Transmission Planning with Power Electronic Systems

By

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Southwest Transmission Expansion Plan (STEP)

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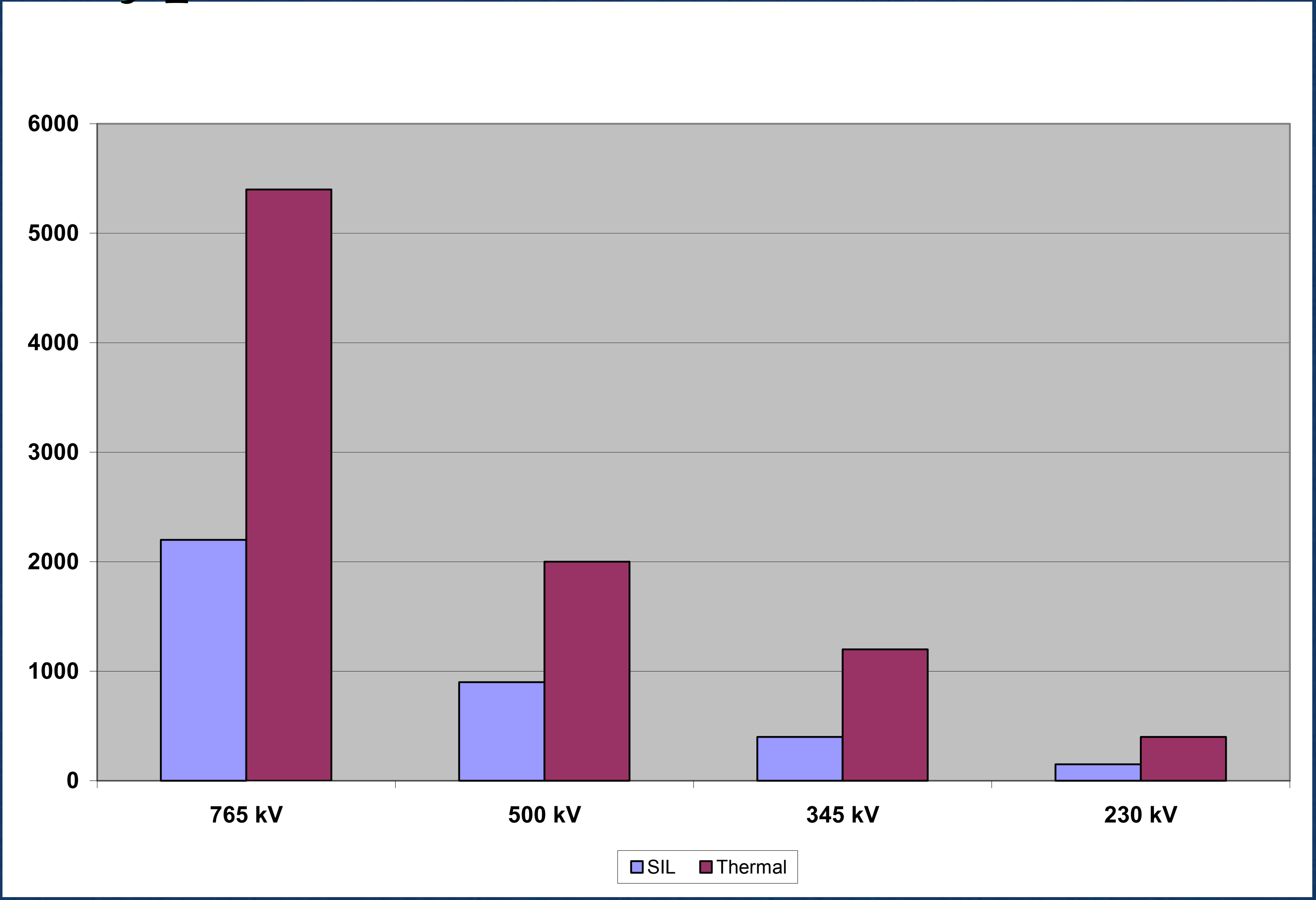
Macroeconomics Factors

- Oil Crisis in 74 and 79
  - 5% of US installed industrial capacity non-competitive
- Energy costs skyrockets
  - smoke stack industry decline
  - shift to Southern States
  - shift from oil to coal and gas
  - demand for conservation
- Environmental movement
  - NIMBY, BANANA etc.
  - Transmission lines expected to perform functions not envisioned by the system planners

EPRI's FACTS Initiative

- Planning began in 1986
- Paper by Jim Tice et. al. in 1984
  - coal power from Midwest to oil power regions in South and West
- DOE study comparing ac and dc
  - team members decided to look at how far ac could be pushed
- FACTS is a concept
  - maximize power transfer over existing lines
  - Postpone investments in new lines for as long as possible

Typical Line Performance Limits



SVC Systems

- SVC for Transmission -
  - EPRI-M P&L and Westinghouse - Shannon 1978
    - 45 MVA TCR and 72 MVA capacitor bank
    - 320 to 400 MW transfer limit
  - ABB - KG&E, Wichita, Kansas
    - 300 MVA and 200 MVA TSC systems
    - Voltage stability enhancement

SVC Controls
Brute Force or Smart

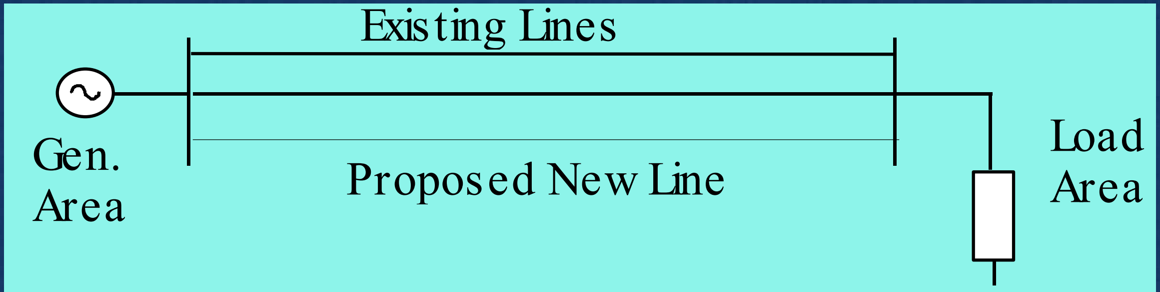
- Aggressive use of control power can save money
- Chester SVC
  - Supplemental Modulation Controls
  - Smaller SVC
  - SSI damping controls
  - Limited know-how

The Missing Element
Power Flow Control

$$\Delta P = -\frac{\Delta X}{X} P + \frac{\Delta \phi}{tg\phi} P + \frac{\Delta V}{V} P$$

- Impedance
  - Series compensation
- Phase Angle
- Voltage control
  - Not reactive power but active power
  - Narrow allowable control range limit

Line Expansion Scenario

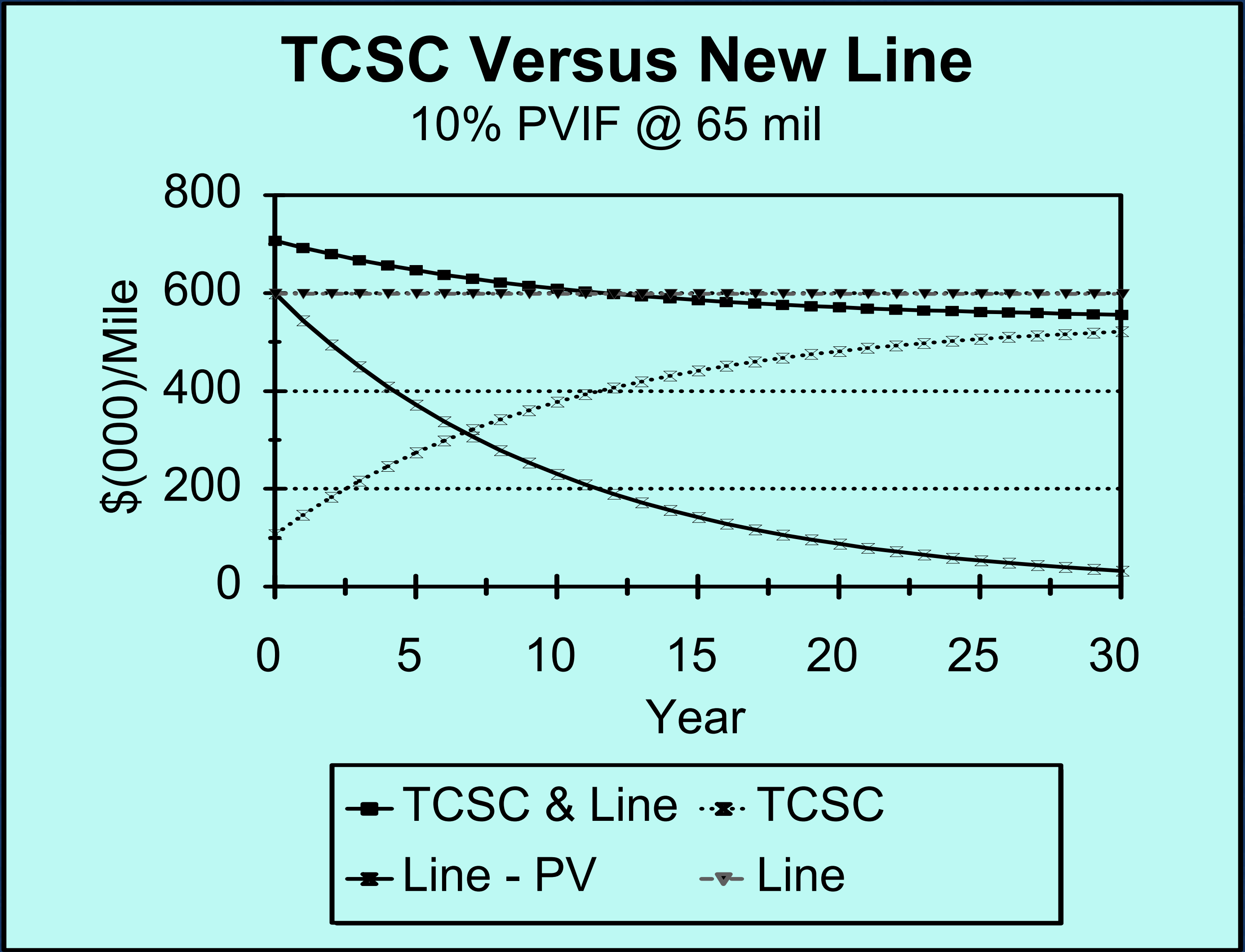


Impedance per mile: 0.55 Ω
X/R ratio: 25
Q/mile at SIL: 1.8 Mvar

The TCSC alternative:

