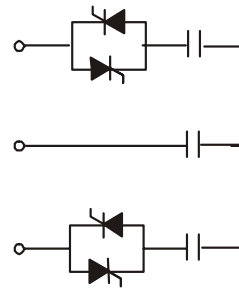
$$T_{rec} = \frac{21}{12} T$$



W33YA



W32DA



W32AY

$$I_T = 0,71 I$$

$$I_C = I$$

$$U_T = 3,35 U$$

$$U_c = 1,12 U$$

$$U_{dc} = \pm 1,12 U$$

$$\pm 0,82 U$$

$$\pm 0,30 U$$

$$I_T = 0,71 I$$

$$I_C = 0,58 I$$

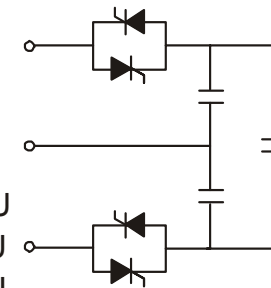
$$U_T = 3,35 U$$

$$U_c = 1,93 U$$

$$U_{dc} = \pm 1,93 U$$

$$\pm 0,52 U$$

$$\pm 1,41 U$$



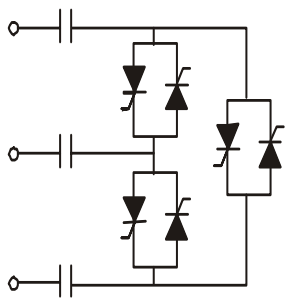
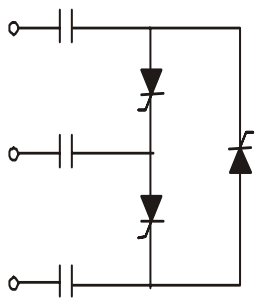
W32AD

$$T_{on} = \frac{7}{12} T$$

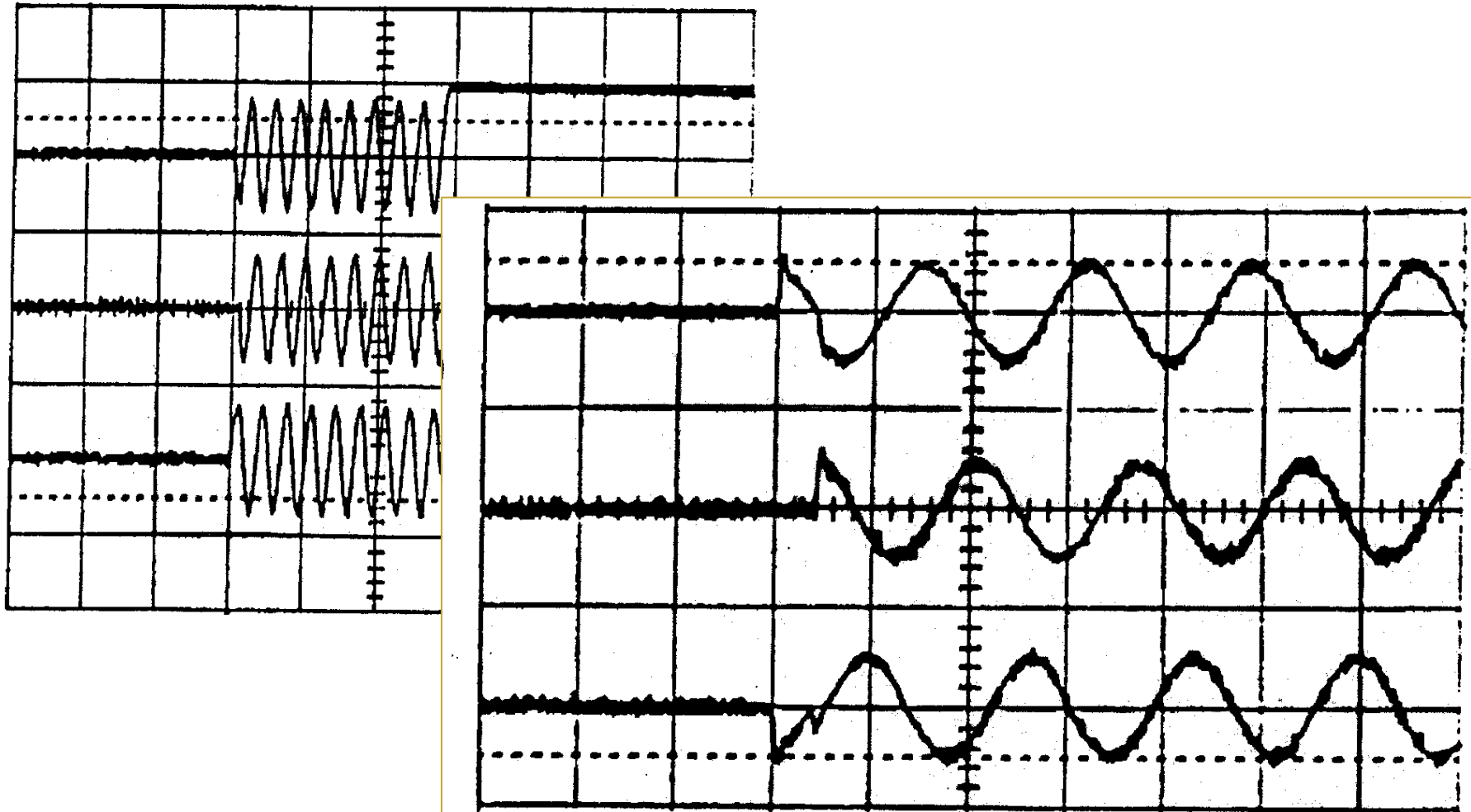
$$T_{off} = \frac{7}{12} T$$

$$T_{rec} = \frac{21}{12} T$$

Thyristor switched capacitors (TSC)

