Seminário de Transmissão de Energia em Linhas de Meia Onda

λ/2 TMO 2013

Campinas, SP - Brasil

FEEC - UNICAMP

26 e 27 de Novembro

Chesf | Eletrobras Eletronorte | ENTE Empresa Norte de Transmissão de Energia S.A. | UFBA | UEFS | UNICAMP

Uso de FACTS para atendimento de pequenas cargas e controle de potência em Linhas de Meia Onda

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COPPE / UFRJ

Linhas de pouco mais que meio comprimento de onda ($\lambda/2^+$) não se configuram como um sistema de transmissão estritamente ponto-a-ponto

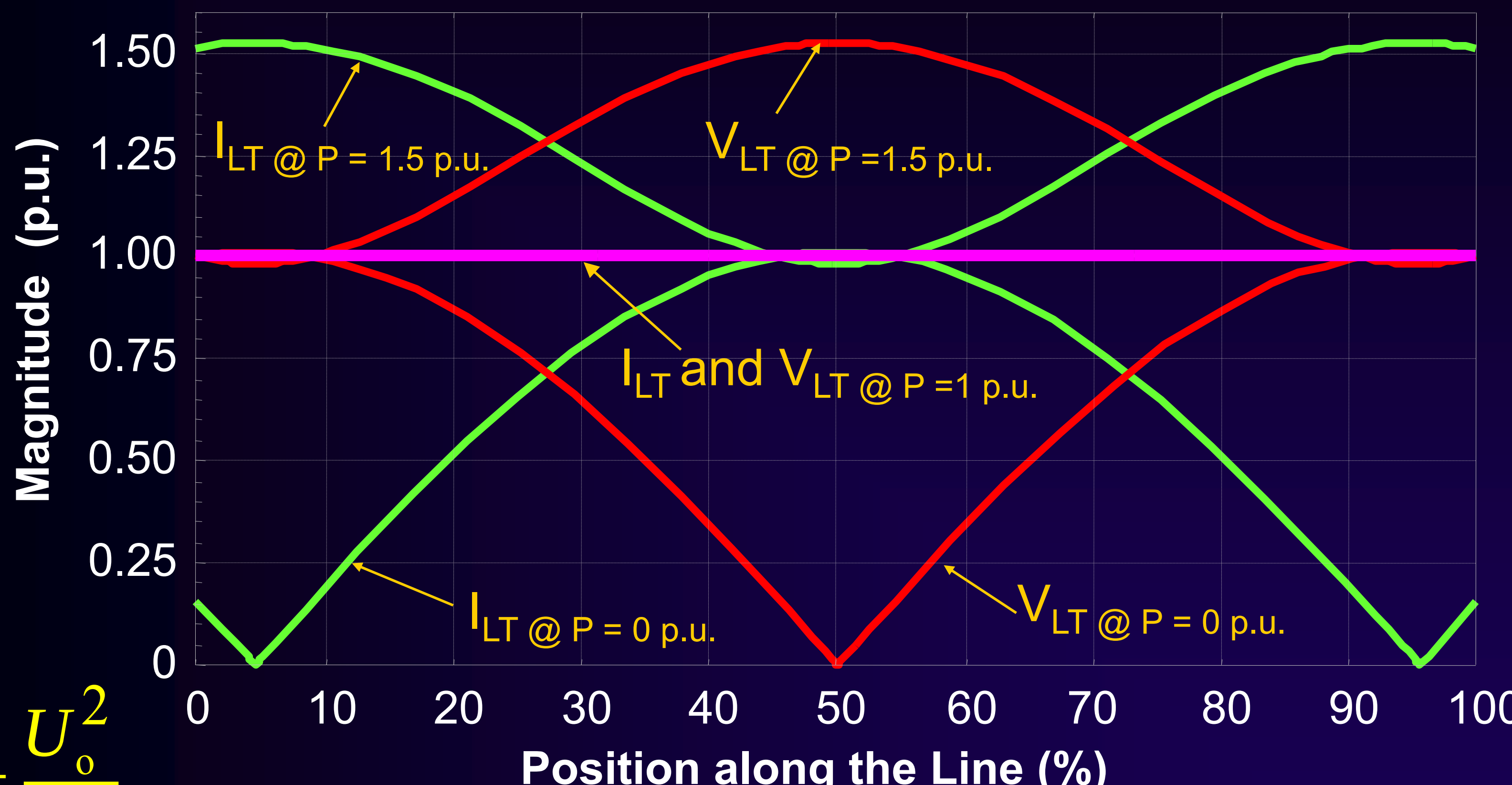
FACTS para controle de fluxo de potência em LT Meia-Onda

Derivação de energia em LT Meia-Onda

LT Meia-Onda ($\lambda/2^+$)

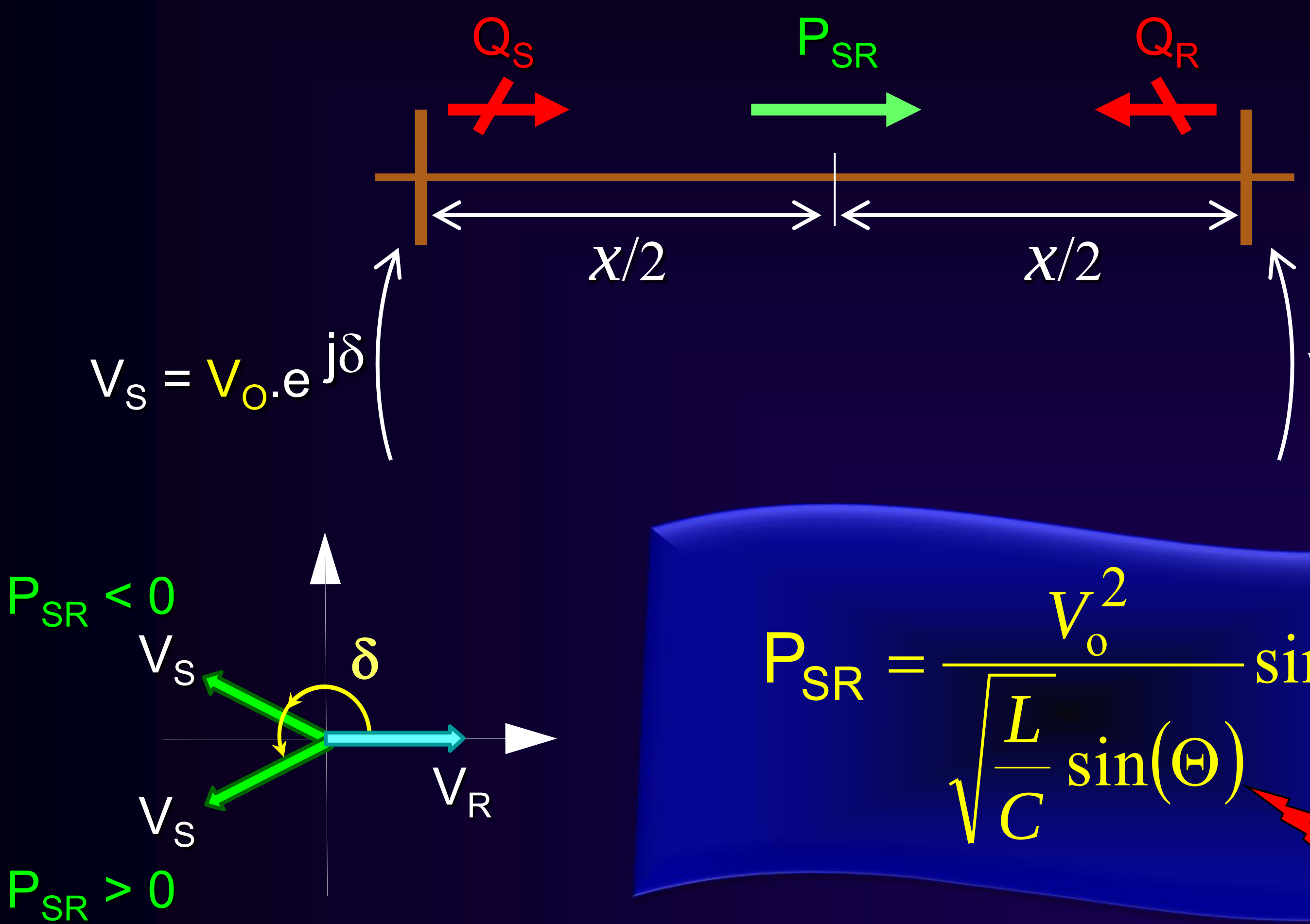
Configuração multiterminal sem descaracterizar LT Meia-Onda

Lines longer than half the wavelength
– voltage and current profile –



$$P_C = \frac{U_o^2}{Z_c}$$

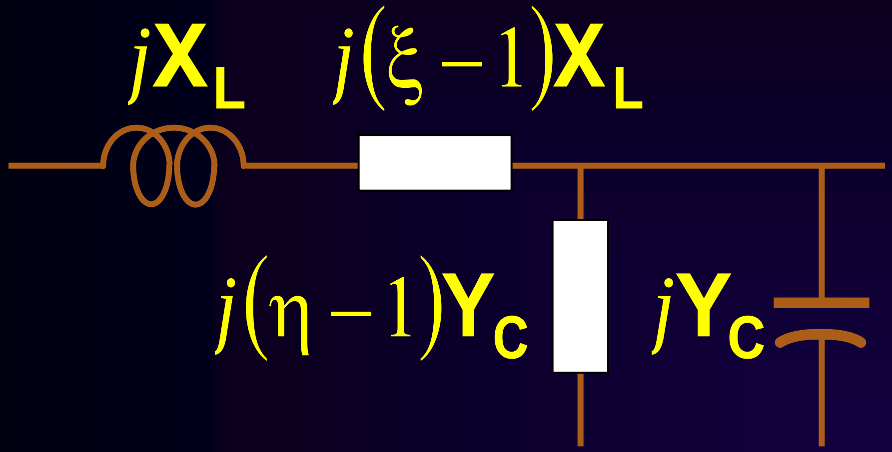
Lines longer than half the wavelength – transmitted active power, P_{SR} –



$$P_{SR} = \frac{V_o^2}{\sqrt{\frac{L}{C}}\sin(\Theta)}\sin(\delta)$$

$$\sin(\Theta) < 0$$

Series and shunt compensation of lines



$$Z'_C = \sqrt{\frac{\xi}{\eta}} \cdot Z_C = \sqrt{\frac{\xi}{\eta}} \cdot \sqrt{\frac{L}{C}}$$