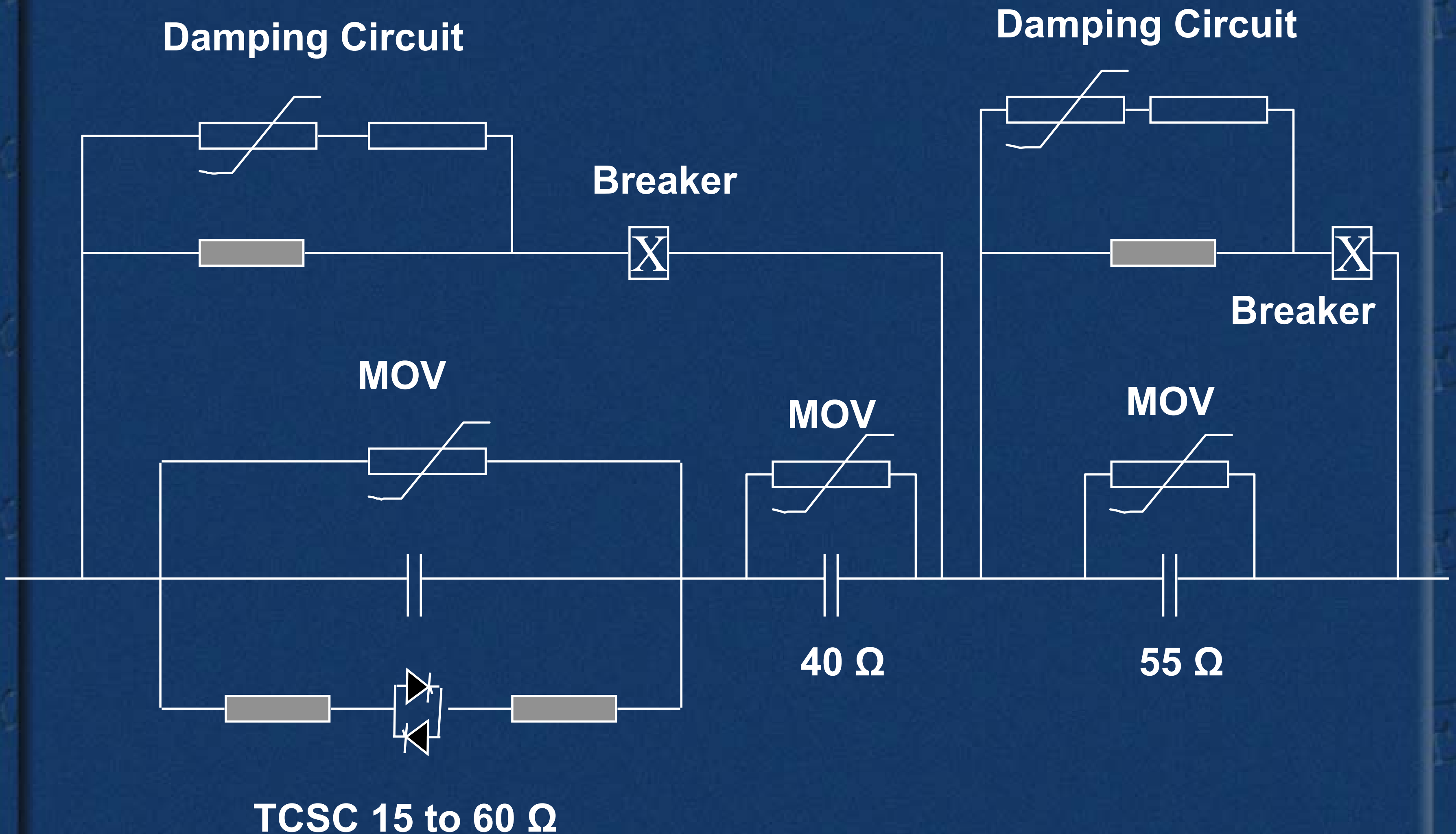
Compensation level: 33%
Cost/mile: $108k

Impact of Losses

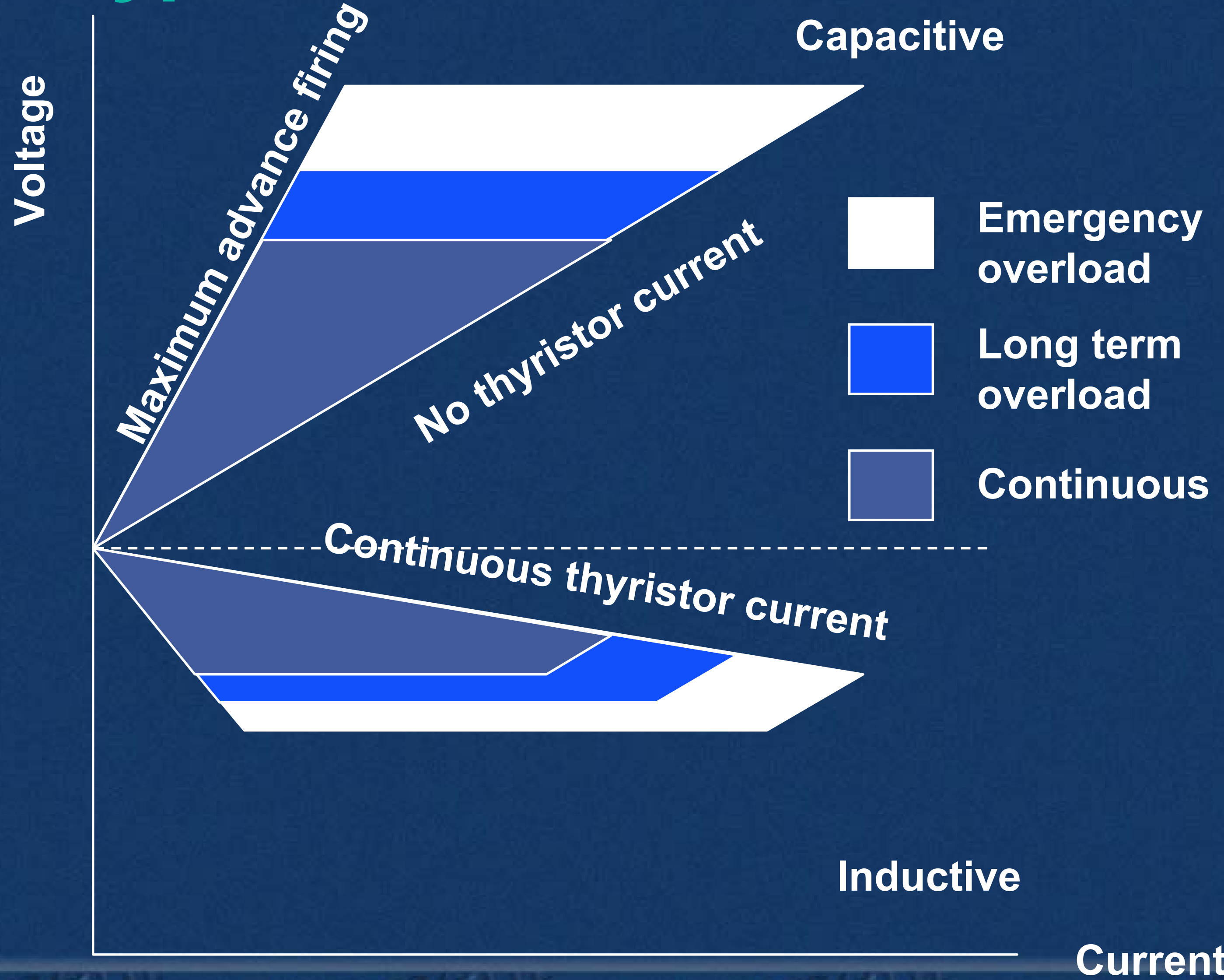


"Baseball is 90% mental; the other half is physical - Yogi Berra, NY Yankees' catcher"