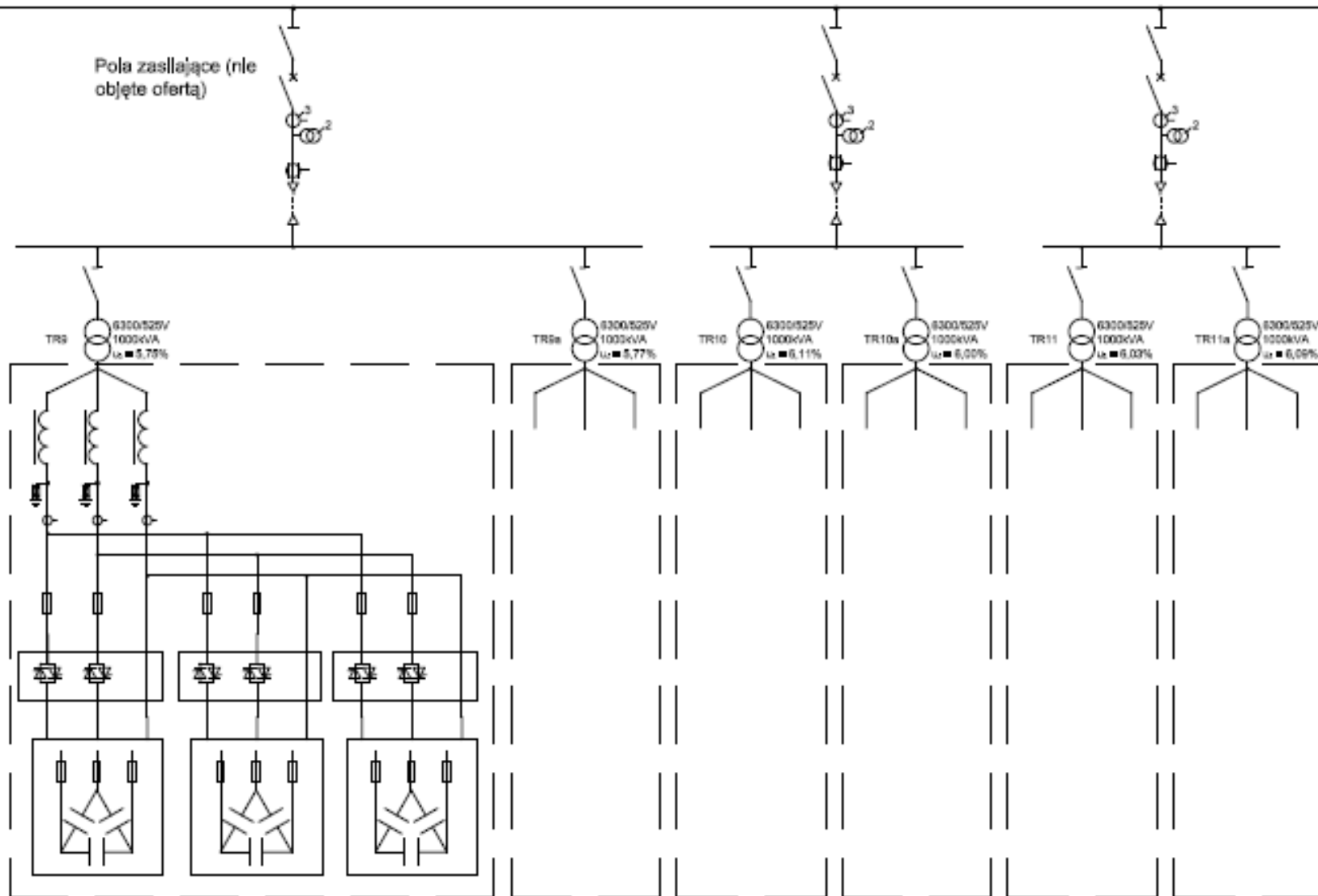
 <p>W33DA</p> <p> $I_T = 0,41 I$ $I_C = I$ $U_T = 3,35 U$ $U_C = 1,12 U$ $U_{dc} = \pm 1,12 U$ $\pm 0,82 U$ $\pm 0,30 U$ </p> <p> $T_{on} = \frac{5}{12} T$ $T_{off} = \frac{1}{2} T$ $T_{rec} = \frac{21}{12} T$ </p>	 <p>U33DA</p> <p> $I_T = 0,82 I$ $I_C = I$ $U_T = 3,35 U$ $U_C = 1,12 U$ $U_{dc} = \pm 1,12 U$ $\pm 0,82 U$ $\pm 0,30 U$ </p> <p> $T_{on} = \frac{7}{12} T$ $T_{off} = \frac{7}{12} T$ $T_{rec} = -$ </p>
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Thyristor switched capacitors (TSC)

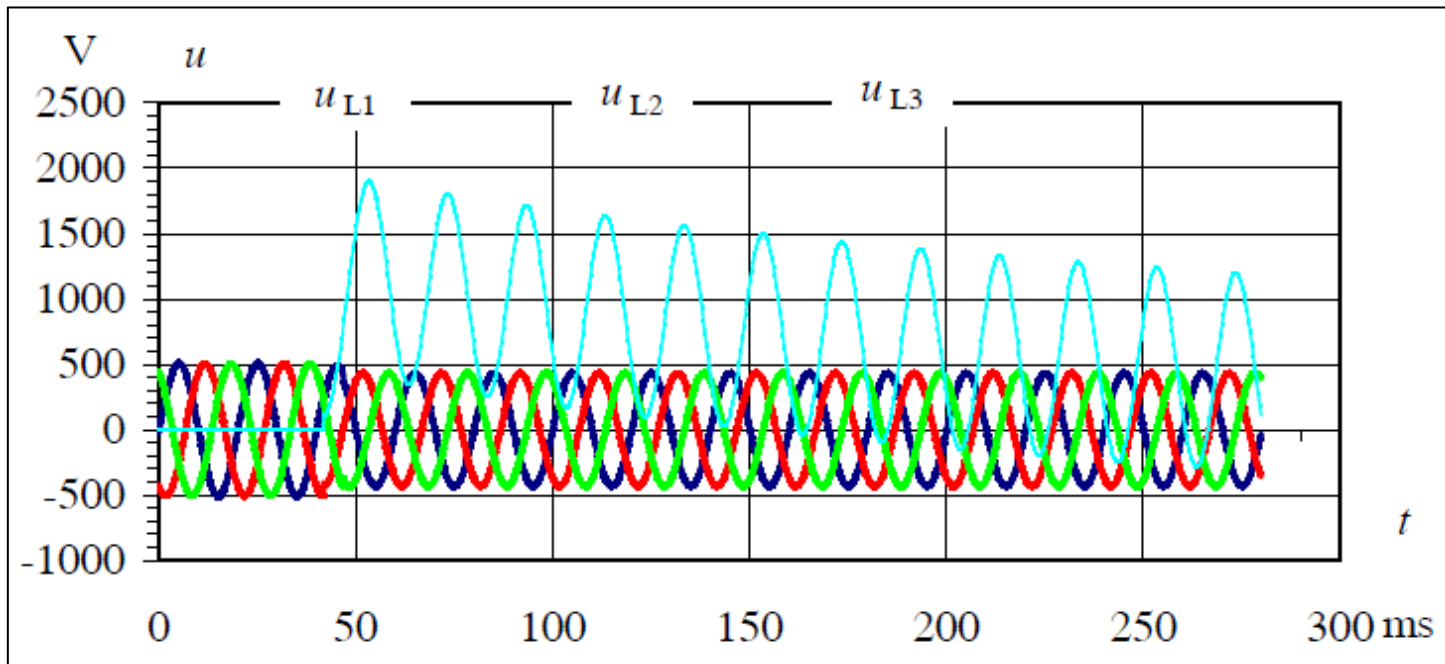
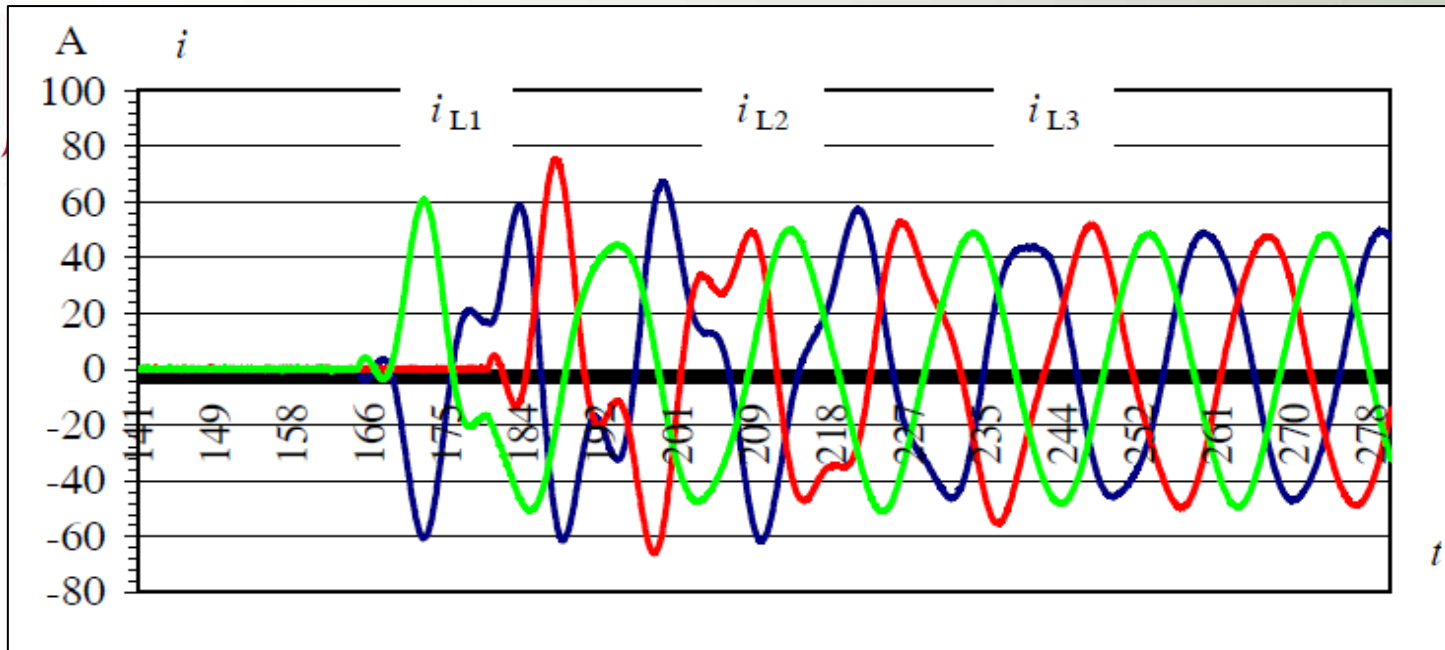