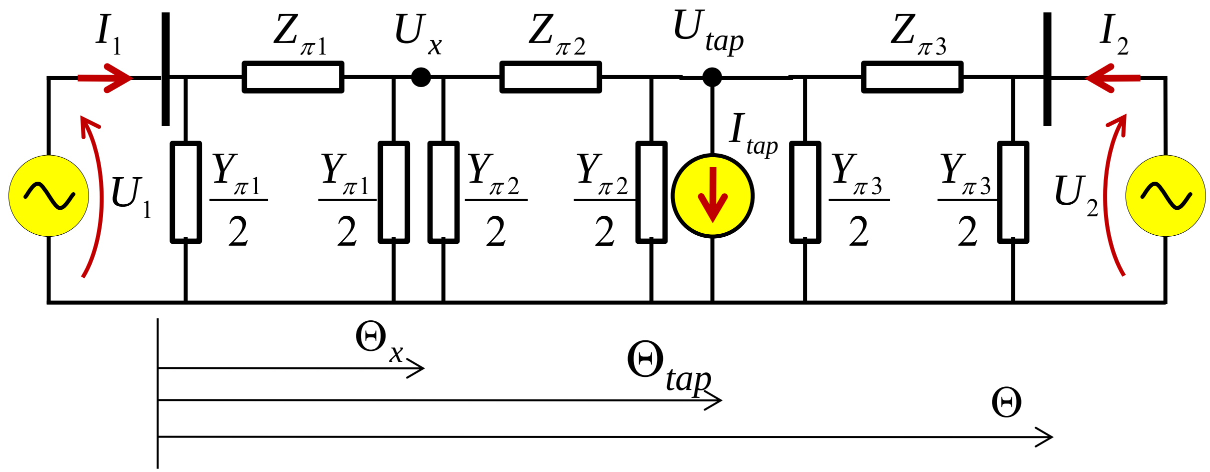
$$\Theta' = \sqrt{\xi\eta} \cdot \Theta = \sqrt{\xi\eta} \cdot \omega\sqrt{LC} \cdot \ell$$

capacitive series compensation: $\xi < 1.0$

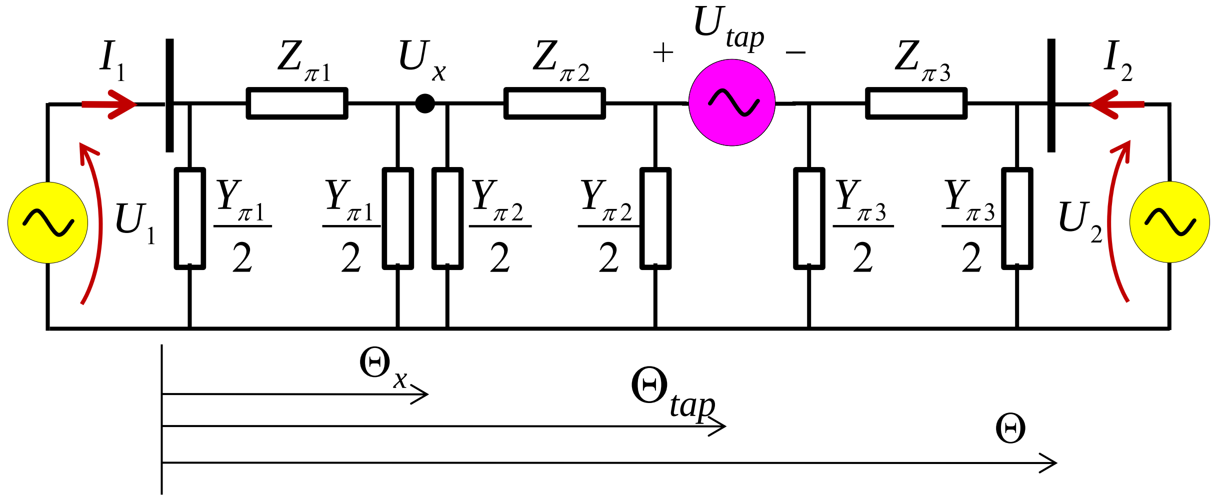
inductive shunt compensation: $\eta < 1.0$

$$P_{SR} = \frac{U_o^2}{\sqrt{\frac{\xi}{\eta}} \cdot Z_c \sin\left(\sqrt{\xi\eta} \cdot \Theta\right)} \sin(\delta)$$

Analytical model of the $\lambda/2^+$ line and the **shunt** FACTS positioned at Θ_{tap}



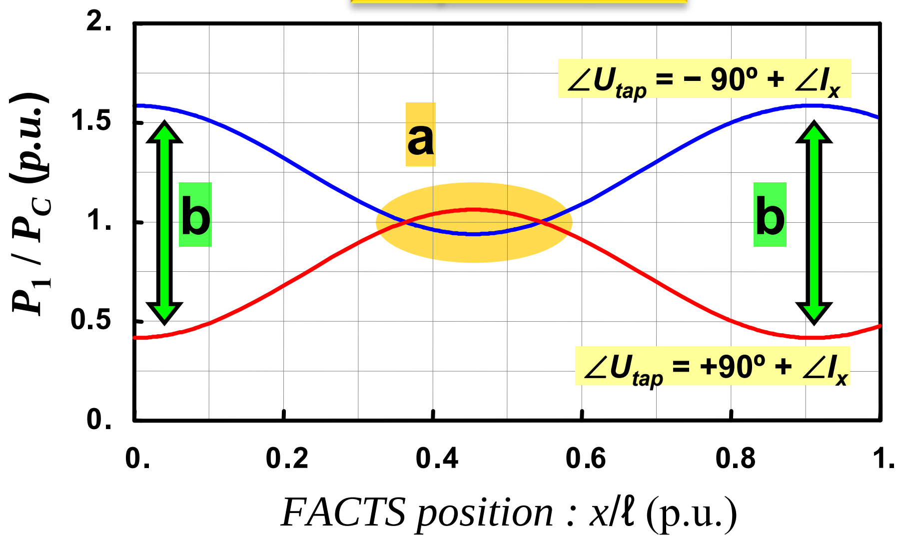
Analytical model of the $\lambda/2^+$ line and the **series** FACTS positioned at Θ_{tap}



Power flow control as a function of the FACTS position

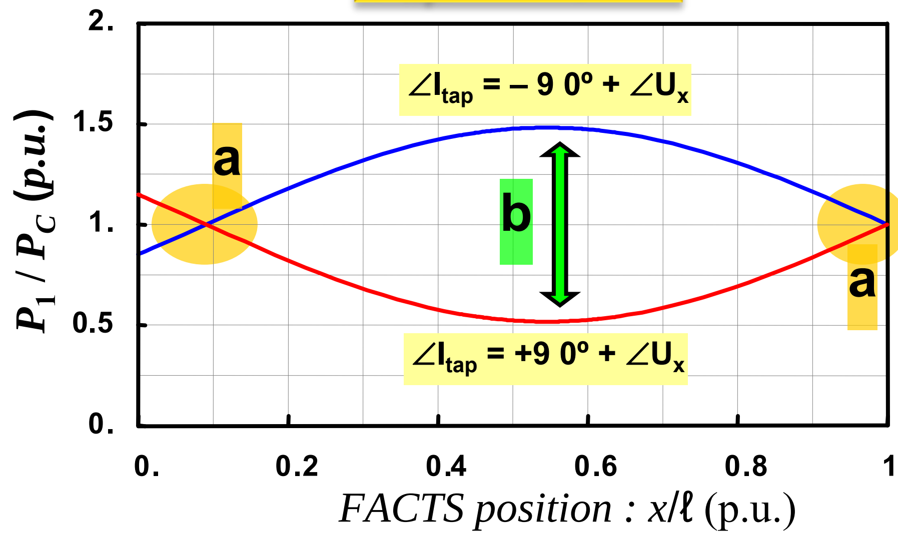
series FACTS

$|U_{tap}| = 0.2\ p.u.$



shunt FACTS

$|I_{tap}| = 0.2\ p.u.$



a section of the λ/2⁺ line: active power can be derived from/to the λ/2⁺ line with negligible influence in the main power flow (Tapping functionality)

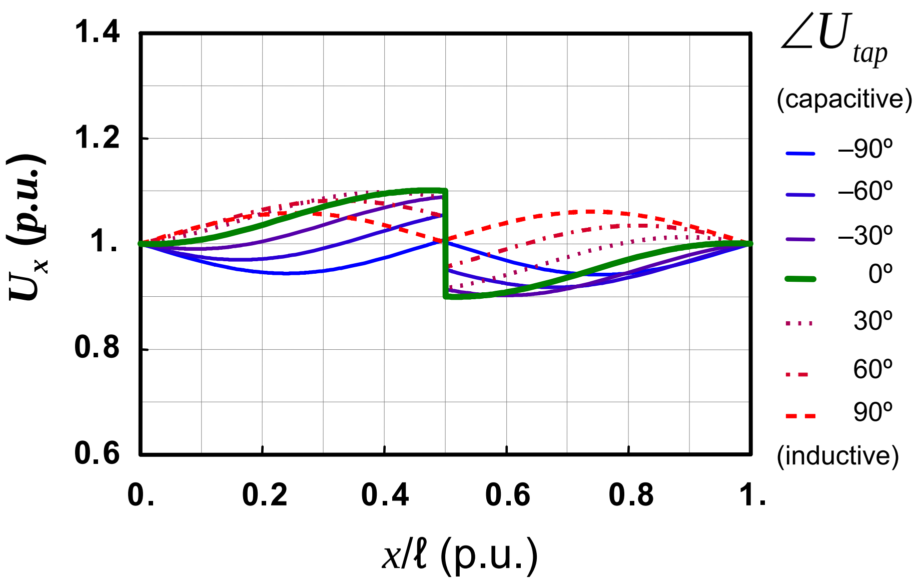
b section of the λ/2⁺ line: reactive power compensation varies significantly the main power flow (Power Flow Controller)

Voltage profile along the λ/2⁺ line as a function of the X/R ratio of the FACTS

- The FACTS is connected in the central section of the line

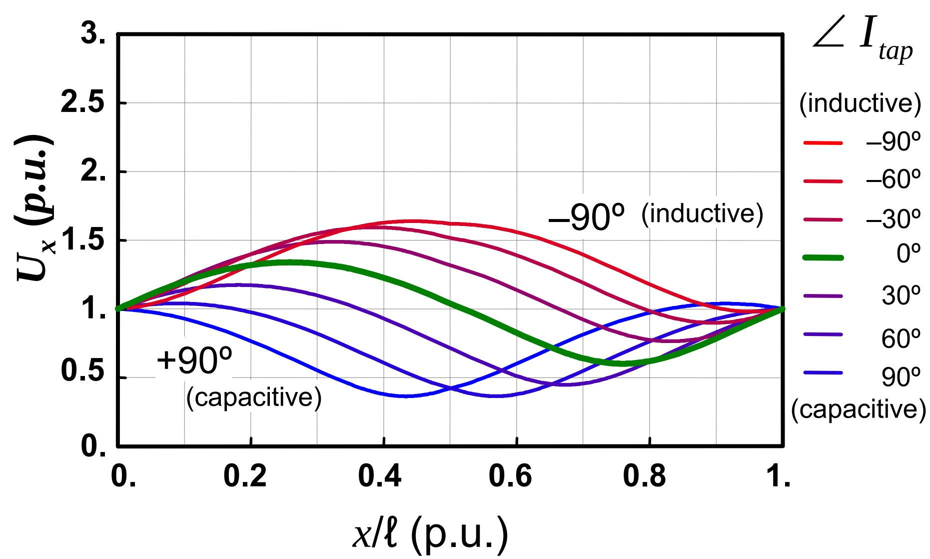
series FACTS

$|U_{tap}| = 0.2$ p.u.



shunt FACTS

$|I_{tap}| = 0.2$ p.u.