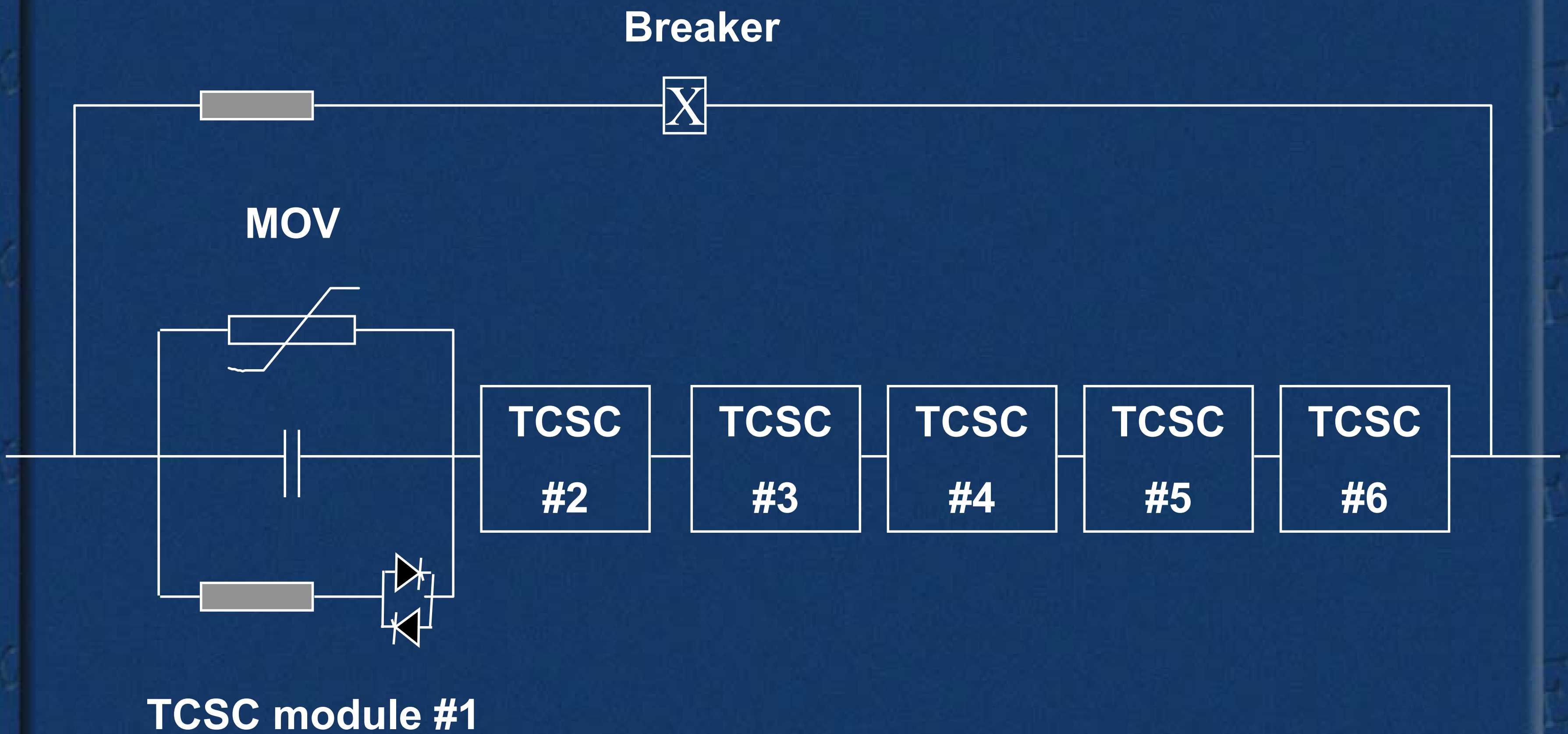
Kayenta TCSC



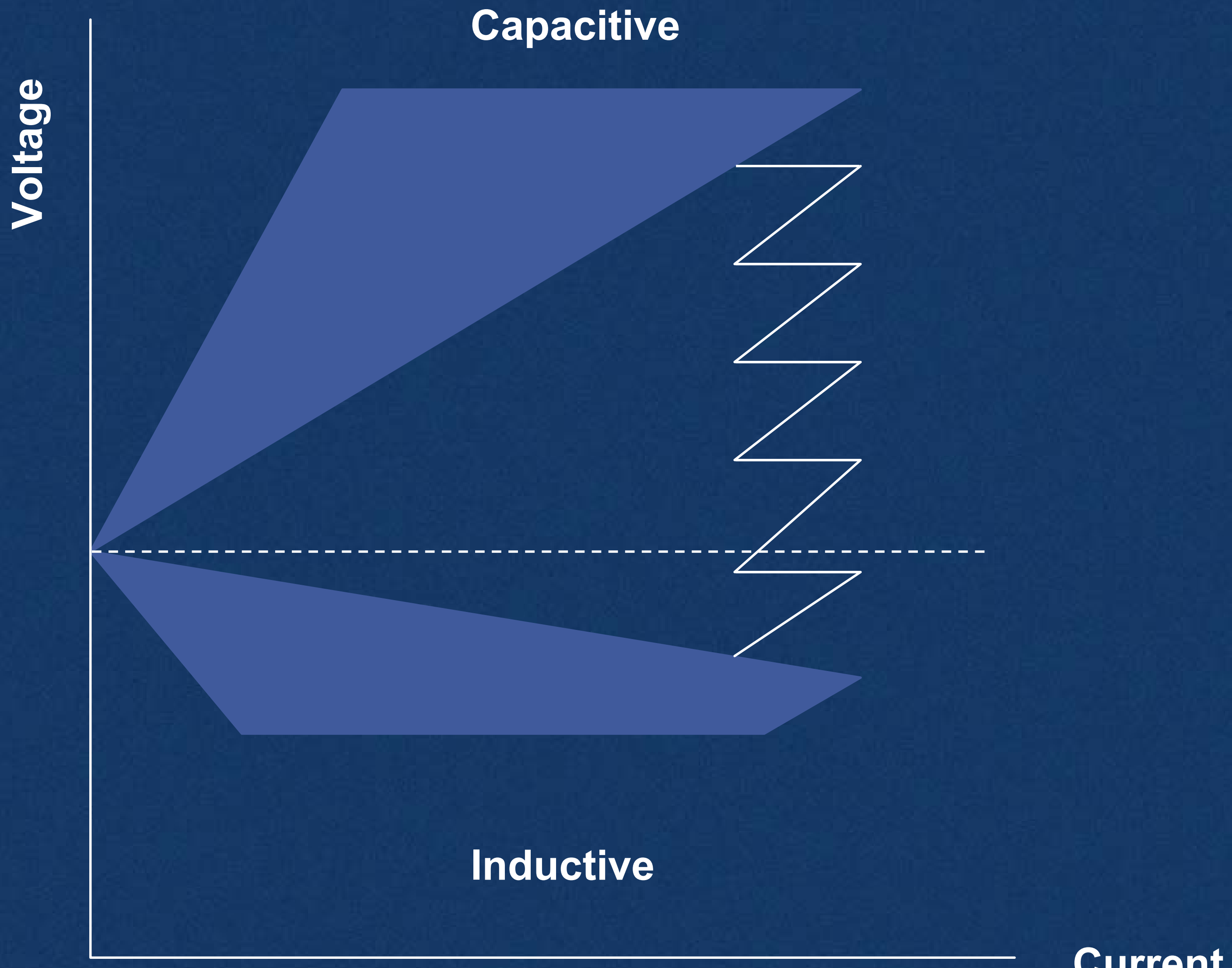
Typical TCSC V-I Characteristic



Slatt TCSC



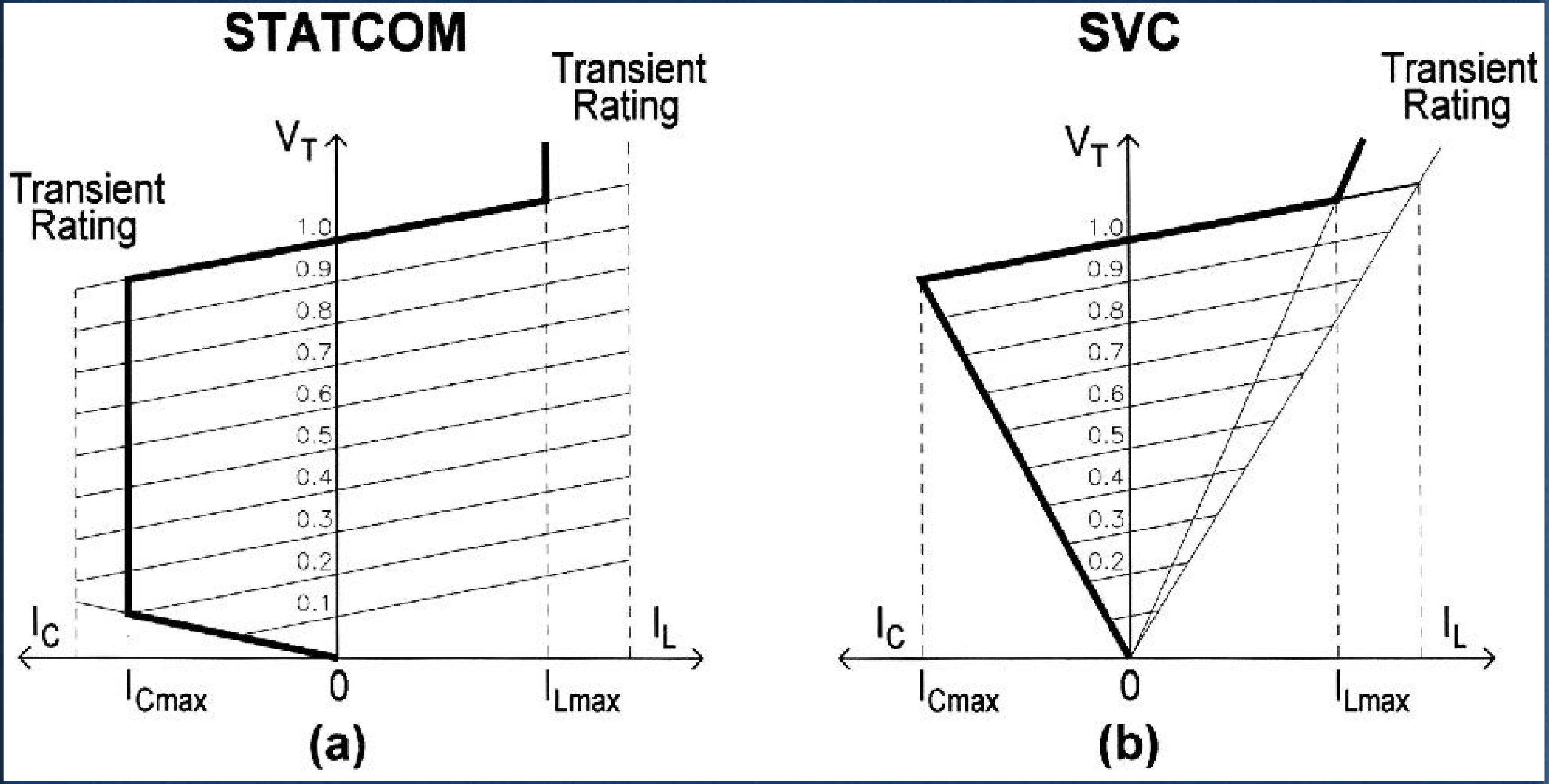
Six Module TCSC V-I Characteristic



TCSC Selection Criteria

- Application determines scheme
  - Transient stability controls
    - TSSC may be adequate in bang-bang control mode (Kawana River)
  - Power flow control
  - Dynamic range
    - short term overload utilizing thermal time constant of thyristors
    - Slatt: 200 MVA continuous, 800 MVA 10 seconds
  - Short circuit levels
    - Operation during through faults versus ability to provide synchronizing torque for faults on other lines
- SSR Concerns