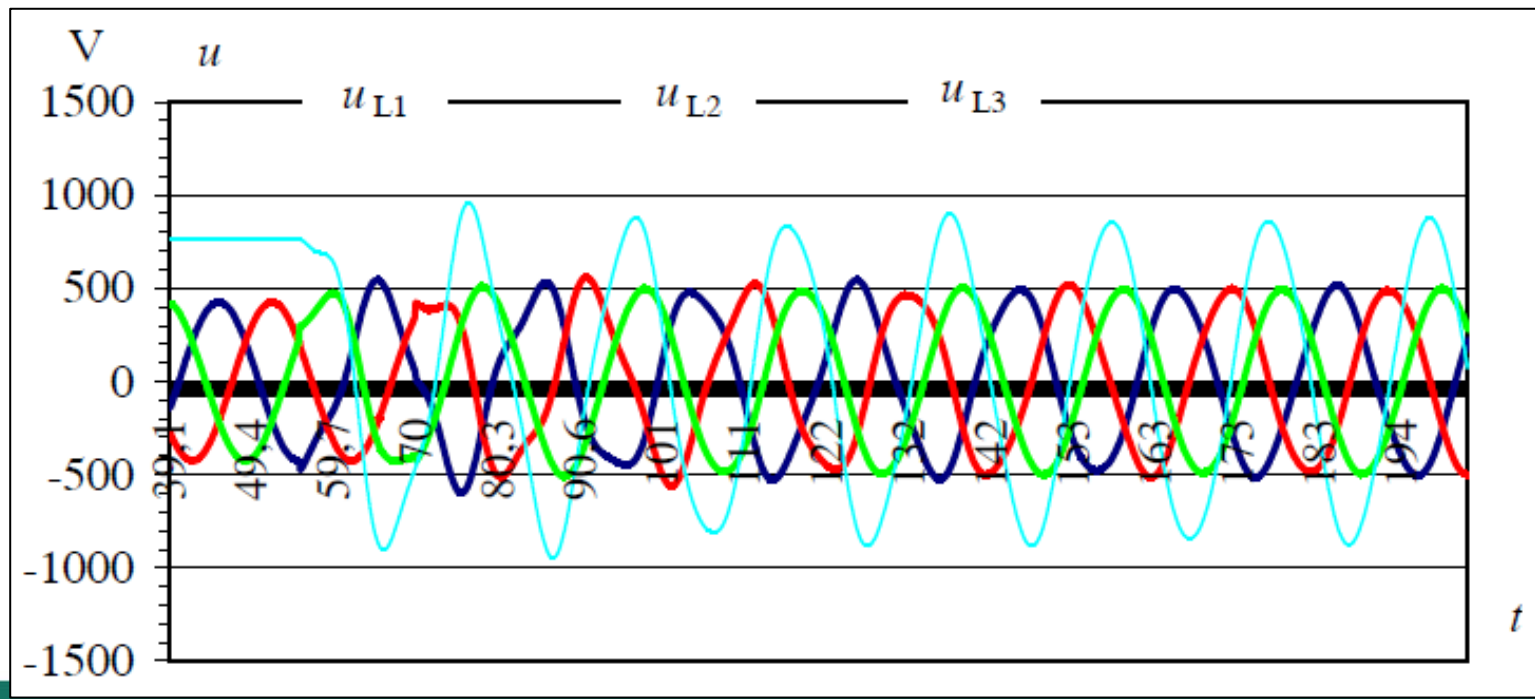
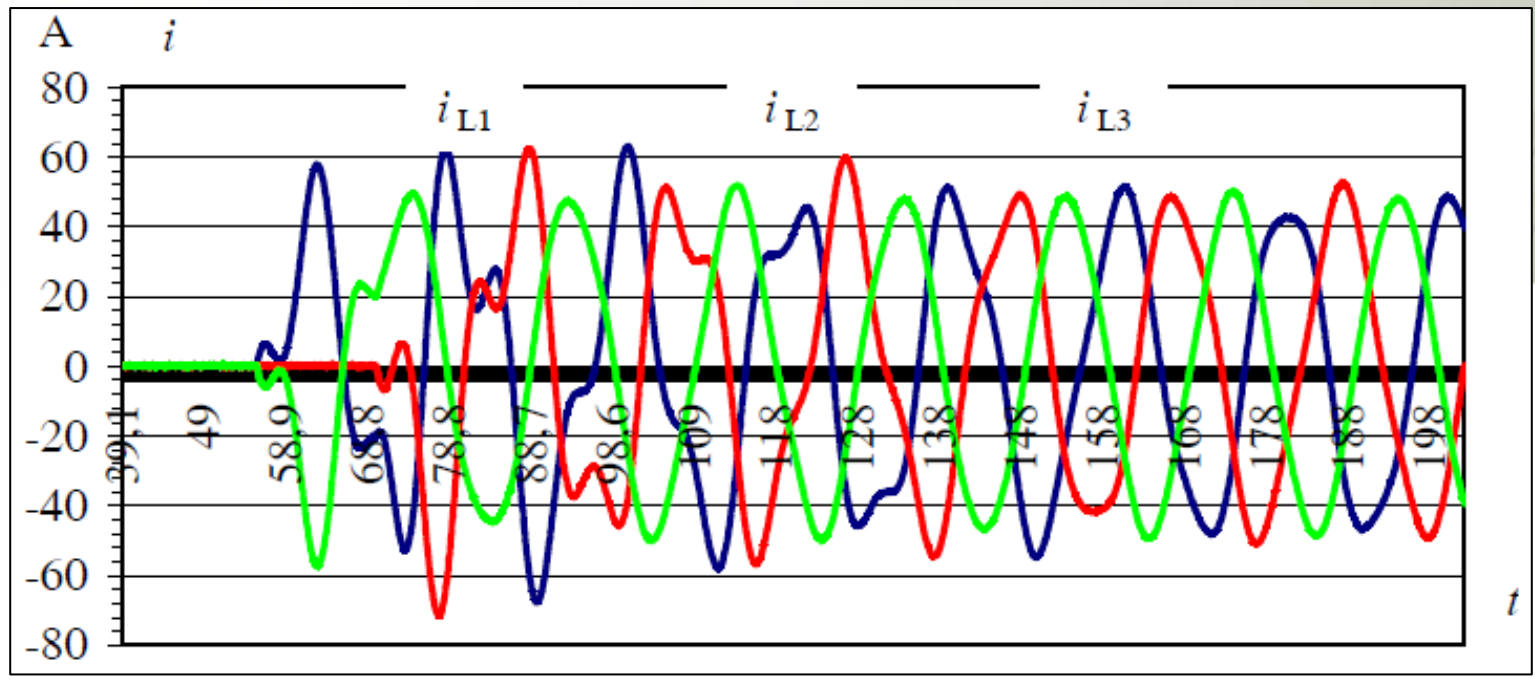
6,3kV
177,5MVA