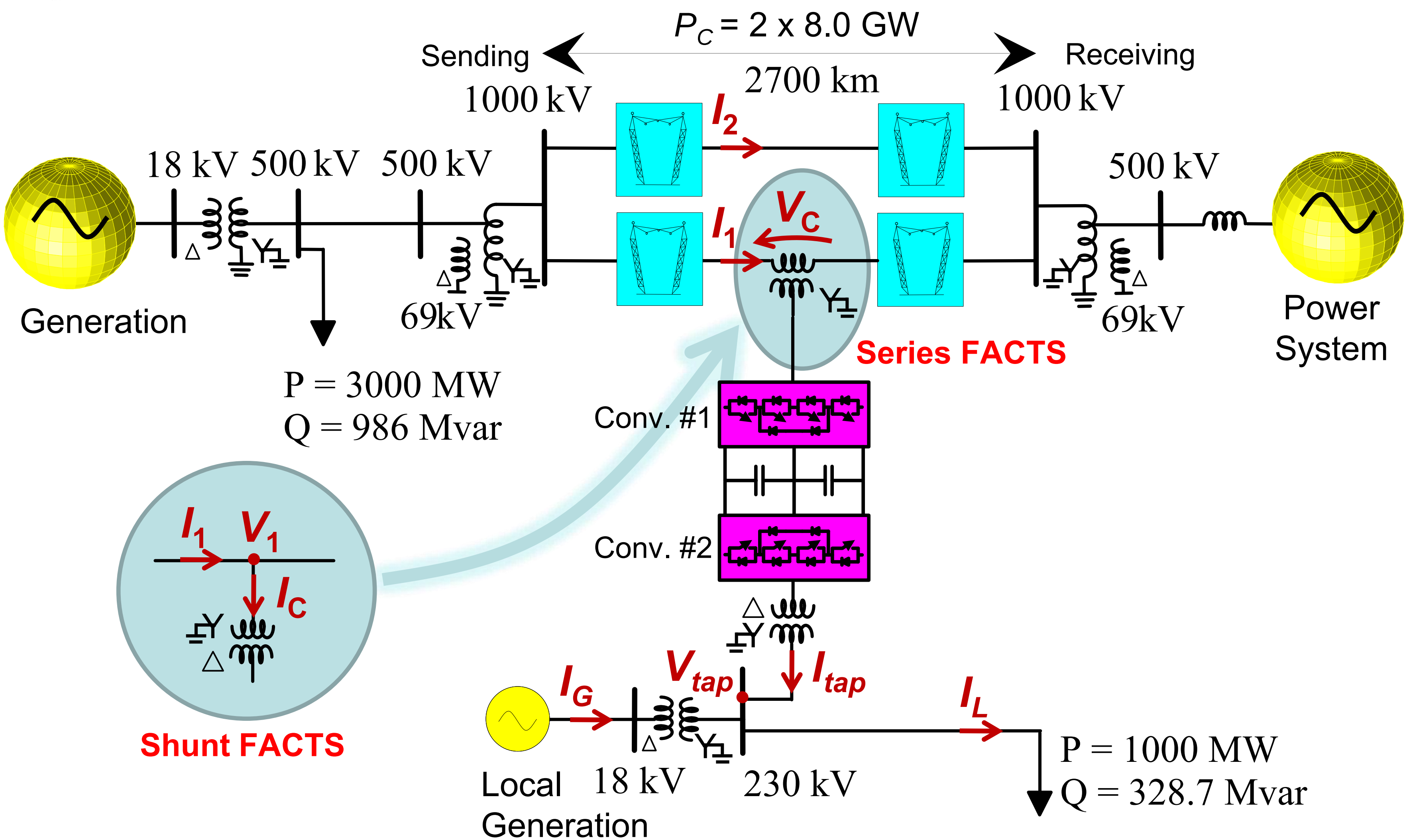
Summing up…

- The voltage profile and the transmitted power of a $\lambda/2^+$ line are very sensitive to a **shunt** FACTS located at the central section of the line.

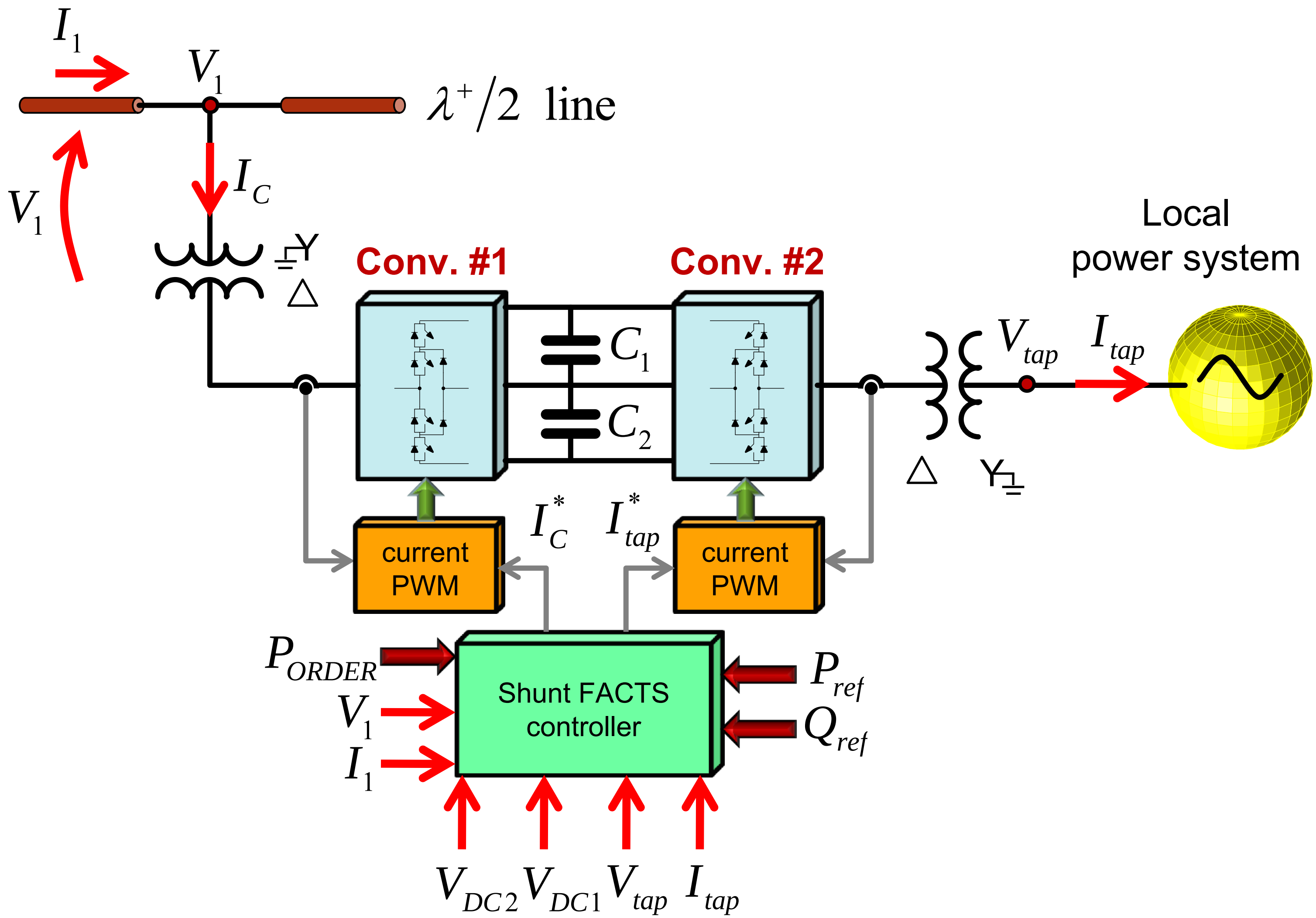
- A **series** FACTS is very effective in controlling the main power flow through the $\lambda/2^+$ line when it is connected at the terminal sections of the line.

- More than one **shunt** FACTS can be connected at a terminal section of the $\lambda/2^+$ line to configure a multiterminal arrangement (fractional active power derivation).

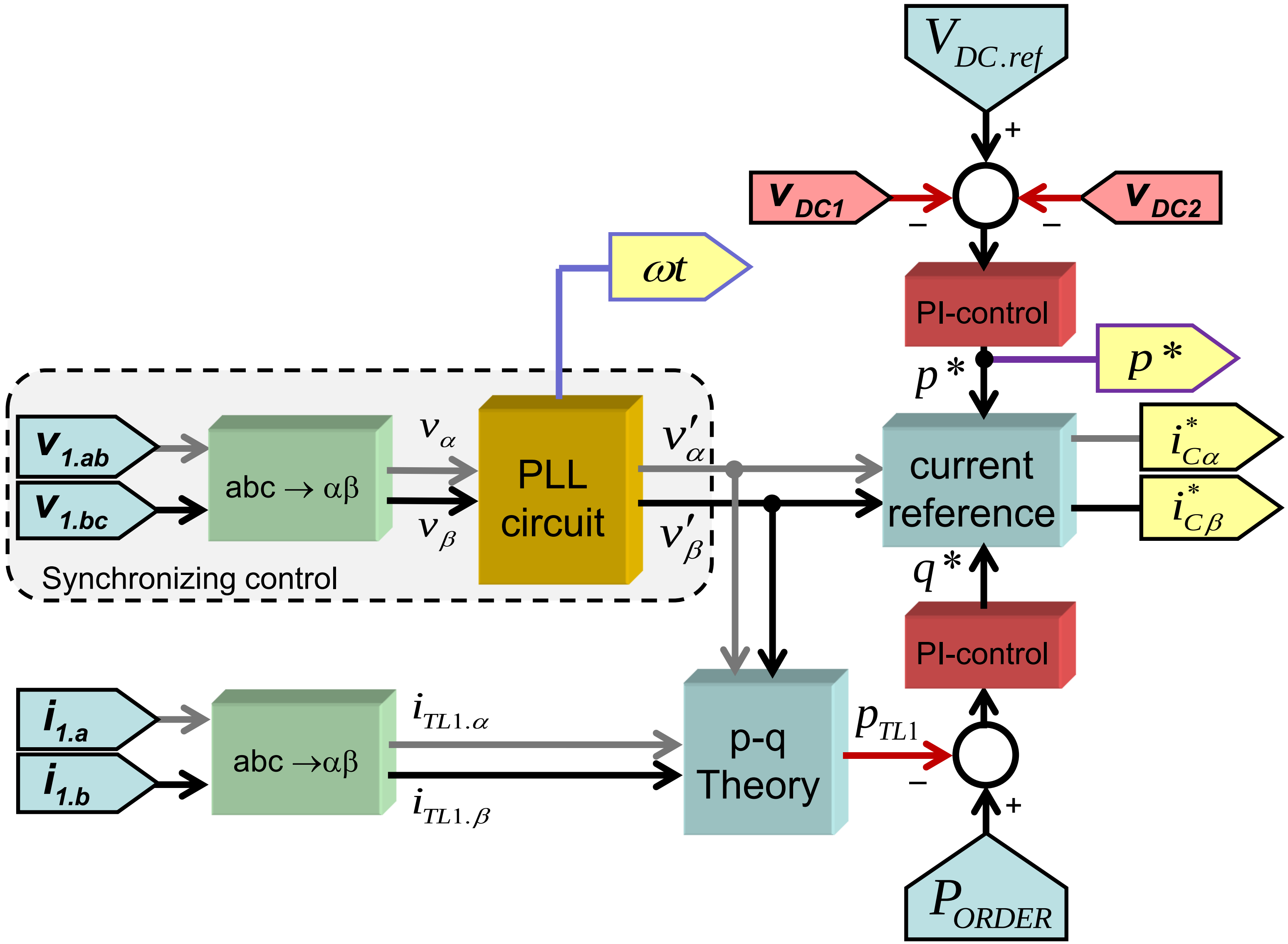
FACTS for Tapping and Power Flow Control in Half-Wavelength Transmission Lines



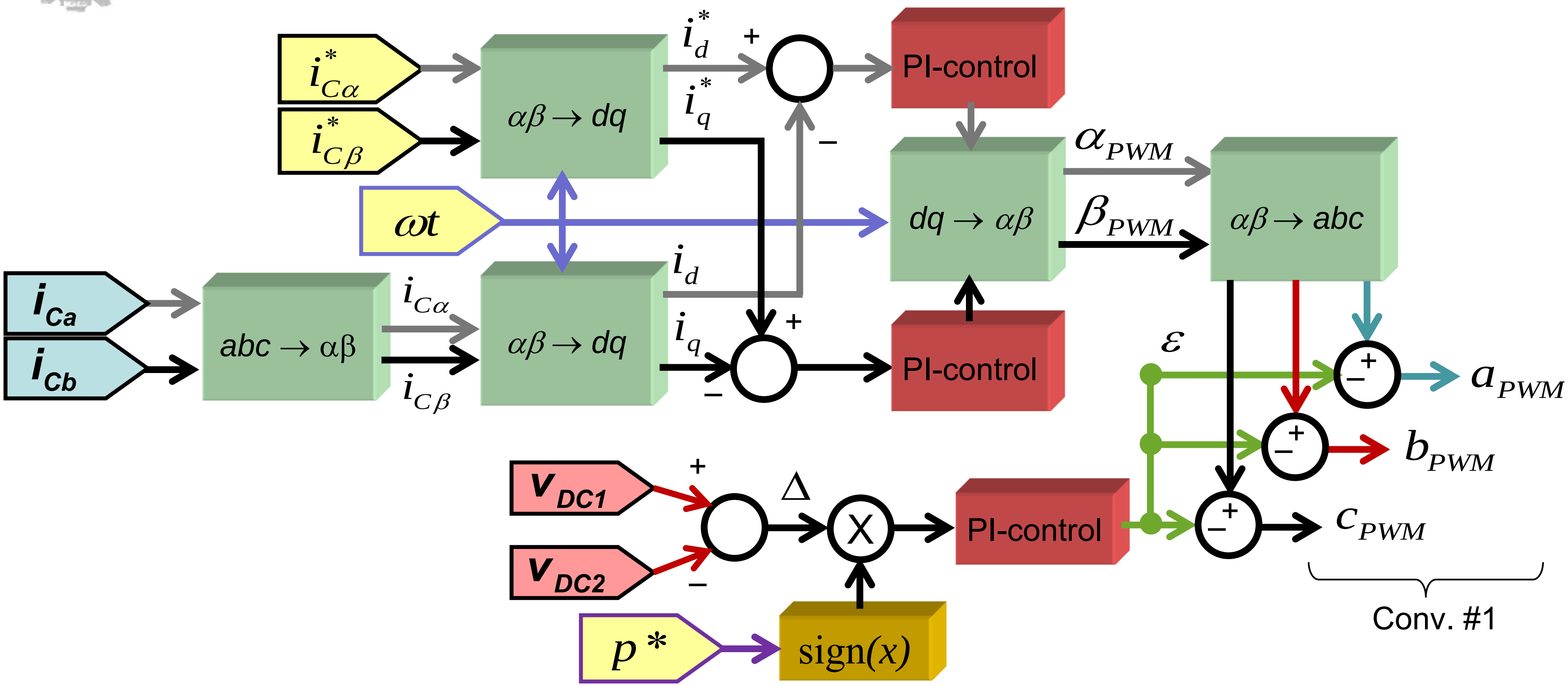
Shunt FACTS for Tapping and Power Flow Control in Half-Wavelength Transmission Lines