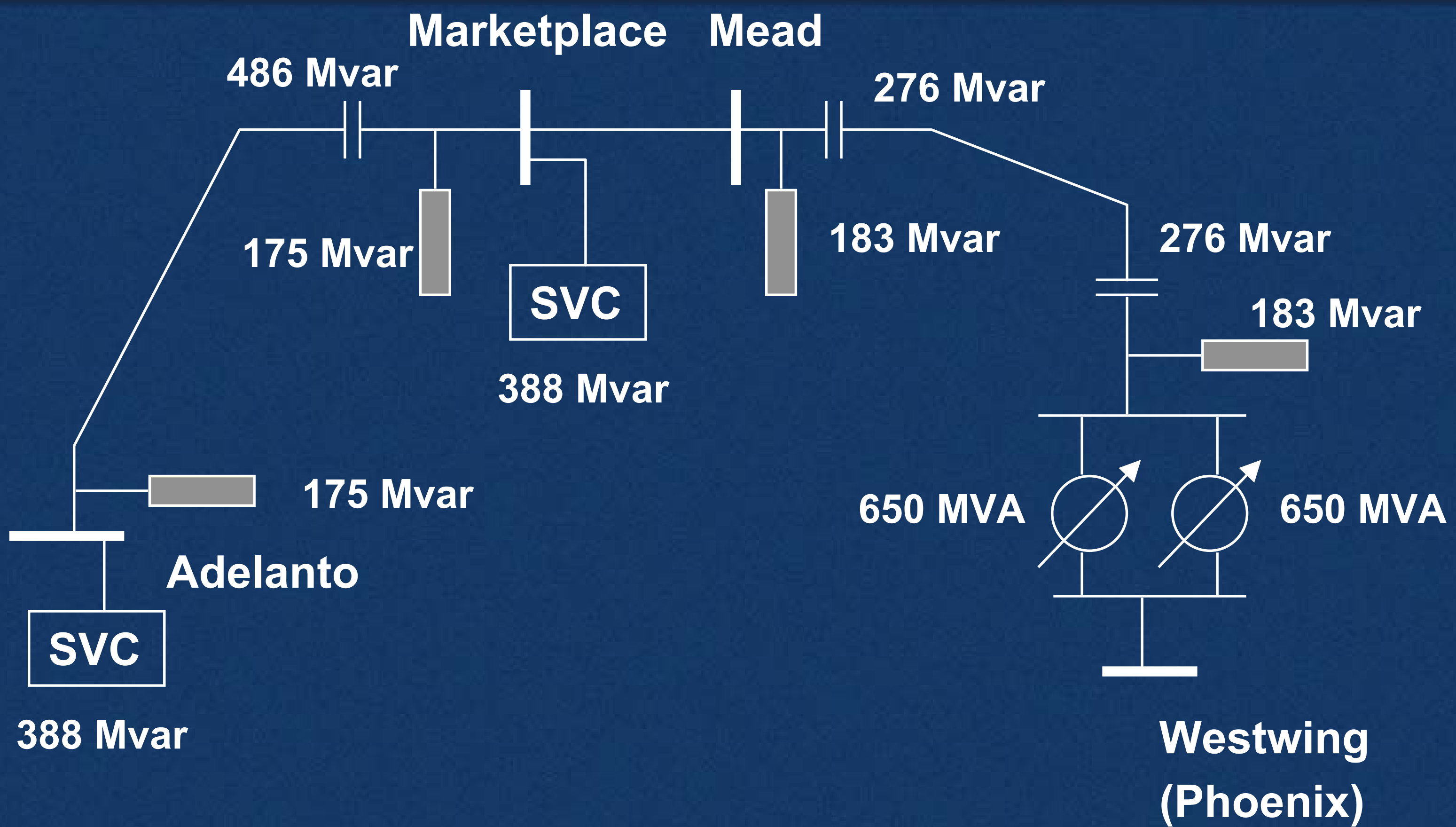
SVC versus STATCOM



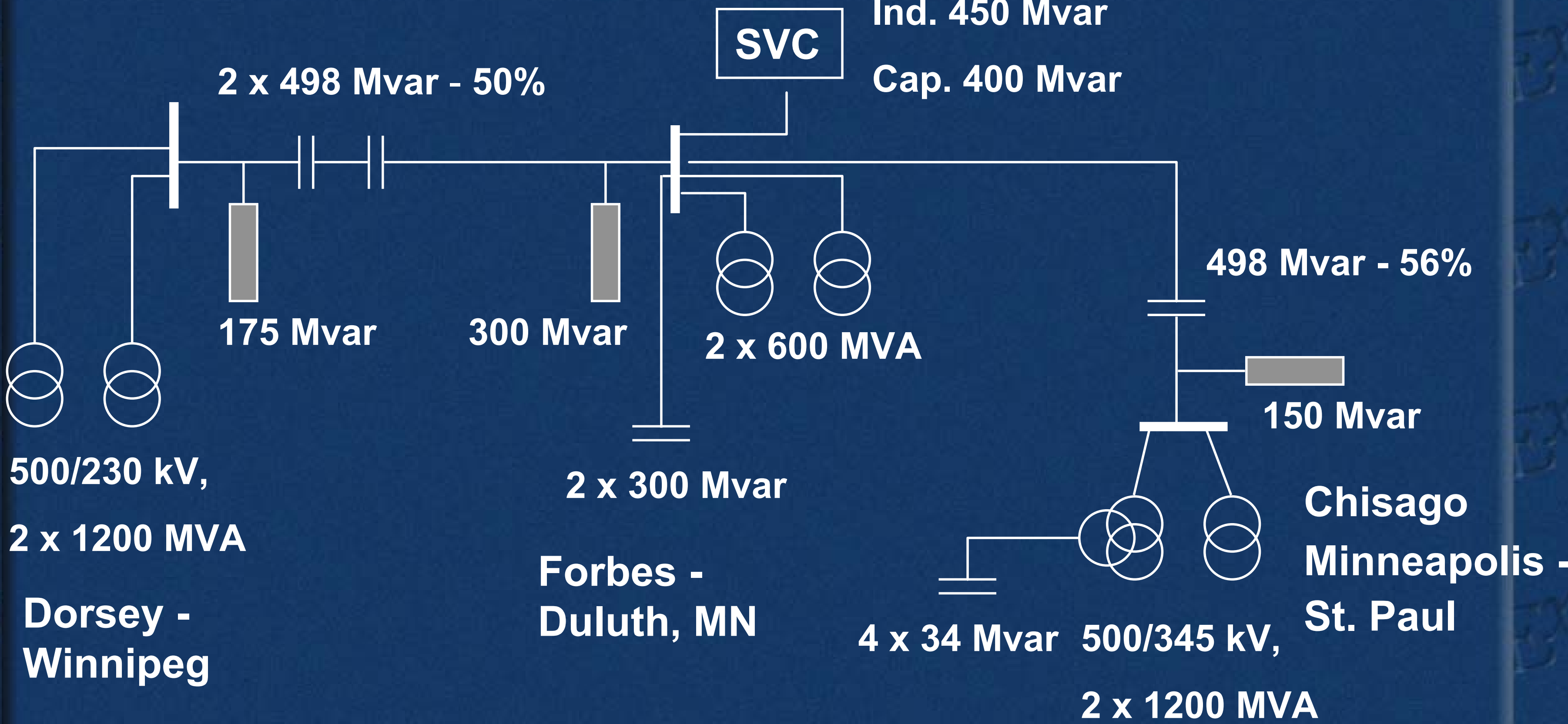
New Shunt Compensation - STATCOM

- Voltage source inverter schemes
  - Several demonstrations
  - Too costly - transformers very complex
- New topology* - harmonic compensated system
  - Practical topology
  - EPRI/TVA/Westinghouse demonstration
    - 100 MVA, 48 pulse system
- Numerous newer topologies

* "I want to be the fastest woman in the world in a manner of speaking - Shirley Muldowney, drag racer."