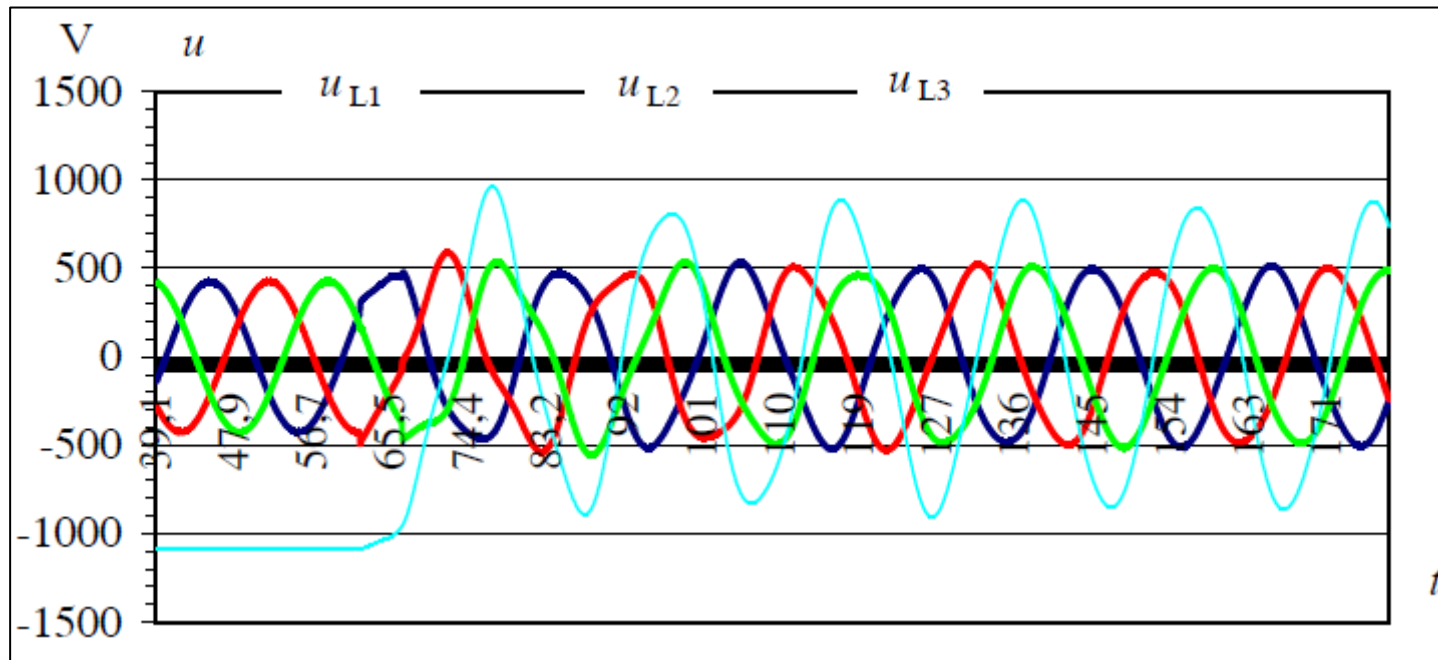
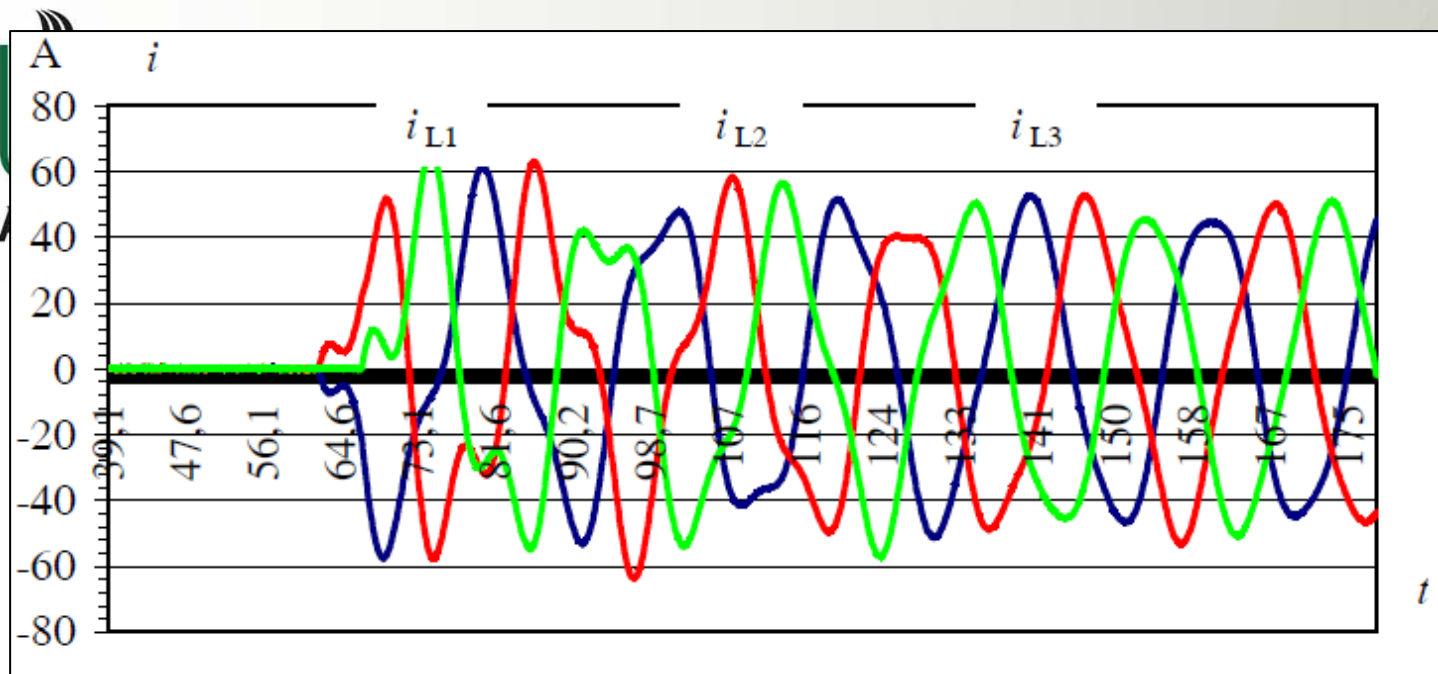
Pola zasilające (nie objęte ofertą)