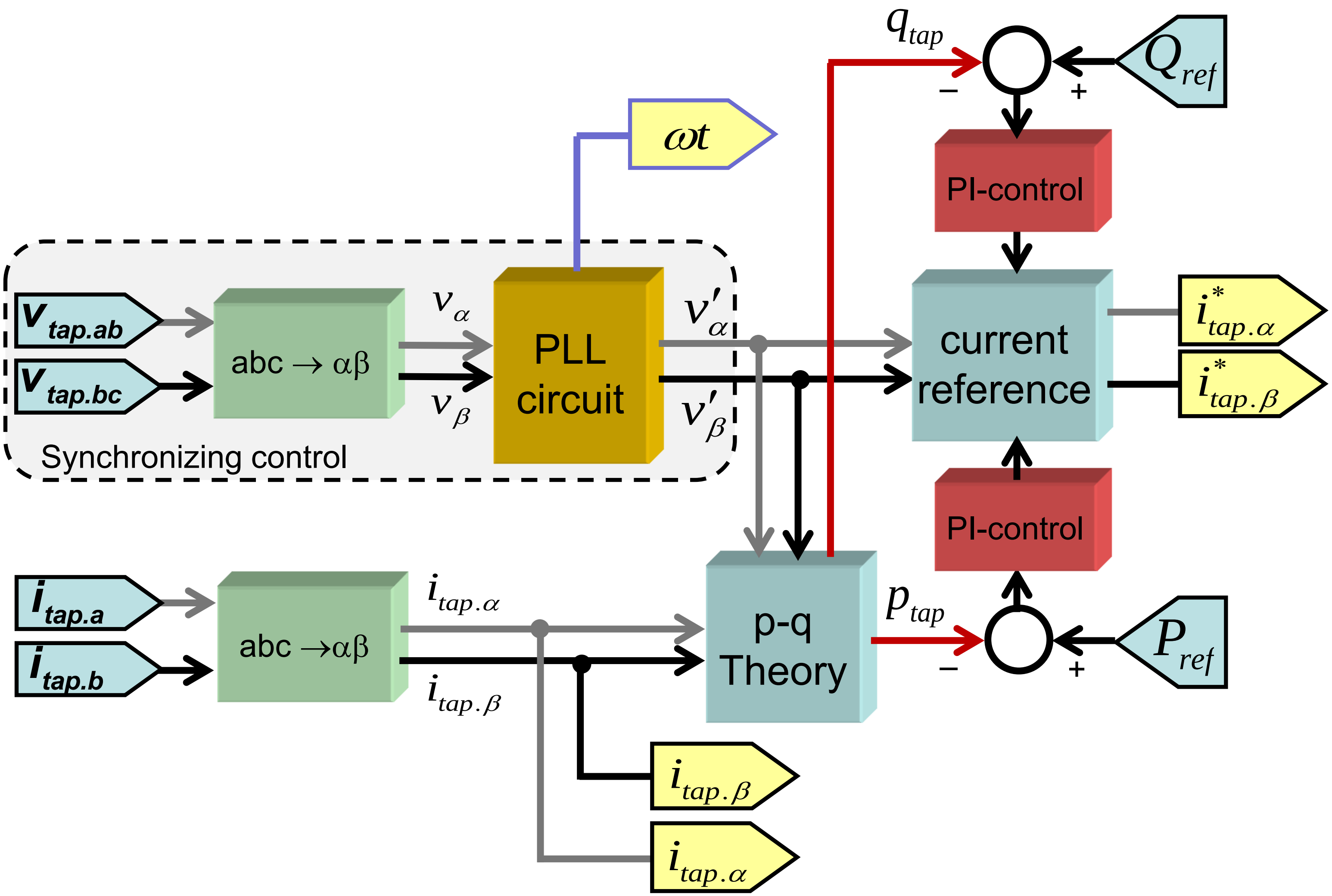
Controller of the Converter #1 of the Shunt FACTS



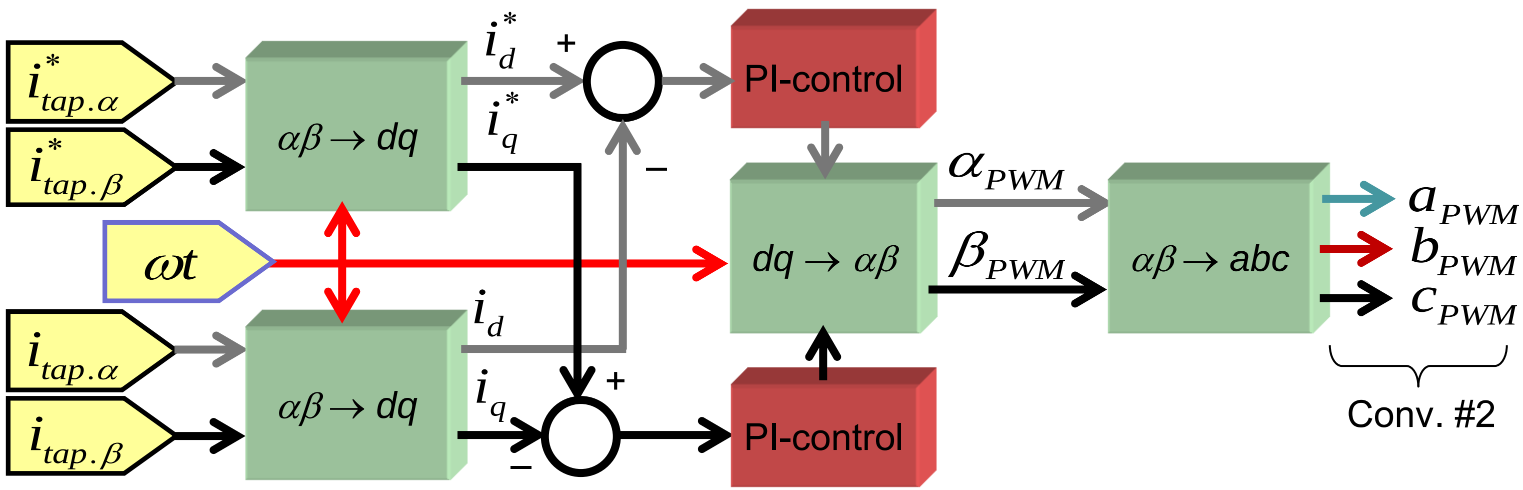
Controller of the Converter #1 of the Shunt FACTS



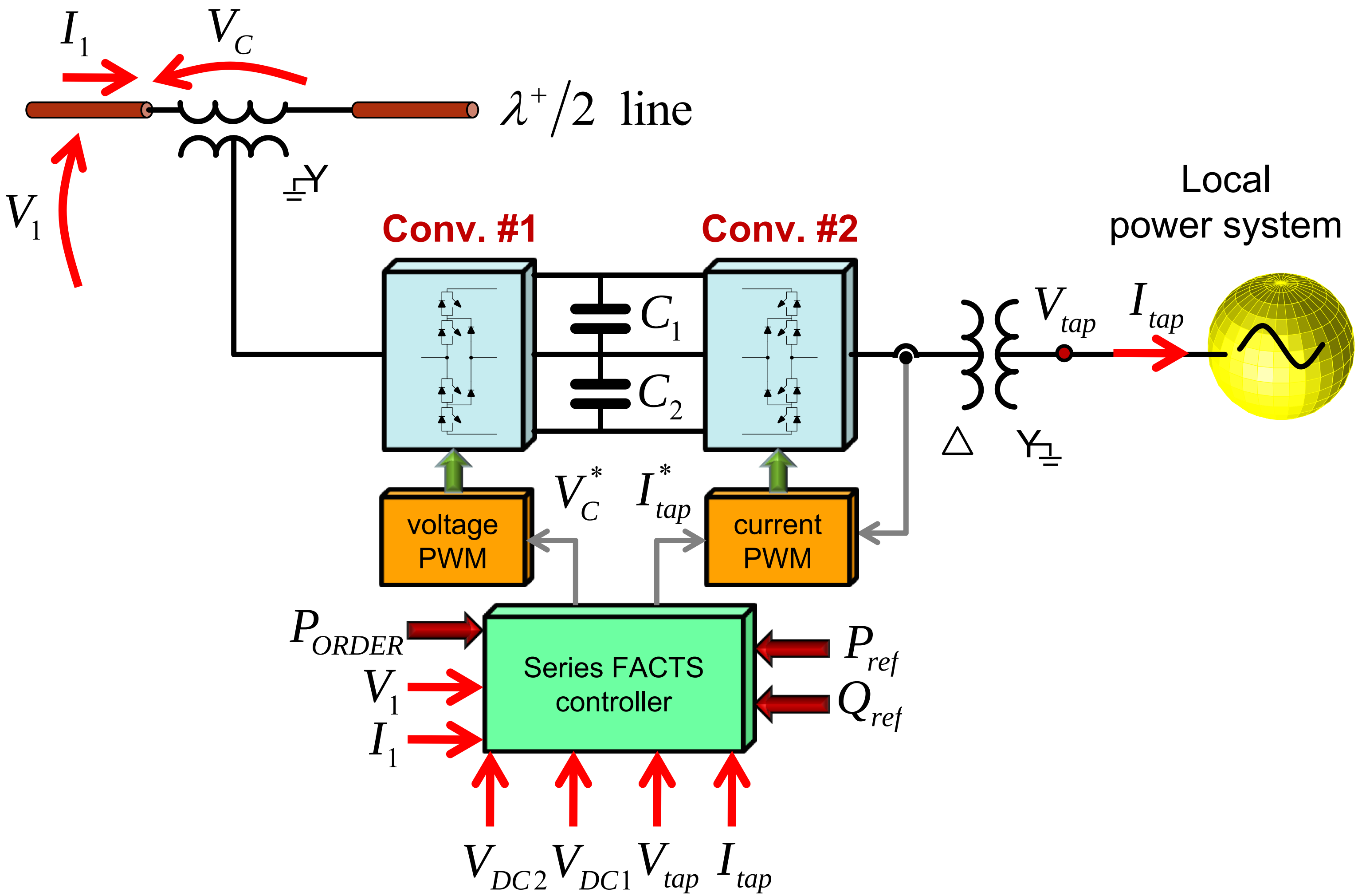
Controller of the Converter #2 of the Shunt FACTS