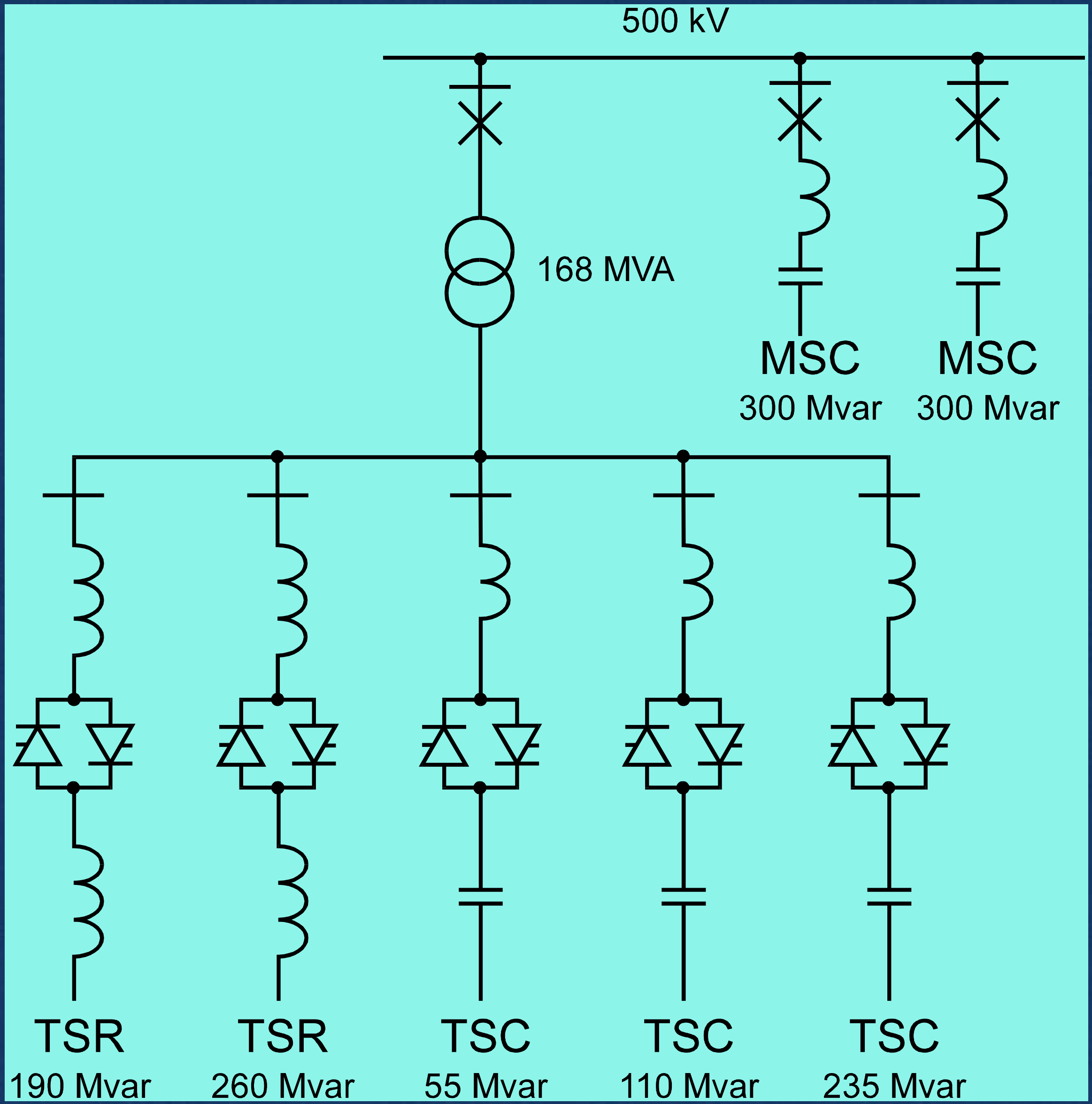


Phoenix-Mead-Adelanto FACTS Application

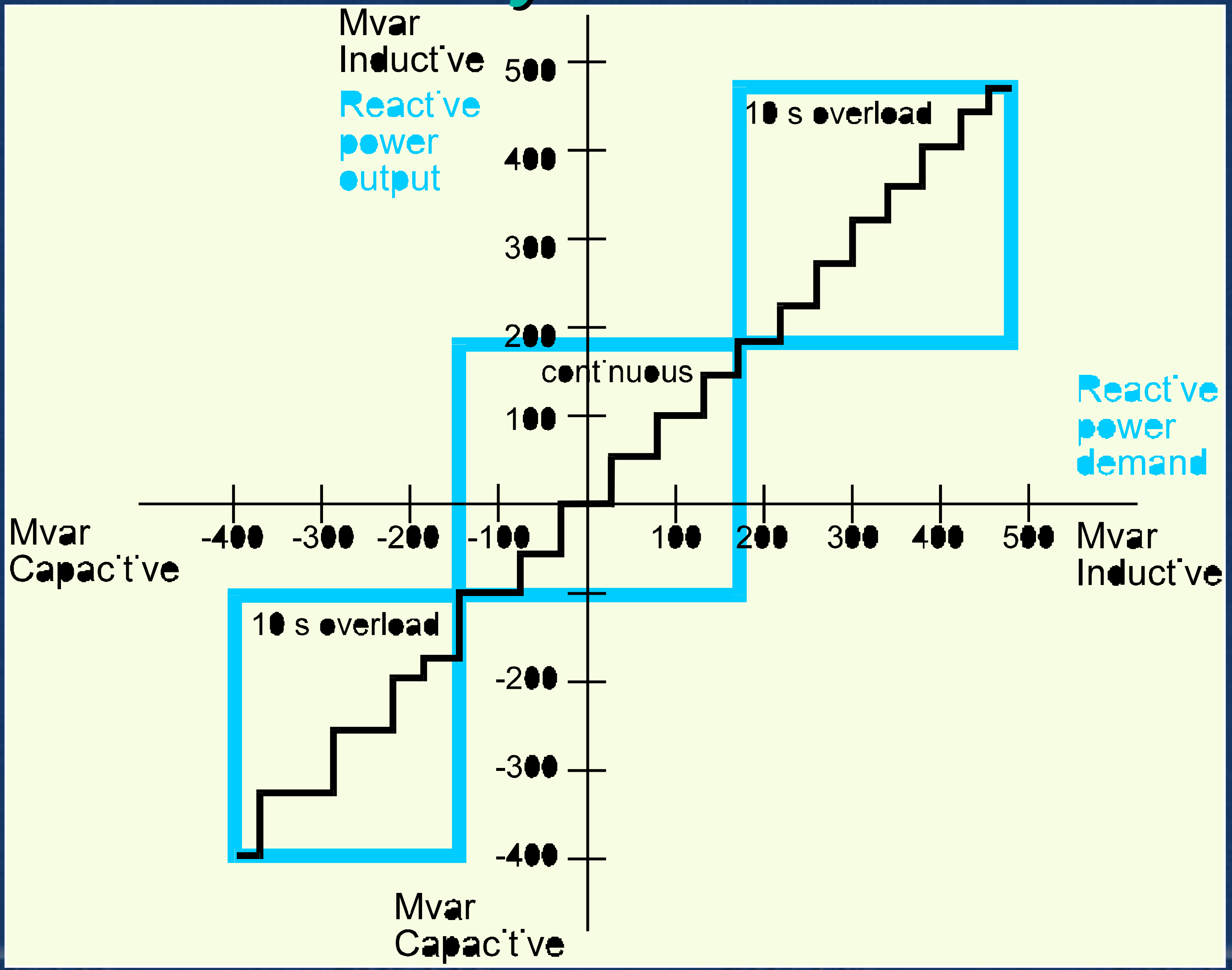


Winnipeg - Twin Cities FACTS Application

Forbes SVC System

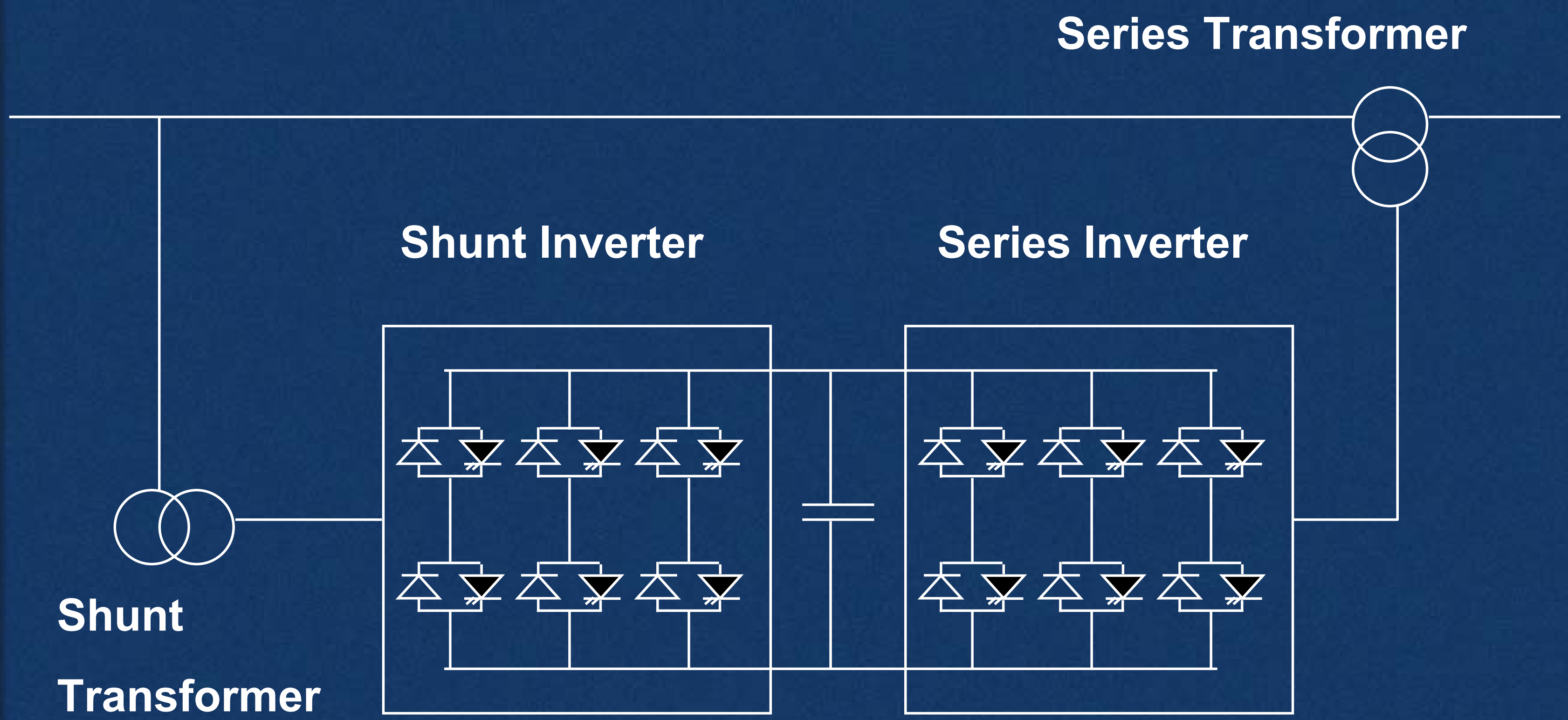


Forbes SVC System



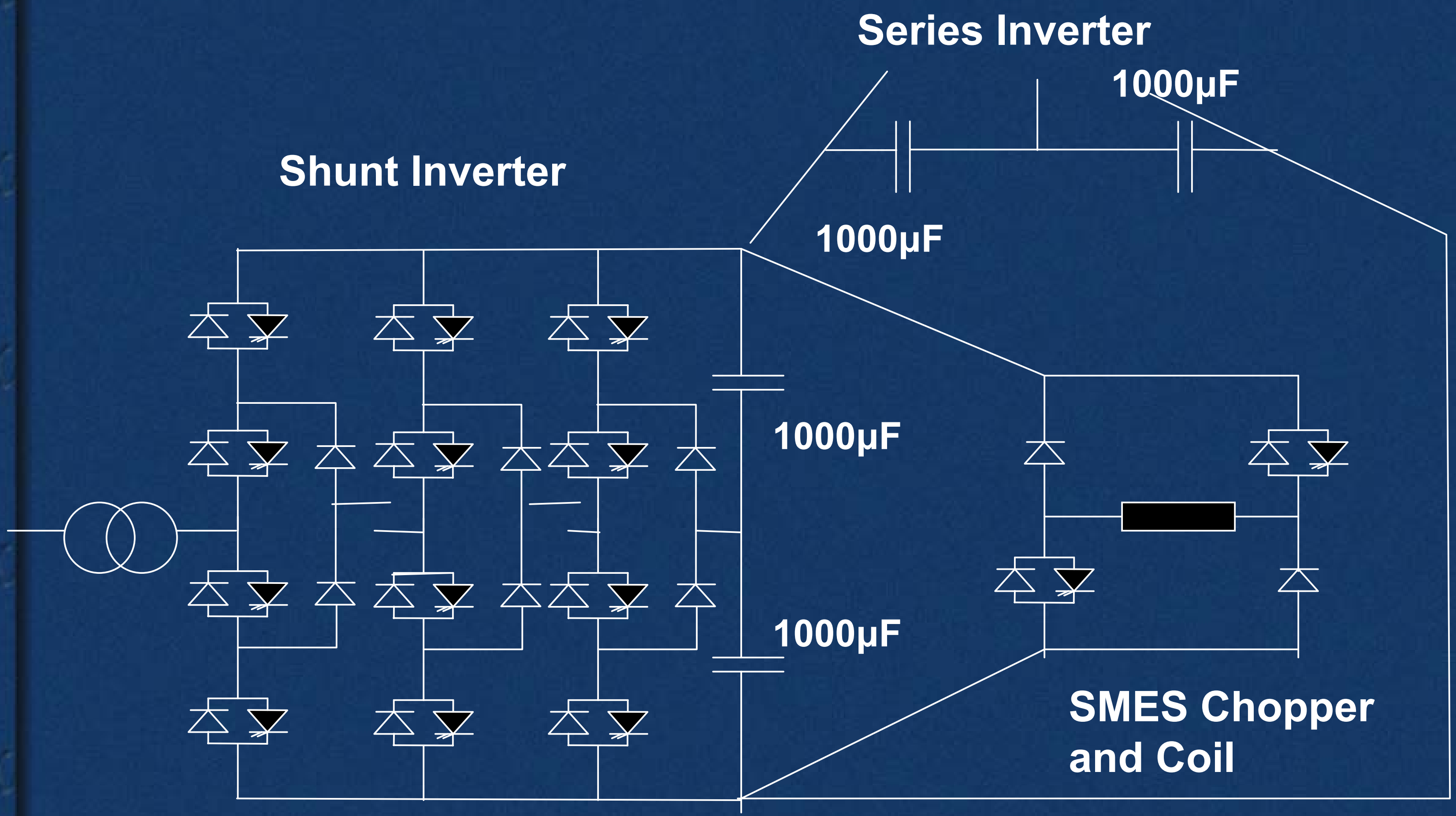