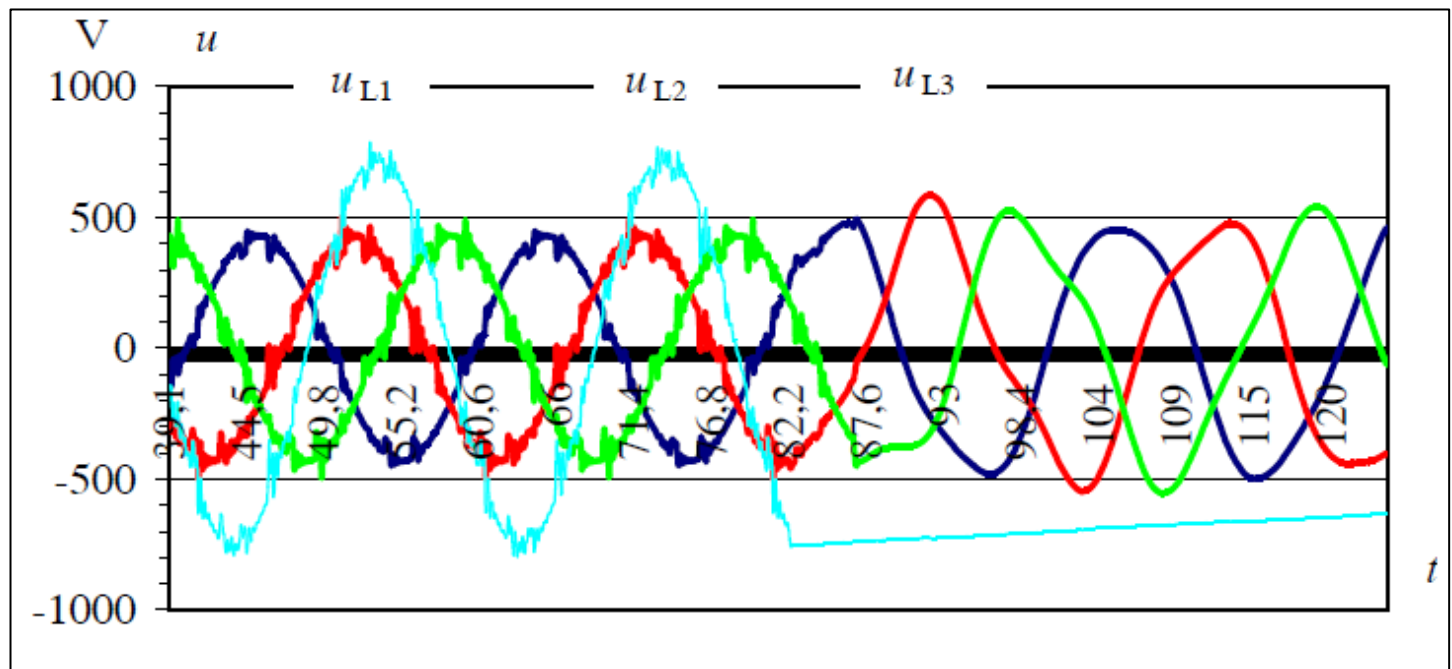
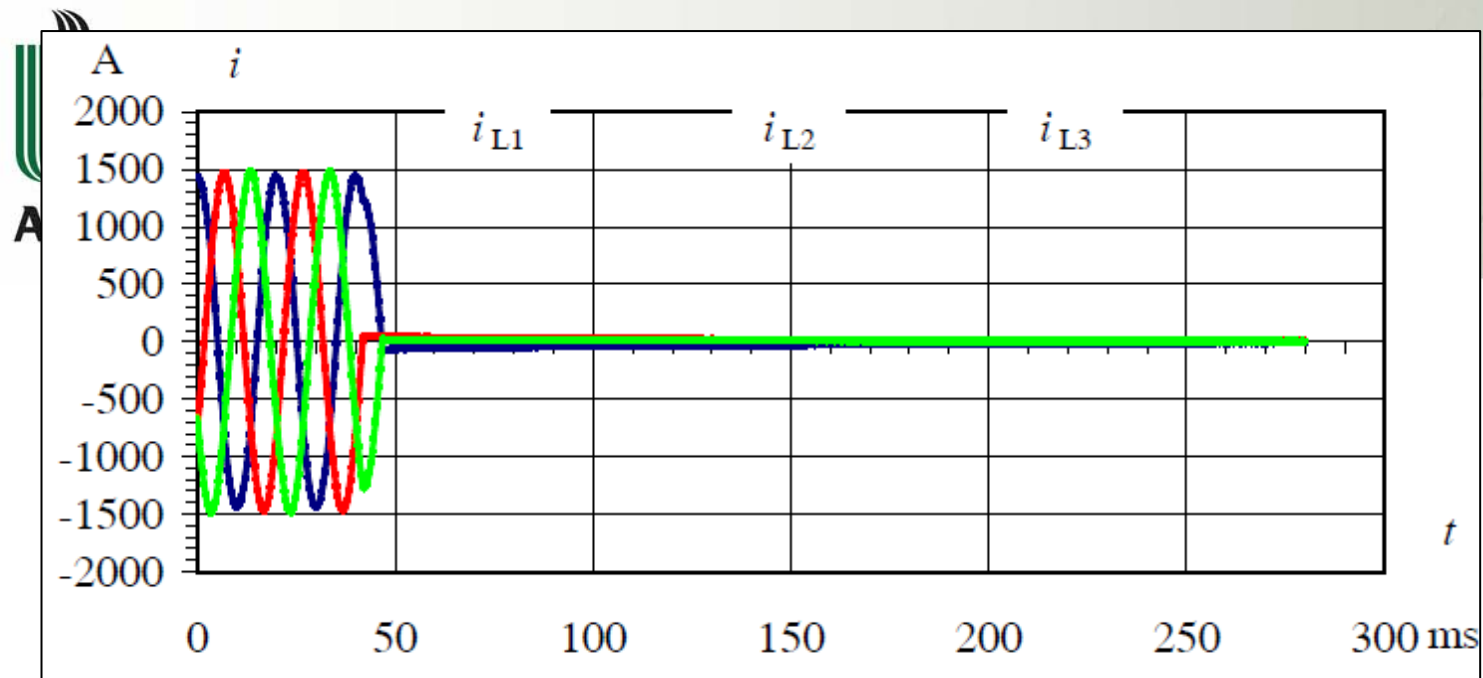