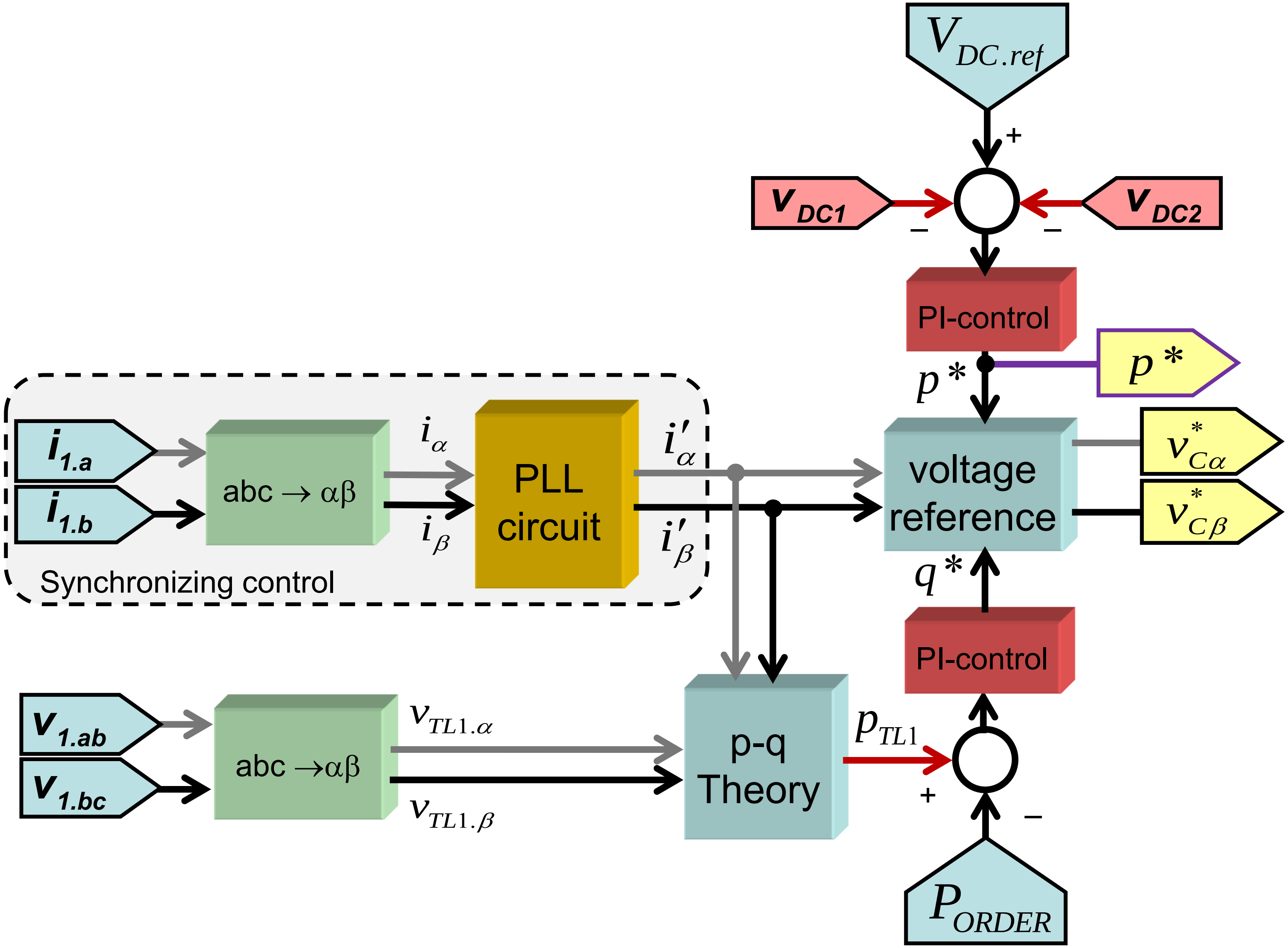
Controller of the Converter #2 of the Shunt FACTS



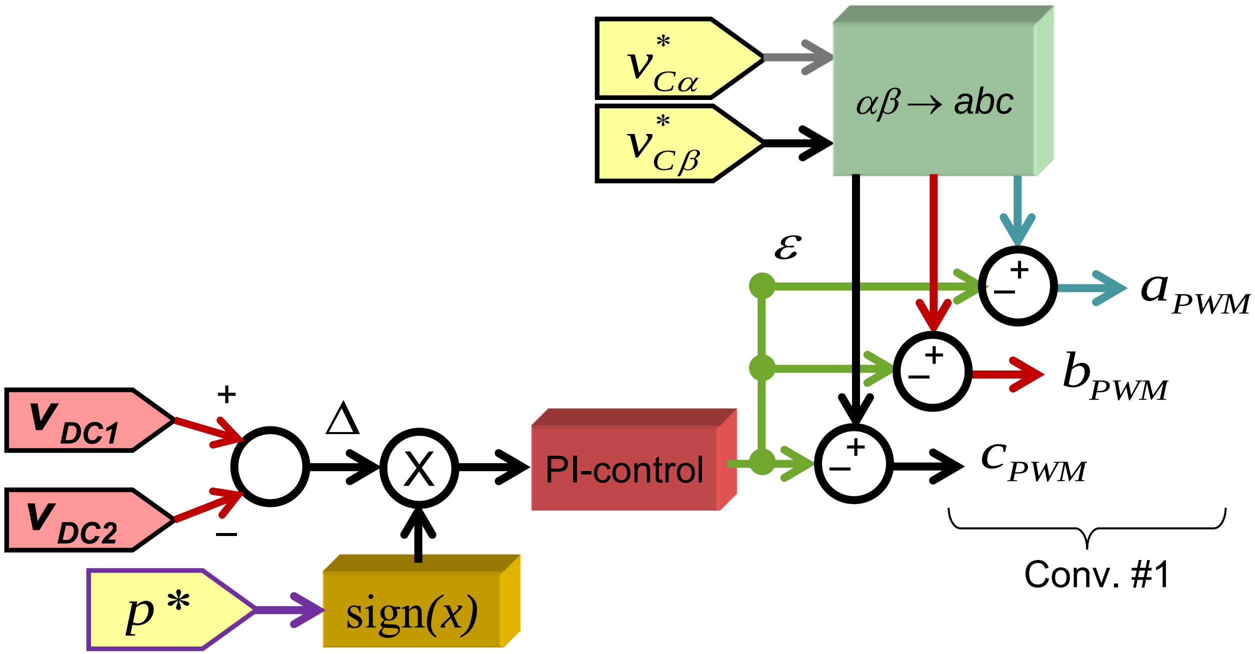
Series FACTS for Tapping and Power Flow Control in Half-Wavelength Transmission Lines



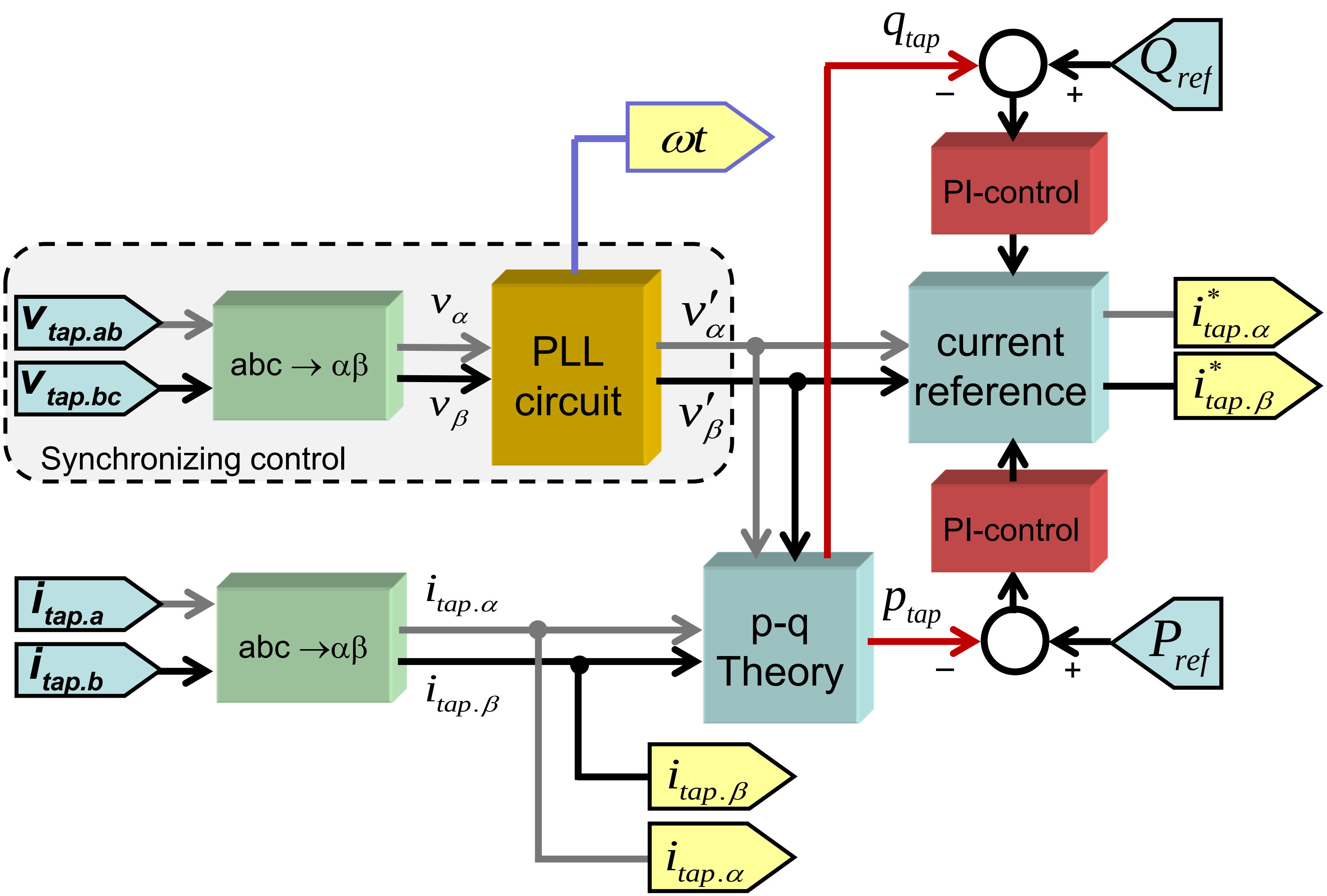
Controller of the Converter #1 of the Series FACTS



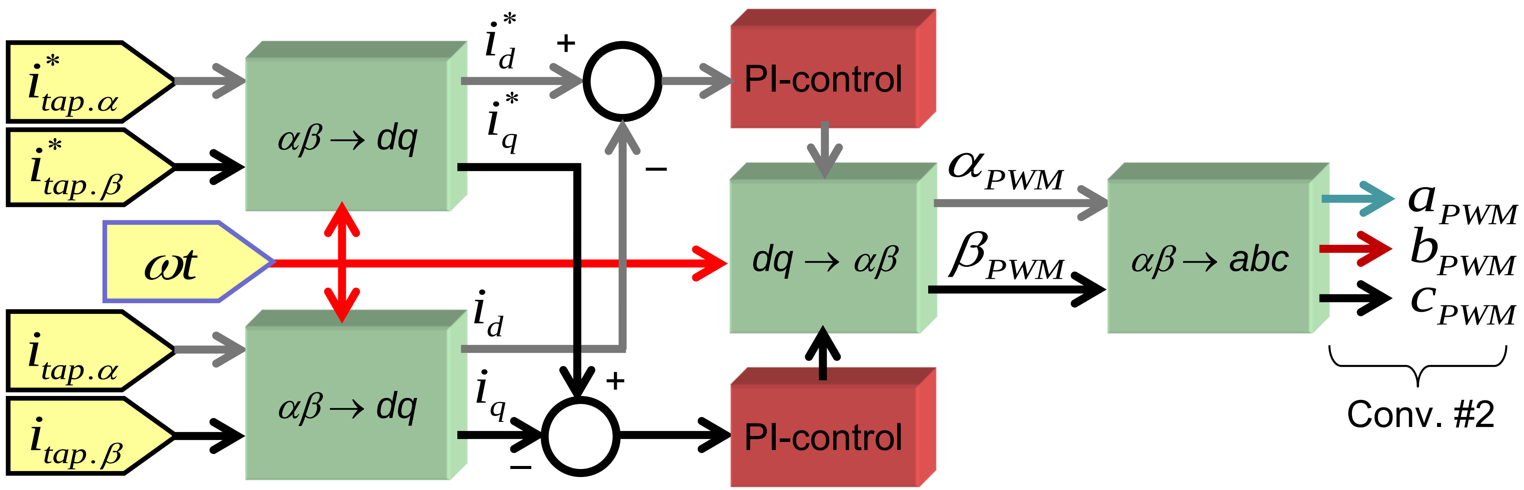
Controller of the Converter #1 of the Series FACTS