Unified Power Flow Controller

Needs PWM or multilevel converter

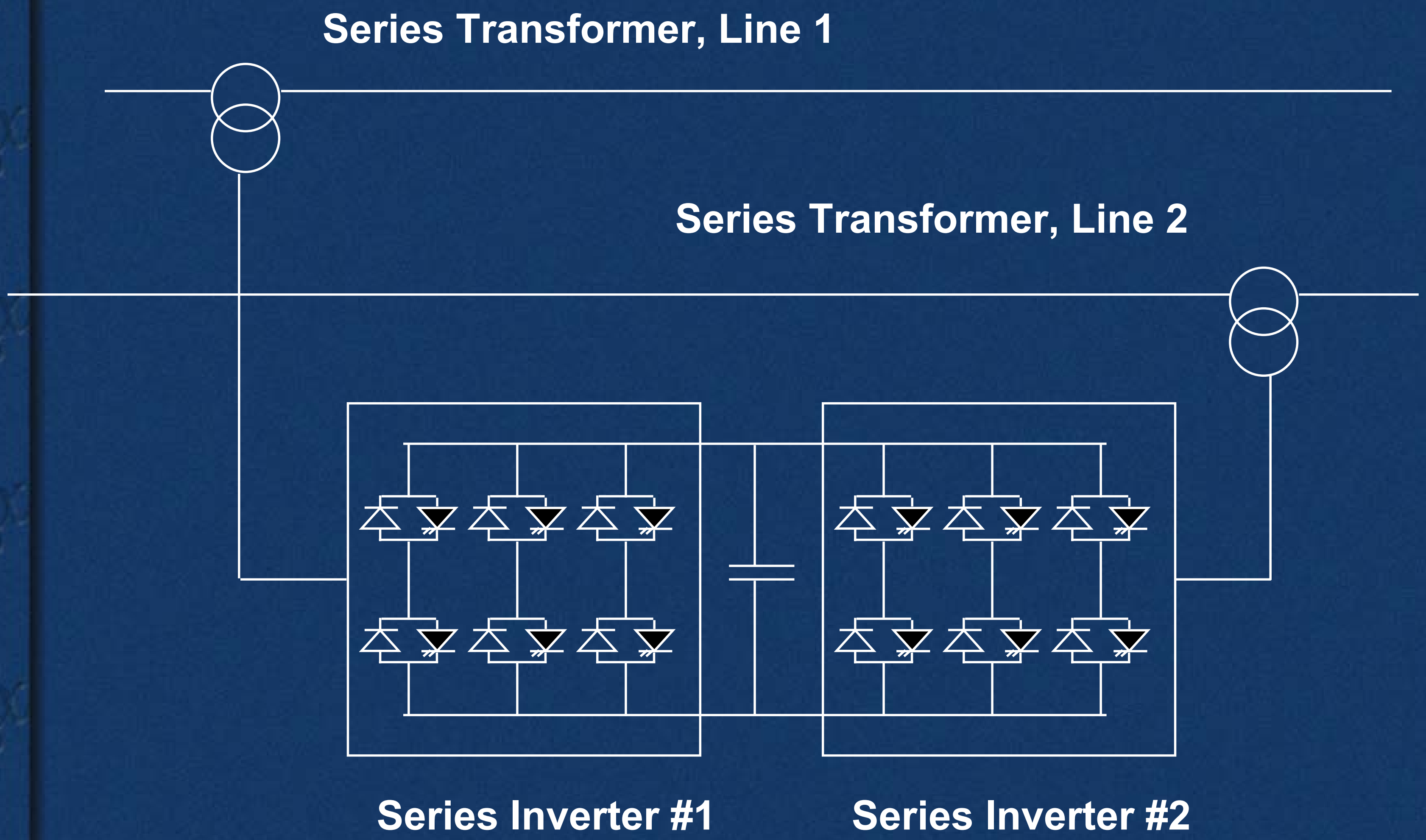


"An hen is only an egg's way of making another egg" - Samuel Butler, British philosopher.

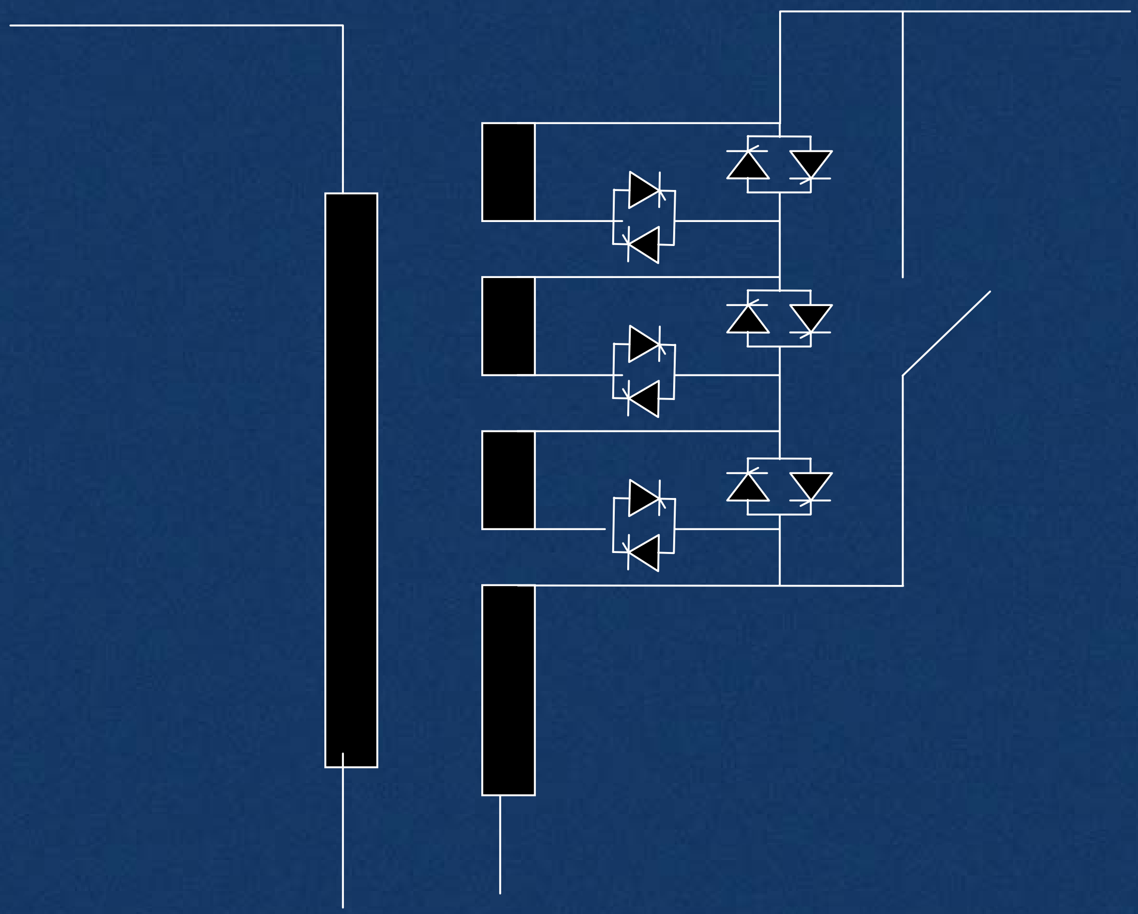
Unified Power Flow Controller - SMES Interface