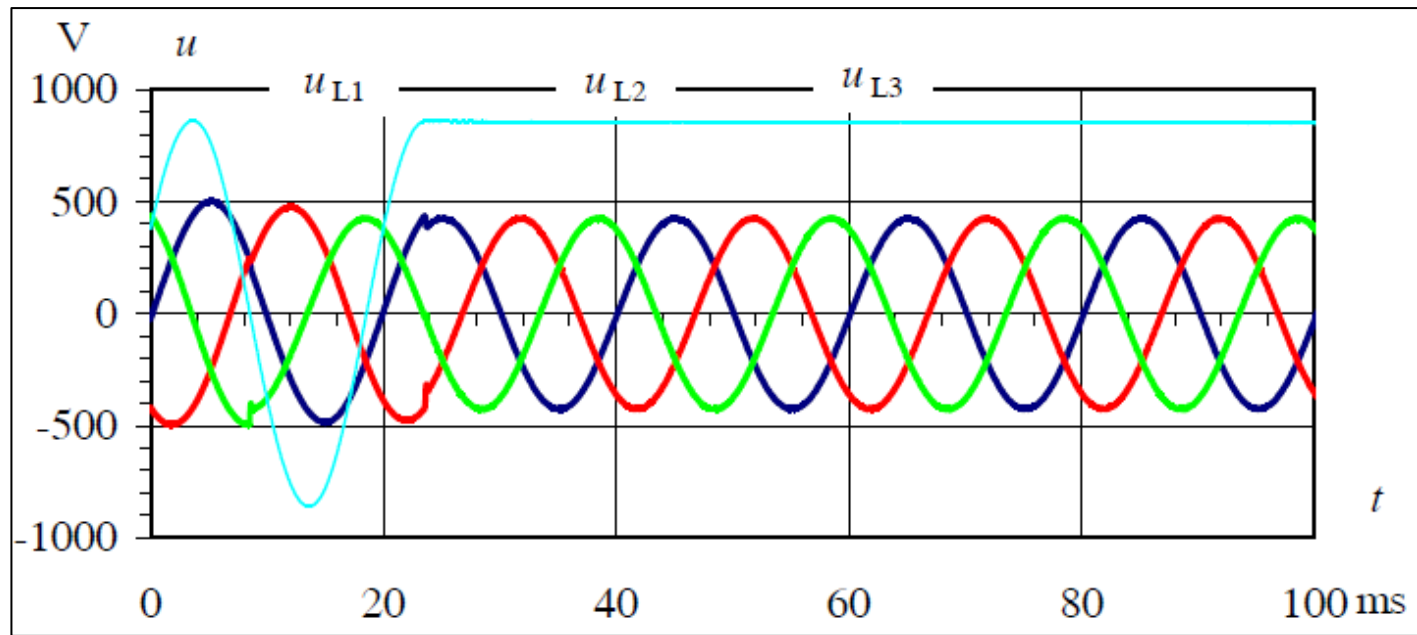
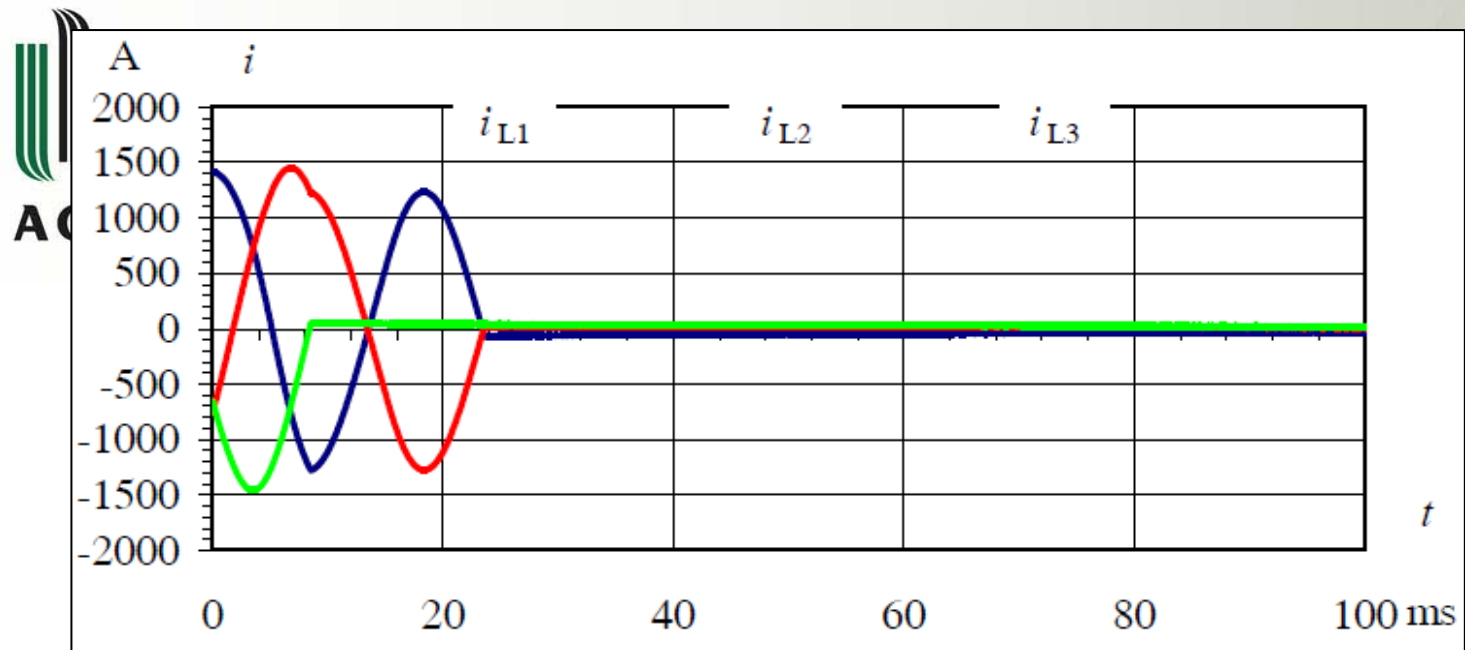
Moc zainstalowana	460kVar 690V	460kVar 690V	460kVar 690V	1380kVar 690V	1380kVar 690V	1380kVar 690V	1380kVar 690V	1380kVar 690V
Moc rzeczywista		925kVar 6300V		925kVar 6300V	925kVar 6300V	925kVar 6300V	925kVar 6300V	925kVar 6300V