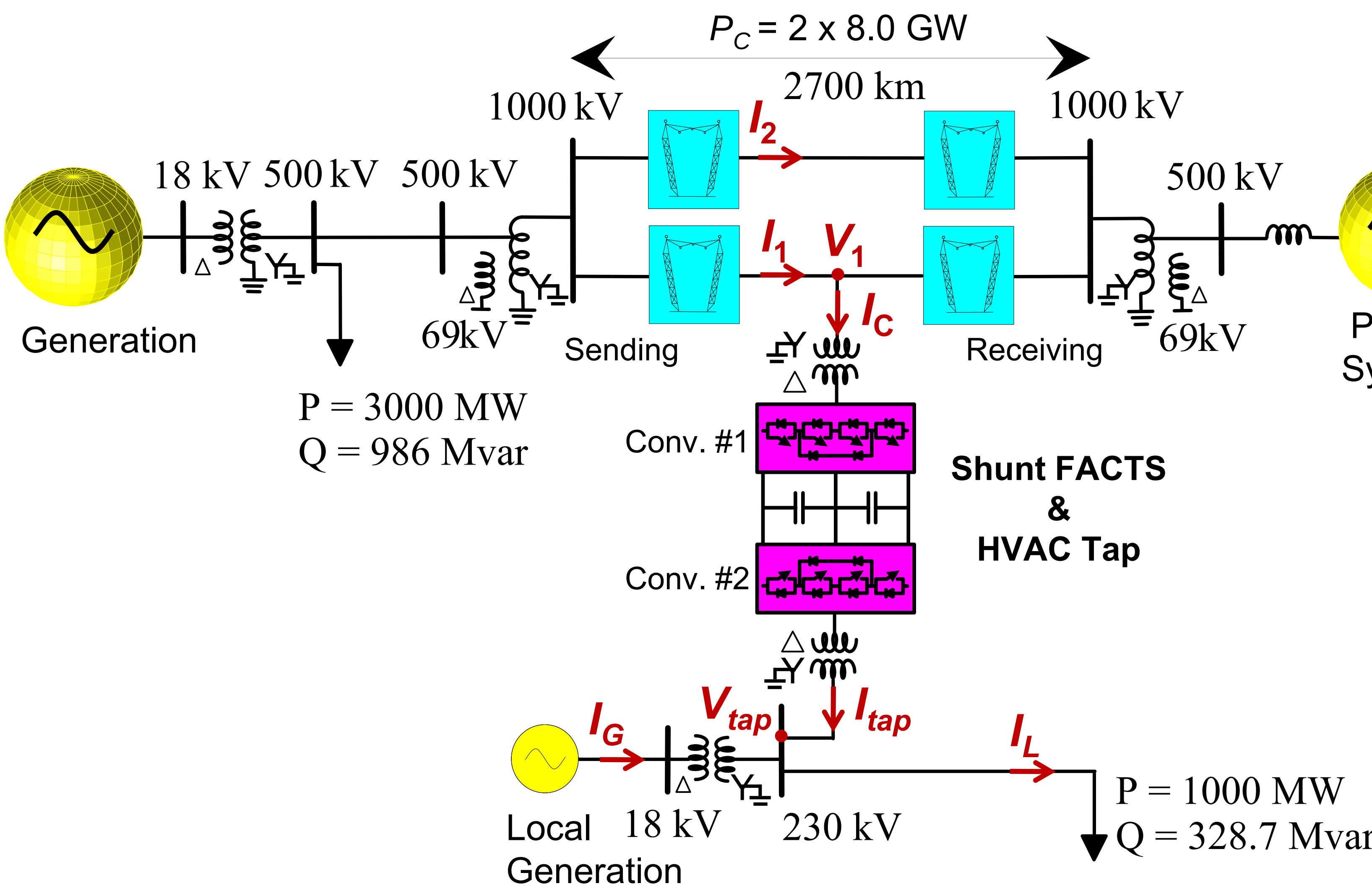
Controller of the Converter #2 of the Series FACTS



Controller of the <u>Converter #2</u> of the <u>Series</u> FACTS



A shunt FACTS in the central section of the Half-Wavelength Transmission Line

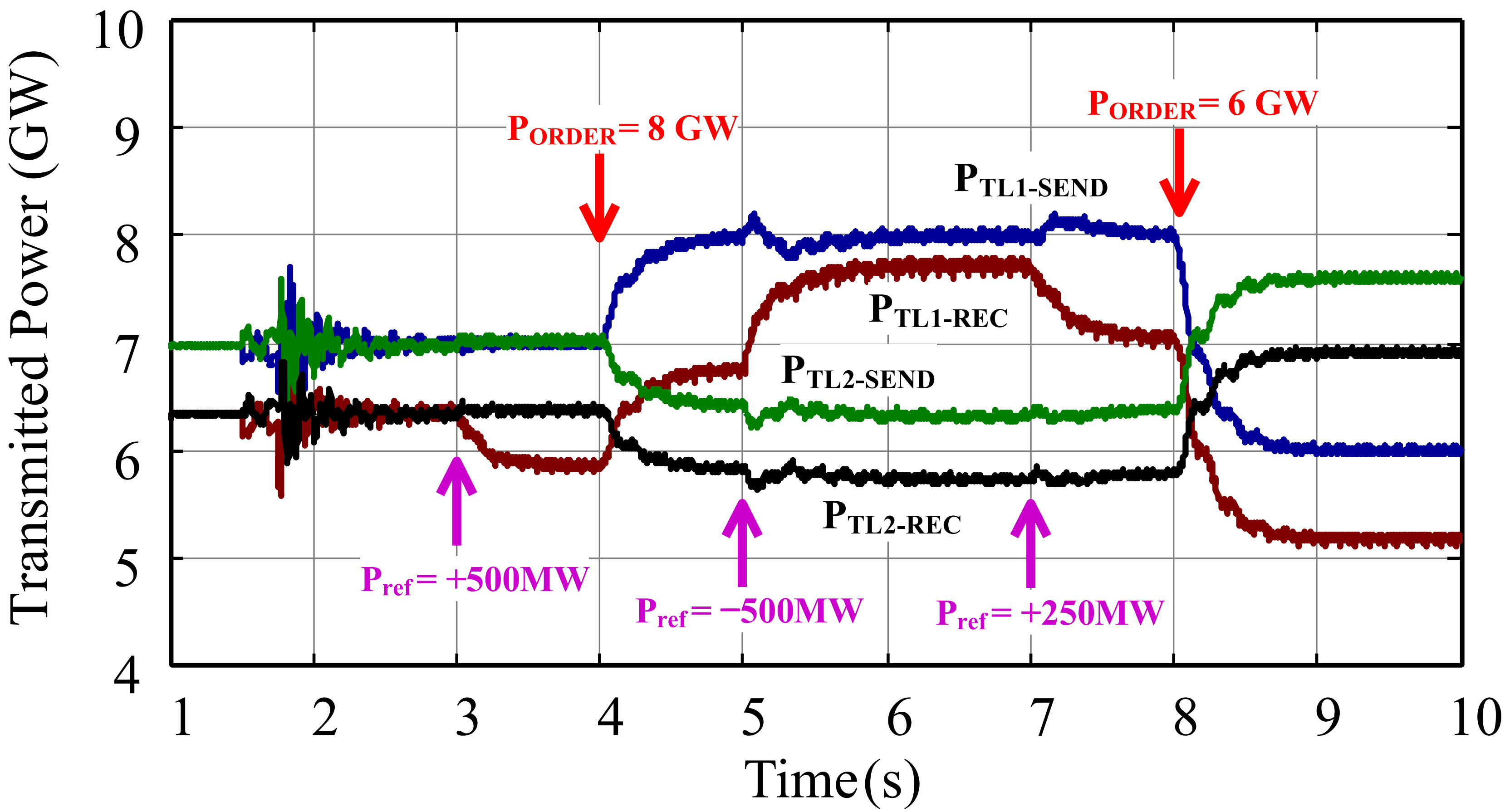


Simulation Results

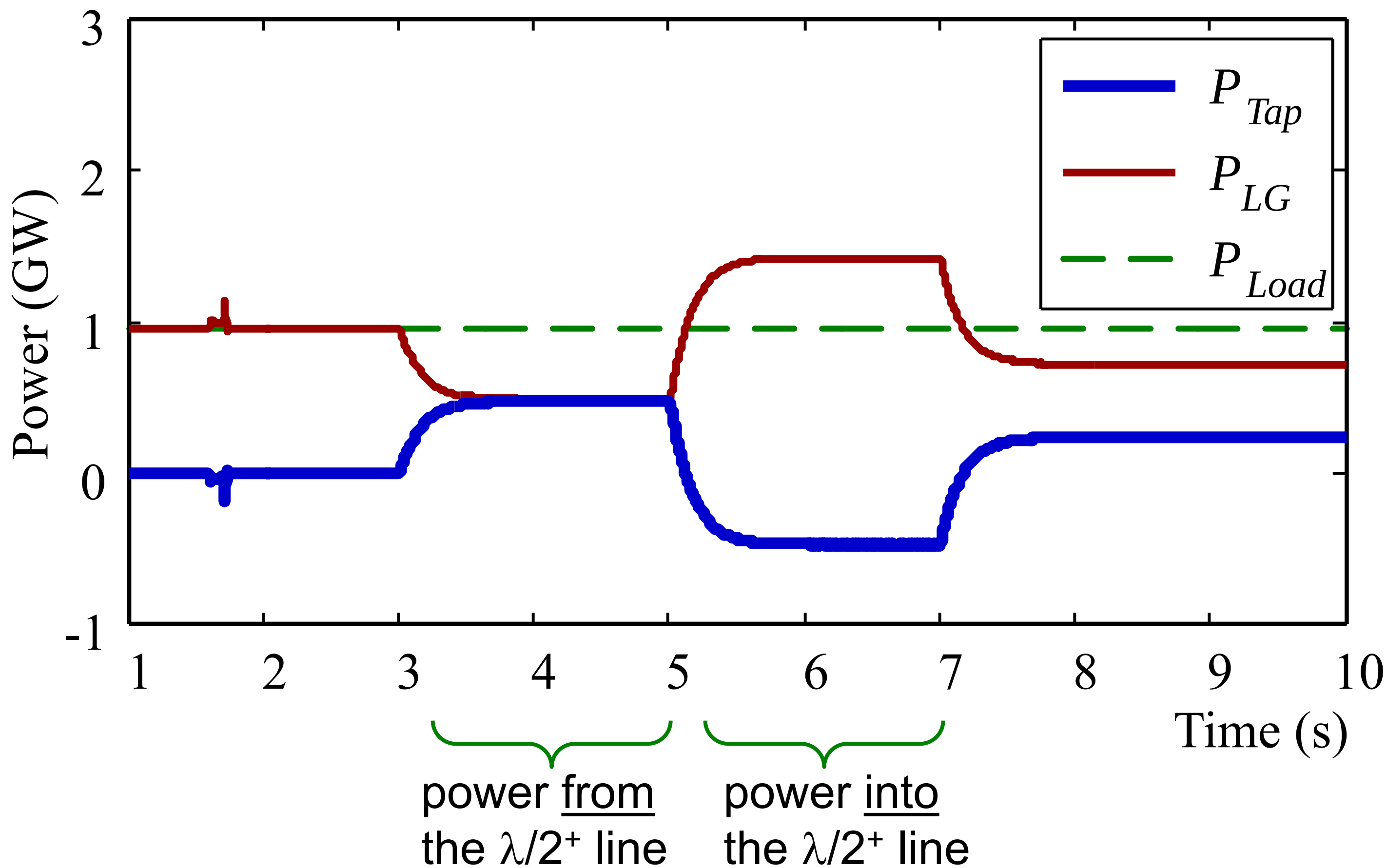
Sequence of Events

time (s)	
0.000	Energization of the $\lambda/2^+$ lines with 77.5Ω pre-insertion resistors
0.019	Bypass of the pre-insertion resistors
0.030	Closing of the receiving-end
1.500	Energization of FACTS shunt transformer with 10Ω pre-charging resistor in the dc link
1.600	Energization of the shunt transformer of converter #2, from the local system
1.650	Energization of converter #2
1.700	Bypass of the pre-charging resistor
1.750	Firing of converter #1
2.000	Firing of converter #2
3.000	Step-change in P_{ref} from 0.0 MW to +500MW.
4.000	Step-change in P_{ORDER} from 7.0 GW to 8.0 GW.
5.000	Step-change in P_{ref} from +500.0 MW to -500MW.
7.000	Step-change in P_{ref} from -500.0 MW to +250MW.
8.000	Step-change in P_{ORDER} from 8.0 GW to 6.0 GW.