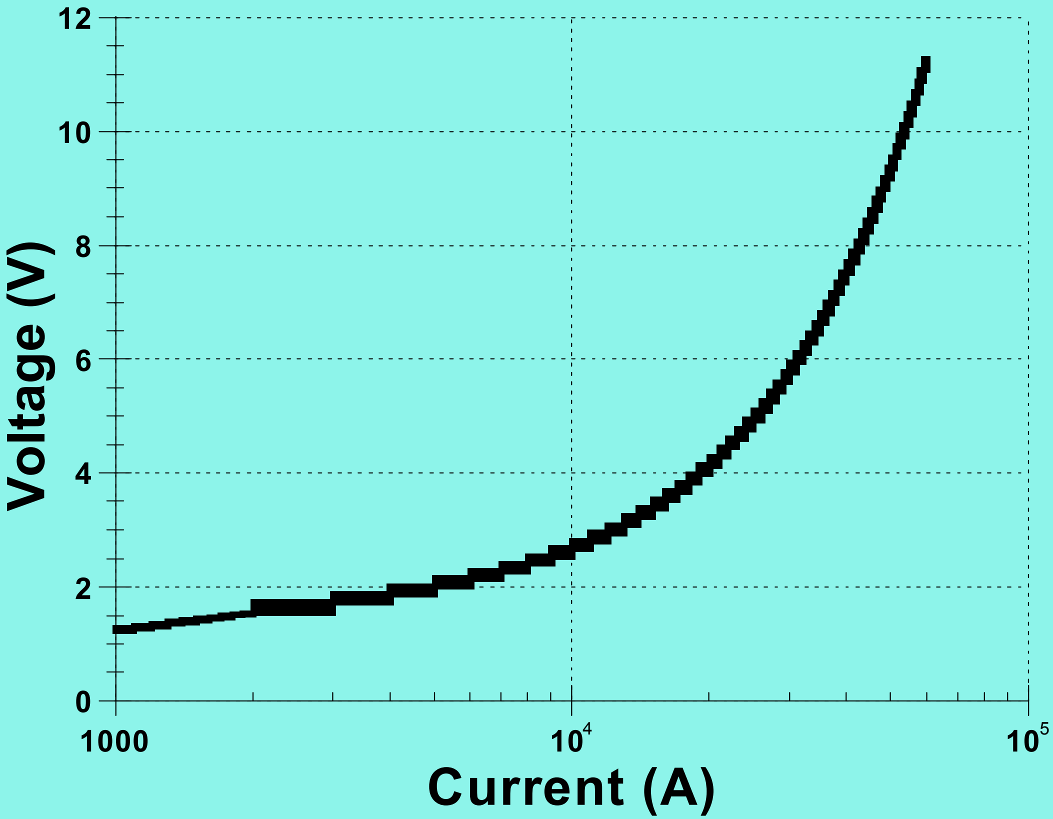
In-Line Power Flow Controller



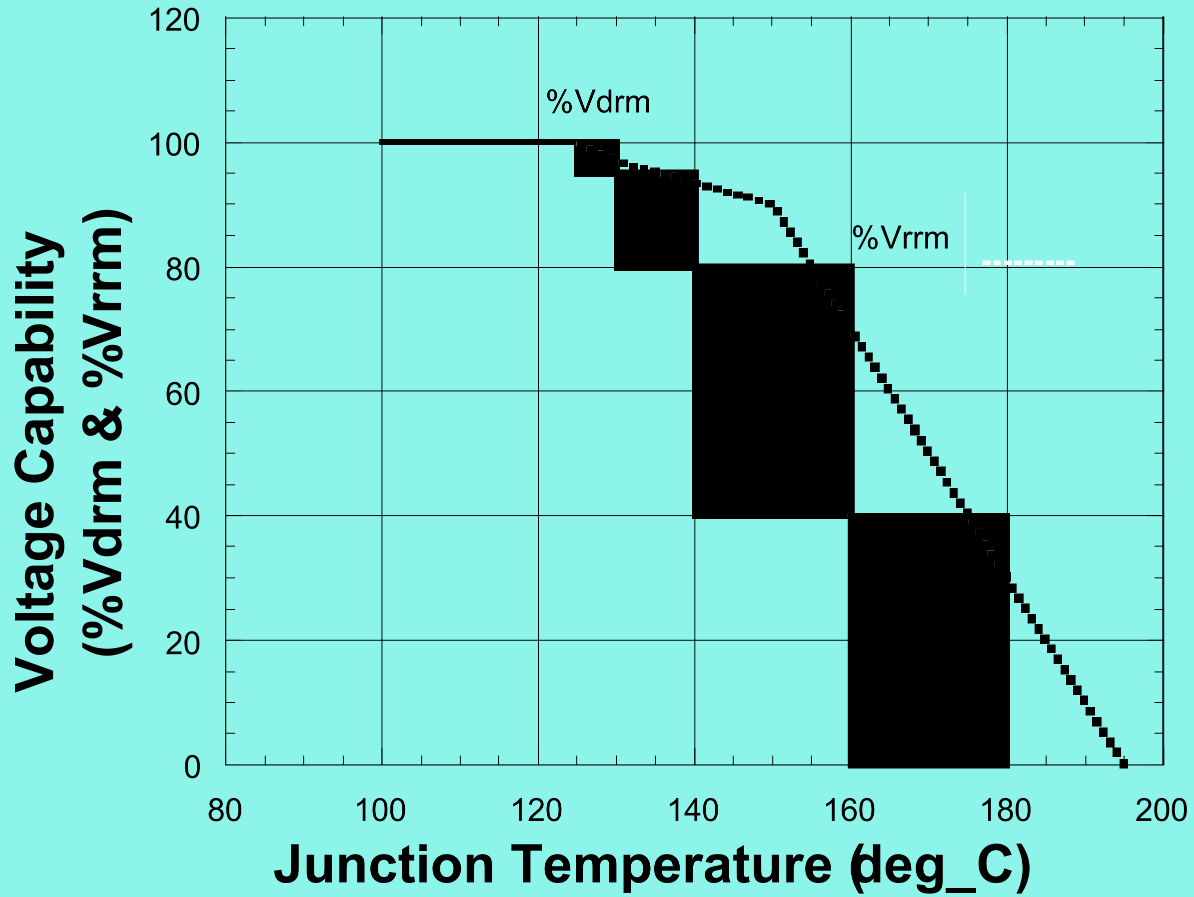
Voltage Regulator
(yet to be developed for transmission applications)