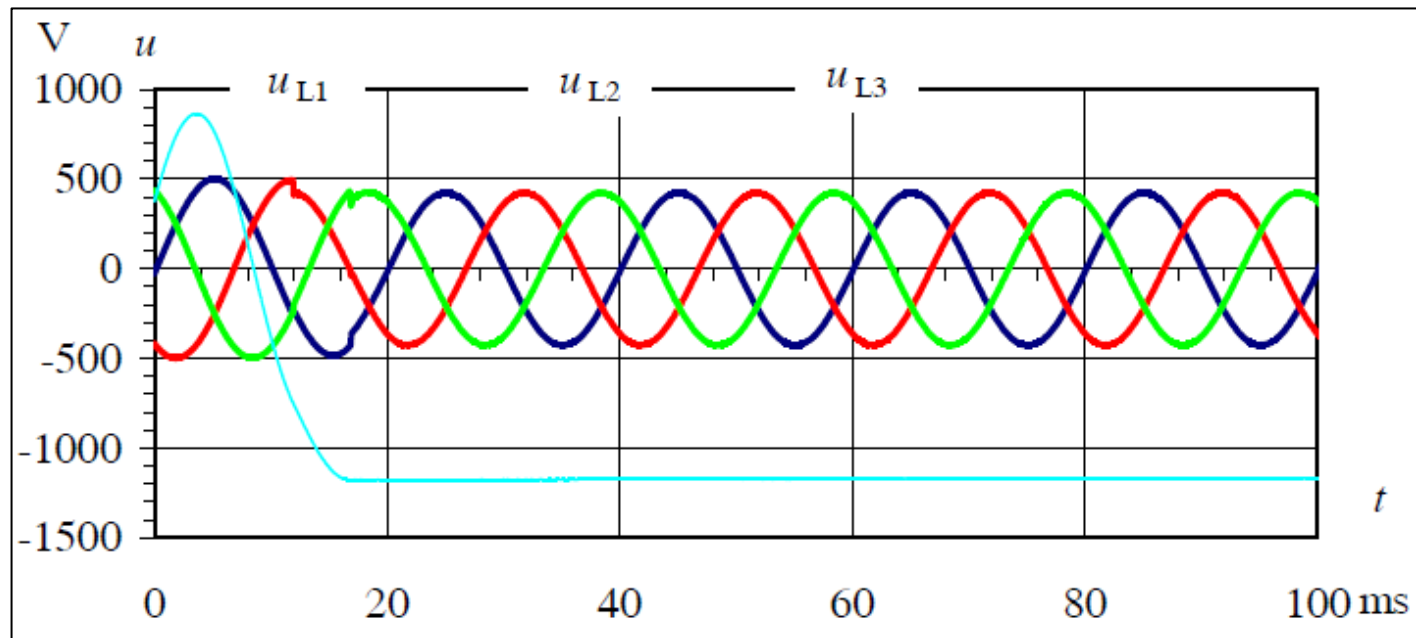
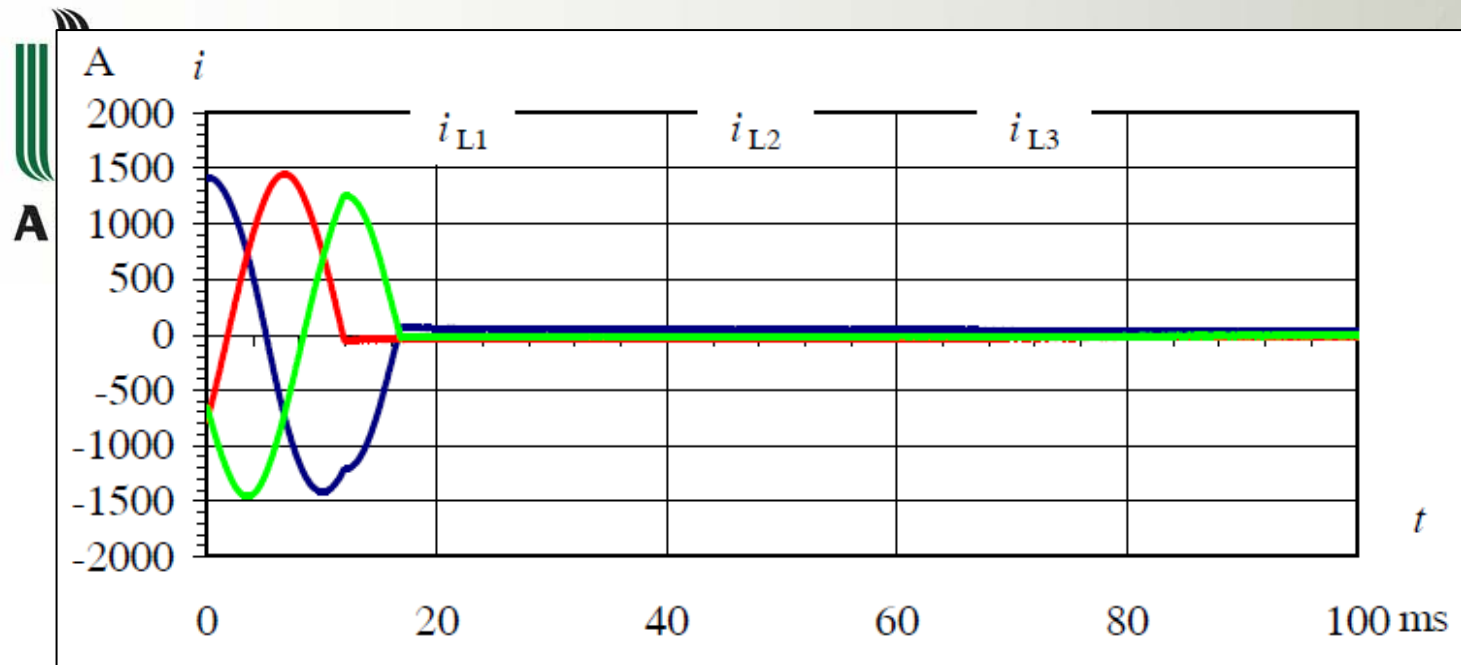