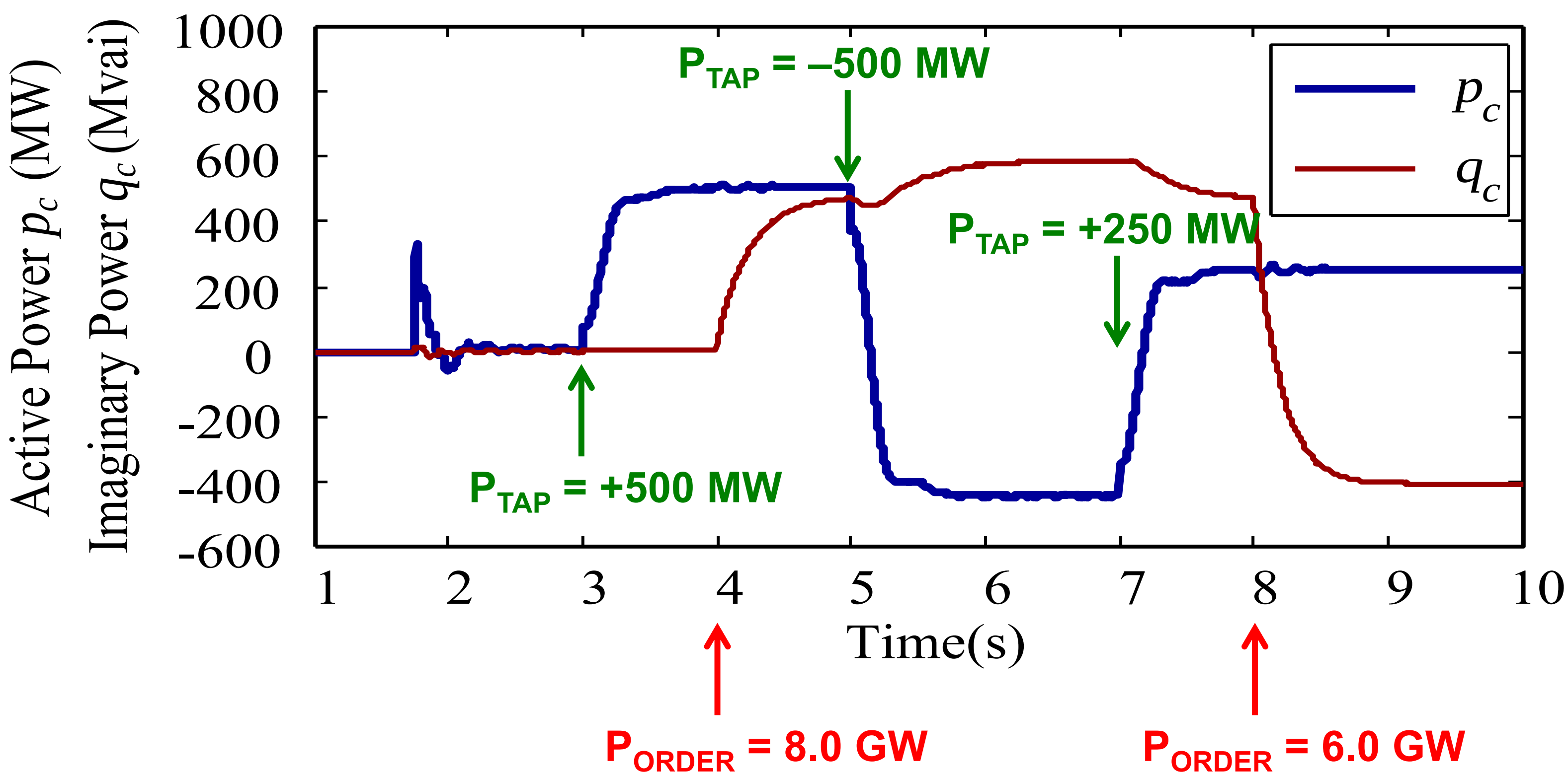
Shunt FACTS: Active power through the $\lambda/2^+$ lines #1 and #2



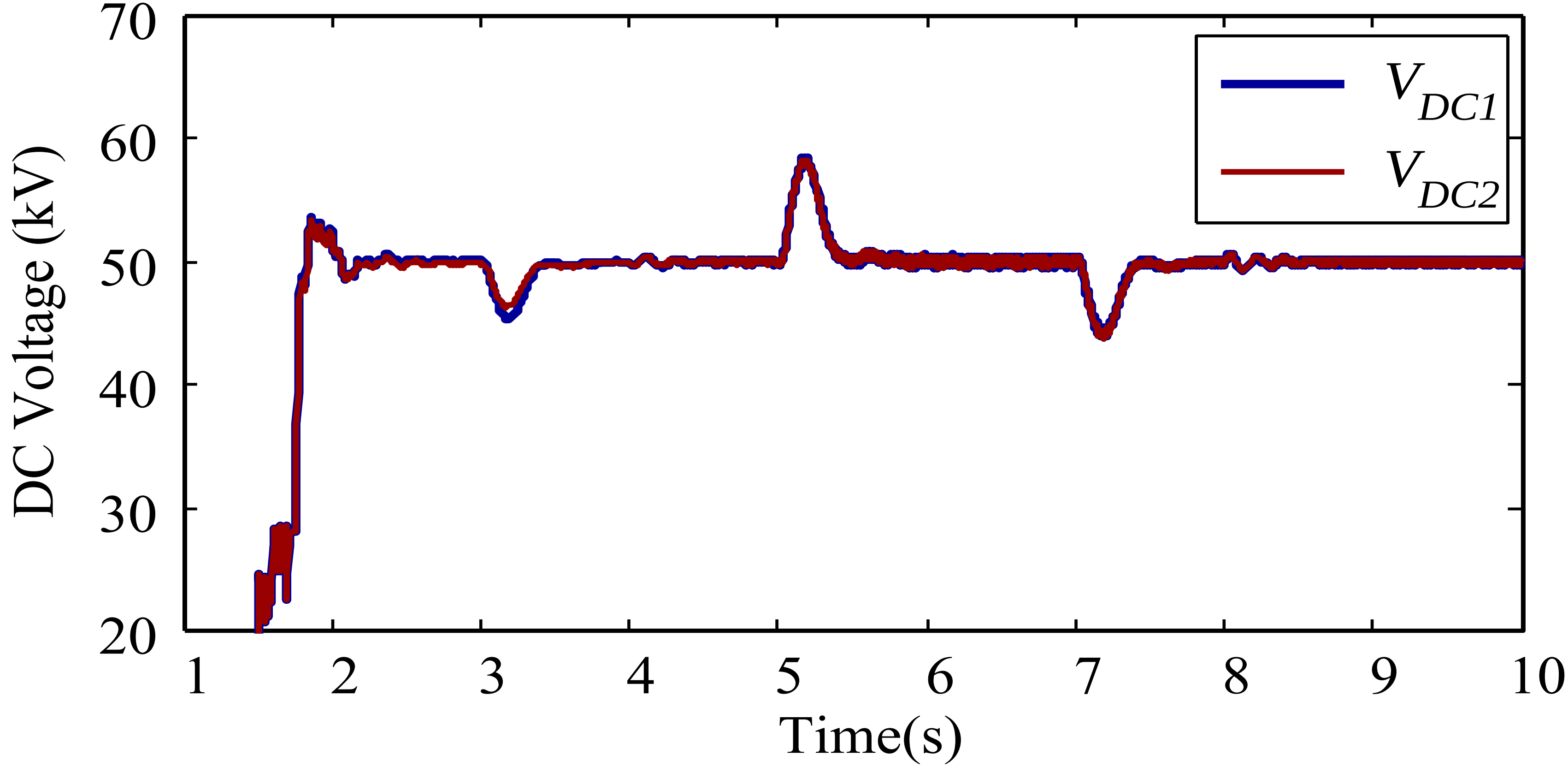
Shunt FACTS:
Active power exchange between the $\lambda/2^+$ line and the local ac system



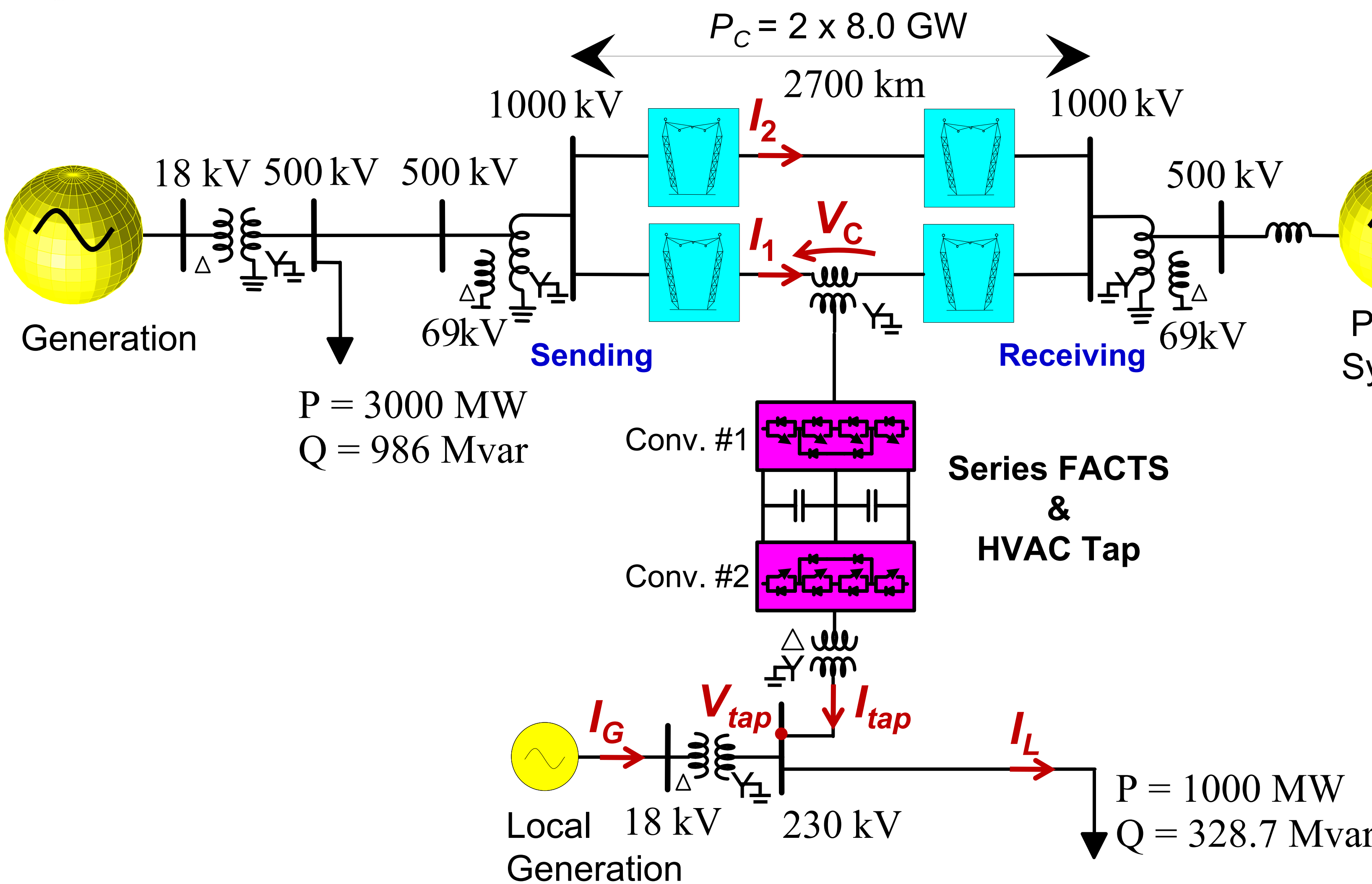
Active and reactive power of converter #1 of the Shunt FACTS



Shunt FACTS:
dc-bus capacitor voltages of the NPC-Converter



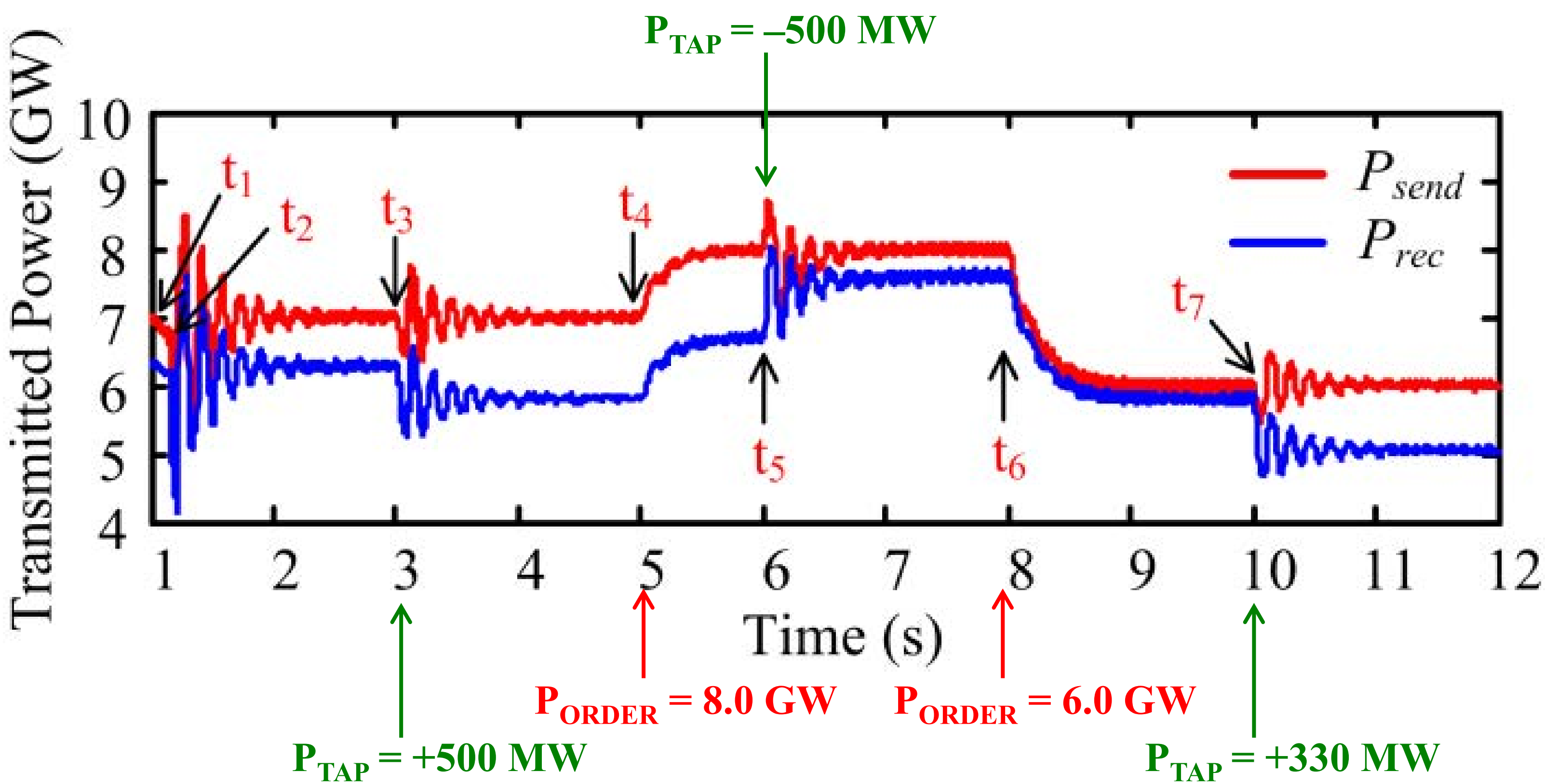
A series FACTS connected 450 km far from the sending-end terminal



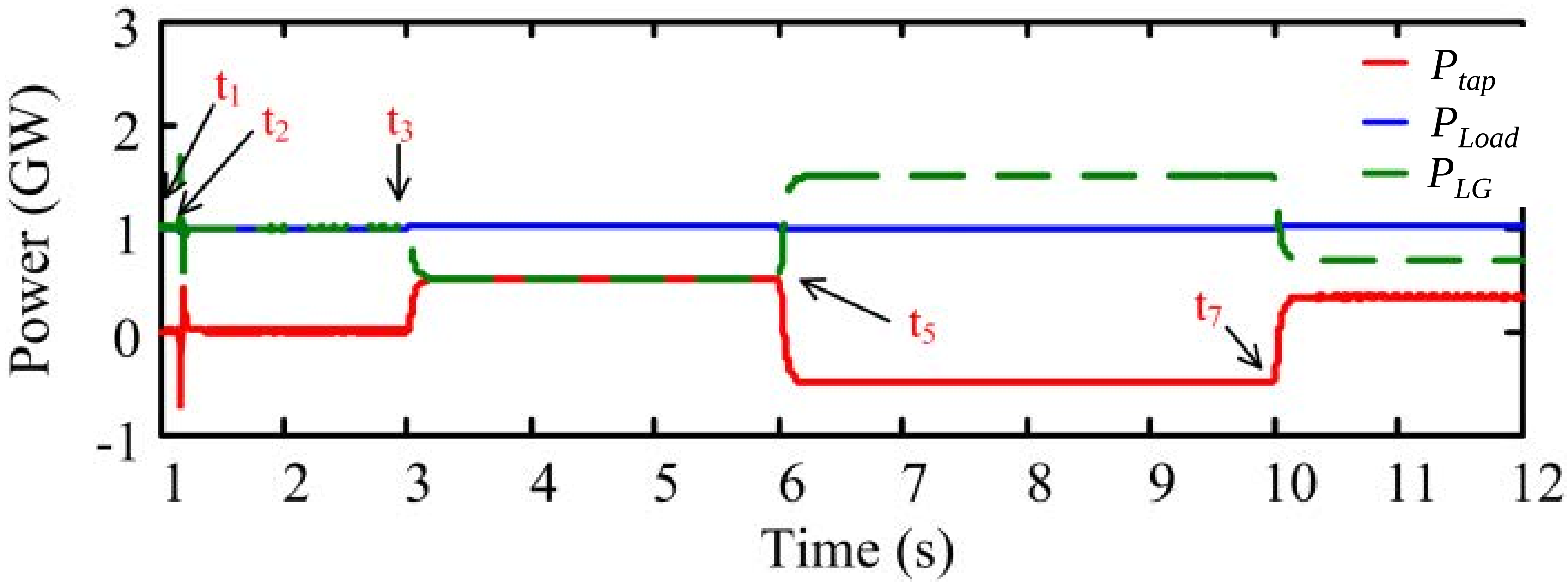
Series FACTS simulation case
Sequence of events

Time	Event
t_1 = 1.0s	HVAC series tap is connected to the line
t_2 = 1.1s	The tap is connected to the local system with P_{tap} = 0
t_3 = 3.0s	Step change to P_{tap} = +500 (the series tap drains 500 MW from the line)
t_4 = 5.0s	The P_{ORDER} order changes to 8.0 GW (1.0 pu)
t_5 = 6.0s	Step change to P_{tap} = –500 (the series tap injects 500 MW into the line)
t_6 = 8.0s	The P_{ORDER} changes to 6.0 GW
T_7 = 10.0s	Step change to P_{tap} = +330 (the series tap drains 330 MW from the line)

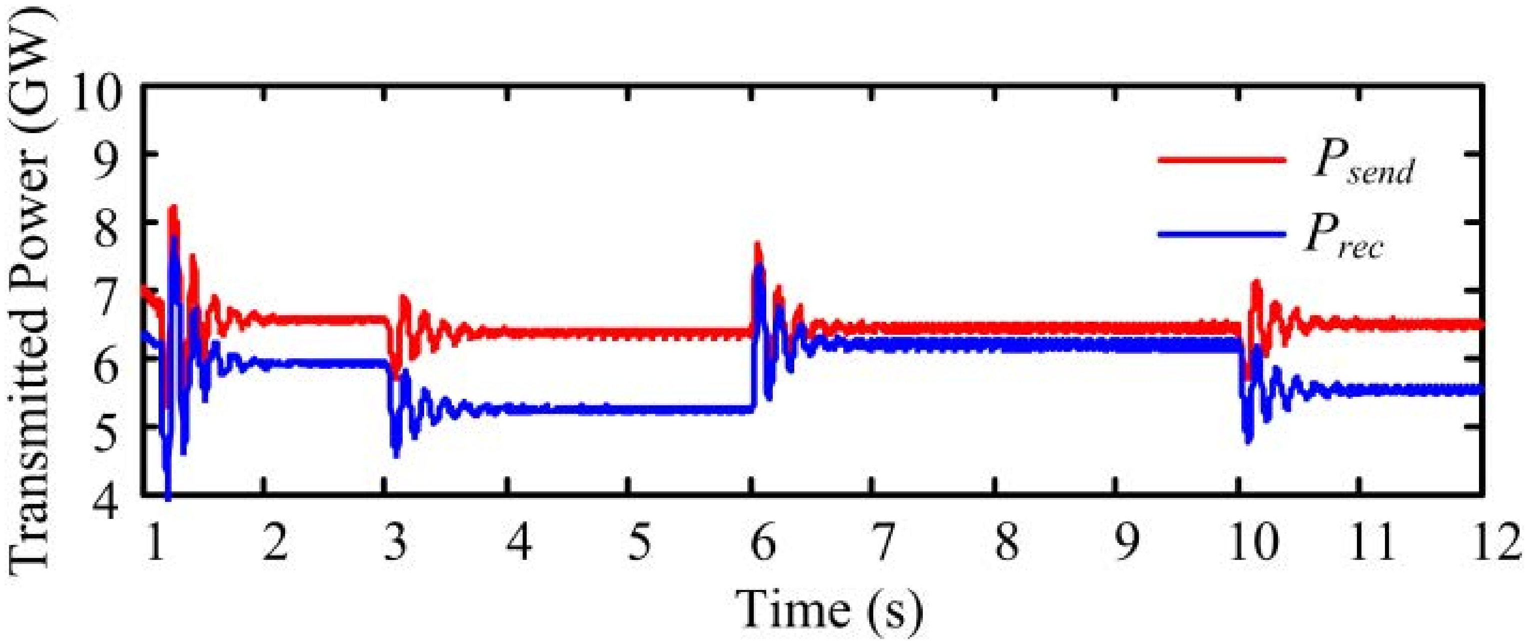
Series FACTS:
Active power in the $\lambda/2^+$ line #1



Series FACTS: Active power exchange between the $\lambda/2^+$ line and the local ac system



Series FACTS performing only HVAC tapping (no power flow control in the $\lambda/2^{+}$ line)



Summing up

- **Shunt** FACTS is an attractive solution for main power flow control and fractional power derivation in $\lambda/2^+$ lines, if connected in the central section of the line;
- Several **shunt** FACTS can be used to configure multiterminal system;
- The **series** FACTS is an attractive solution for main power flow and fractional power derivation in $\lambda/2^+$ lines, if connected in the terminal section of the line.

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Obrigado!

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