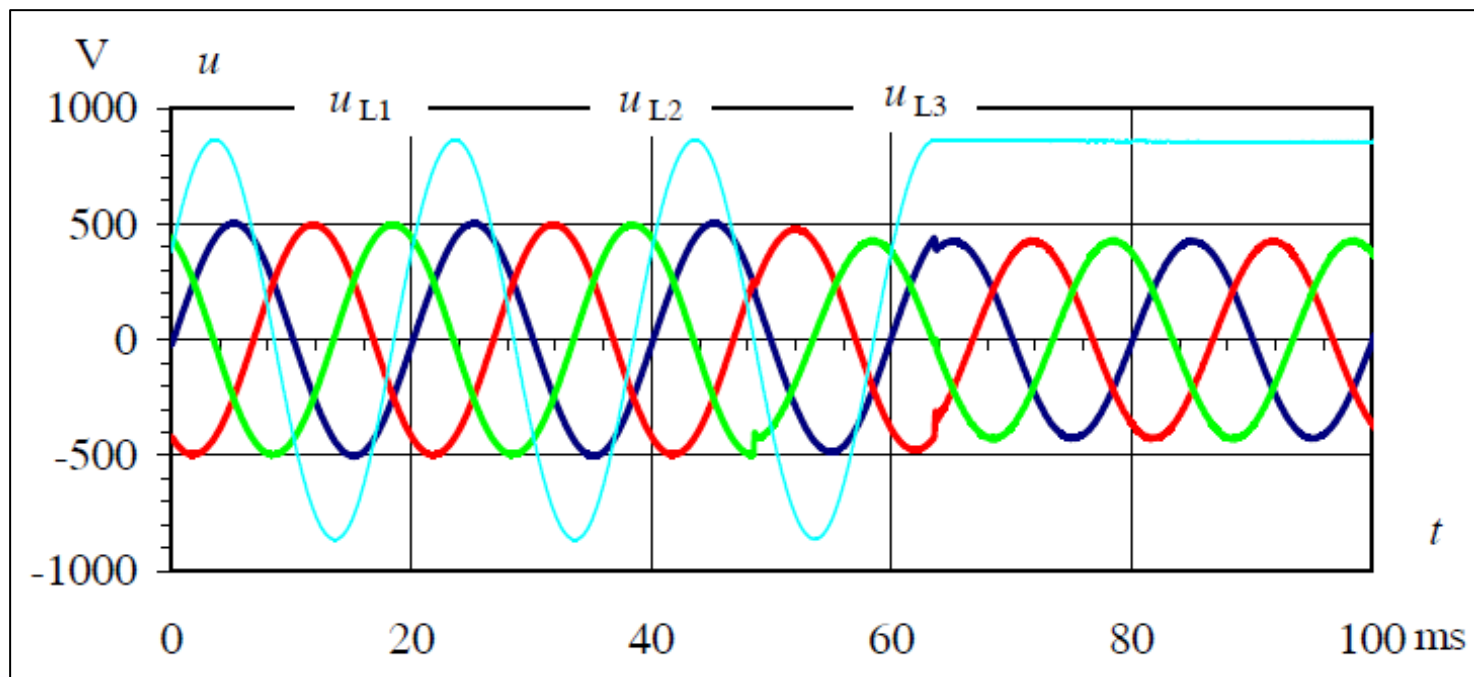
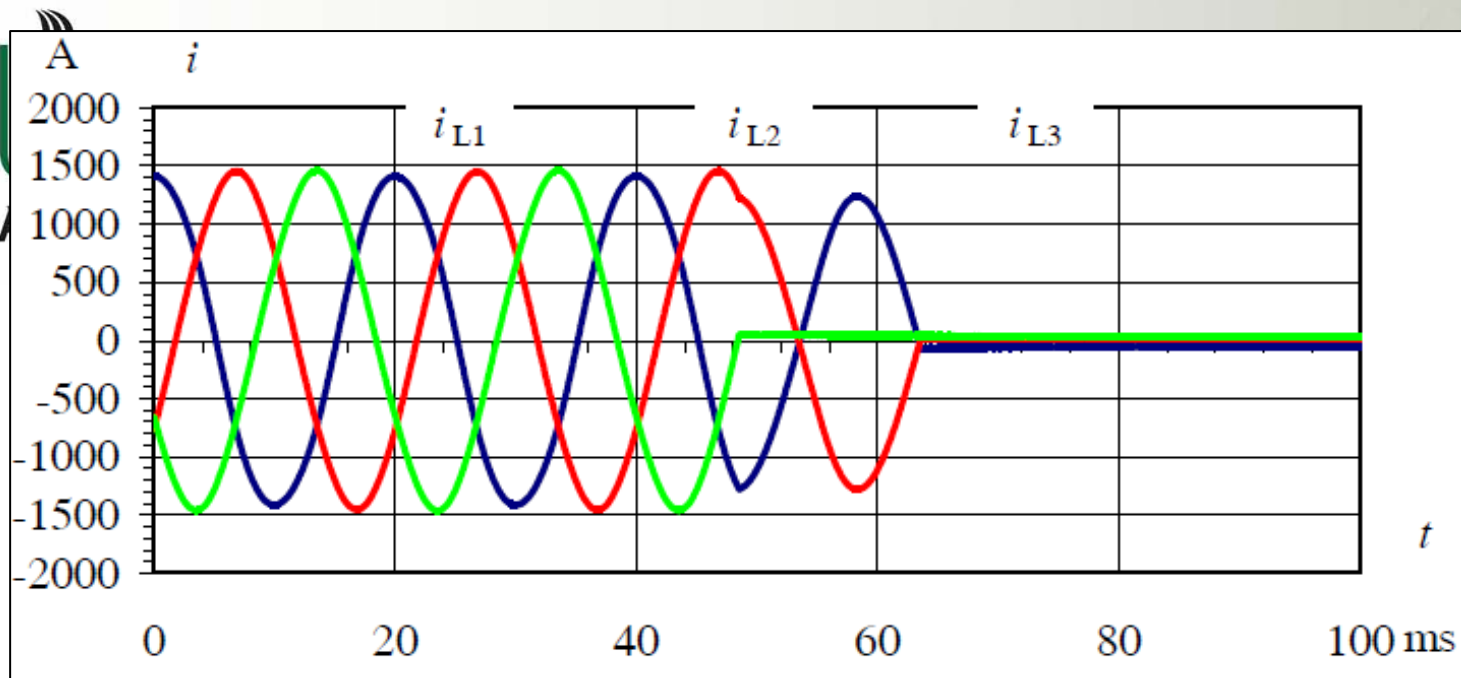














W przypadku instalacji kondensatorów ważne jest, aby:

wykorzystać istniejące możliwości redukcji negatywnych efektów procesu łączenia baterii szczególnie w przypadku odbiorców przemysłowych posiadających dużą liczbę regulowanych napędów lub innego sprzętu energoelektronicznego

energetyka zawodowa posiadała informacje oraz informowała swoich głównych przemysłowych odbiorców odnośnie lokalizacji i procedury łączenia (czasu, sposobu łączenia itp.) dużych baterii kondensatorów

nie zapominać, że instalowanie wejściowych dławików dla urządzeń energoelektronicznych, szczególnie regulowanych napędów, podwyższa ich odporność na przebiegi łączeniowe baterii kondensatorów (również zmniejsza odkształcenie prądu wejściowego)

baterie kondensatorów, szczególnie w sąsiedztwie odbiorników nieliniowych wyposażyć w dławiki odstrajające lub instalować jako filtry harmoniczných



DZIĘKUJE ZA UWAGĘ . . .

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E-mail: hanzel@agh.edu.pl