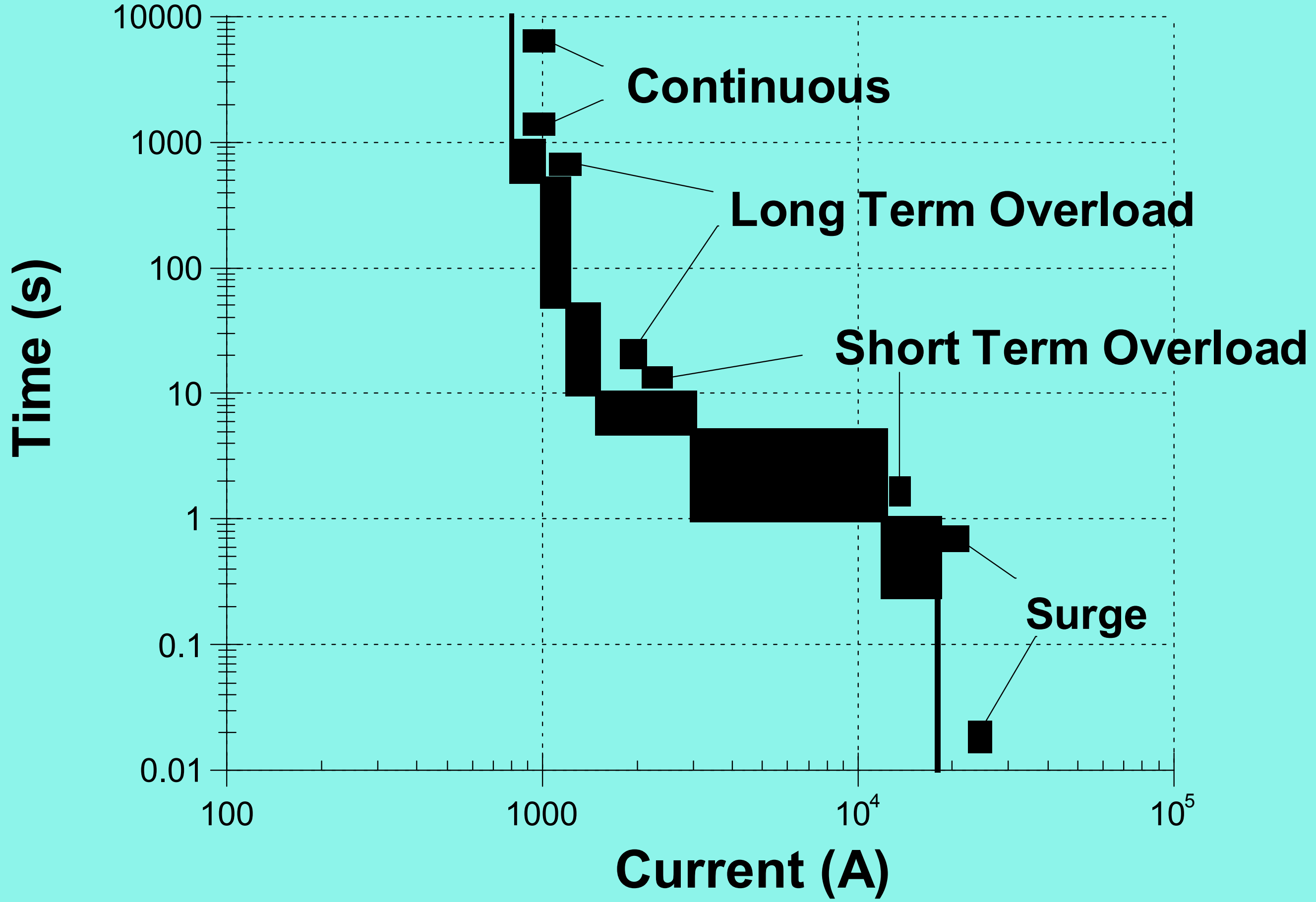
Thyristor Forward Drop = f(I)



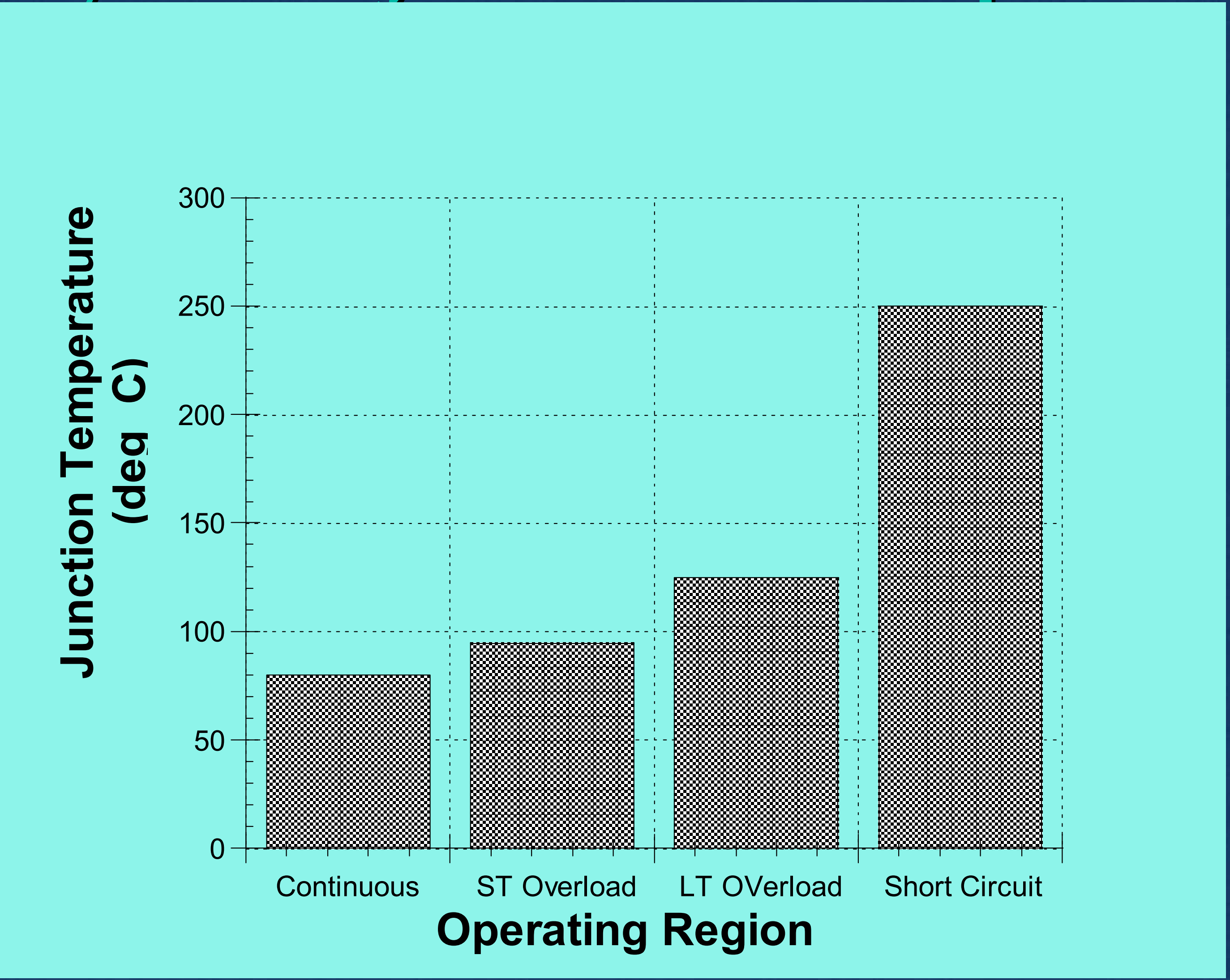
Thyristor Blocking Capability



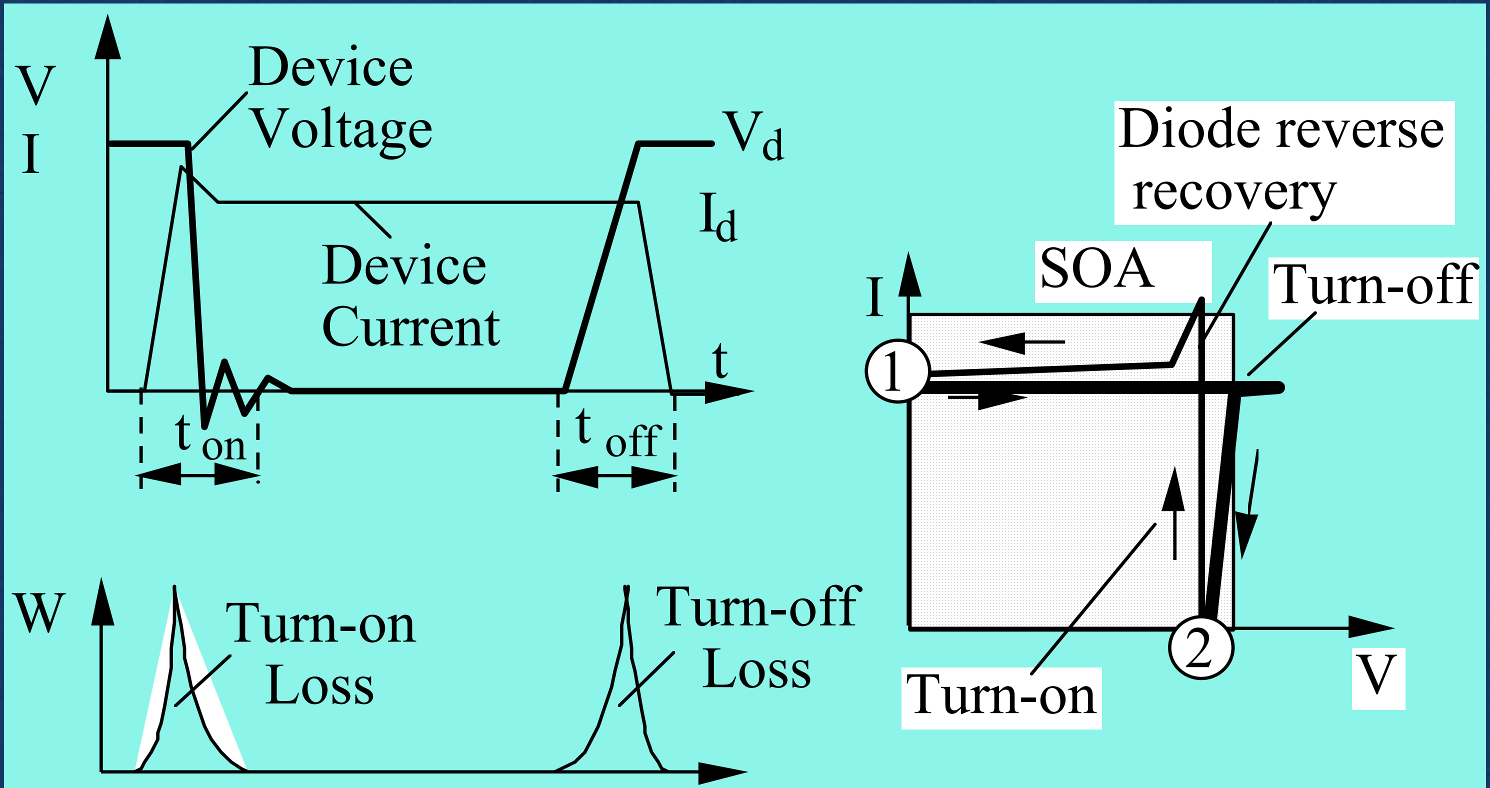
Thyristor Thermal Design



Thyristor Junction Temperature

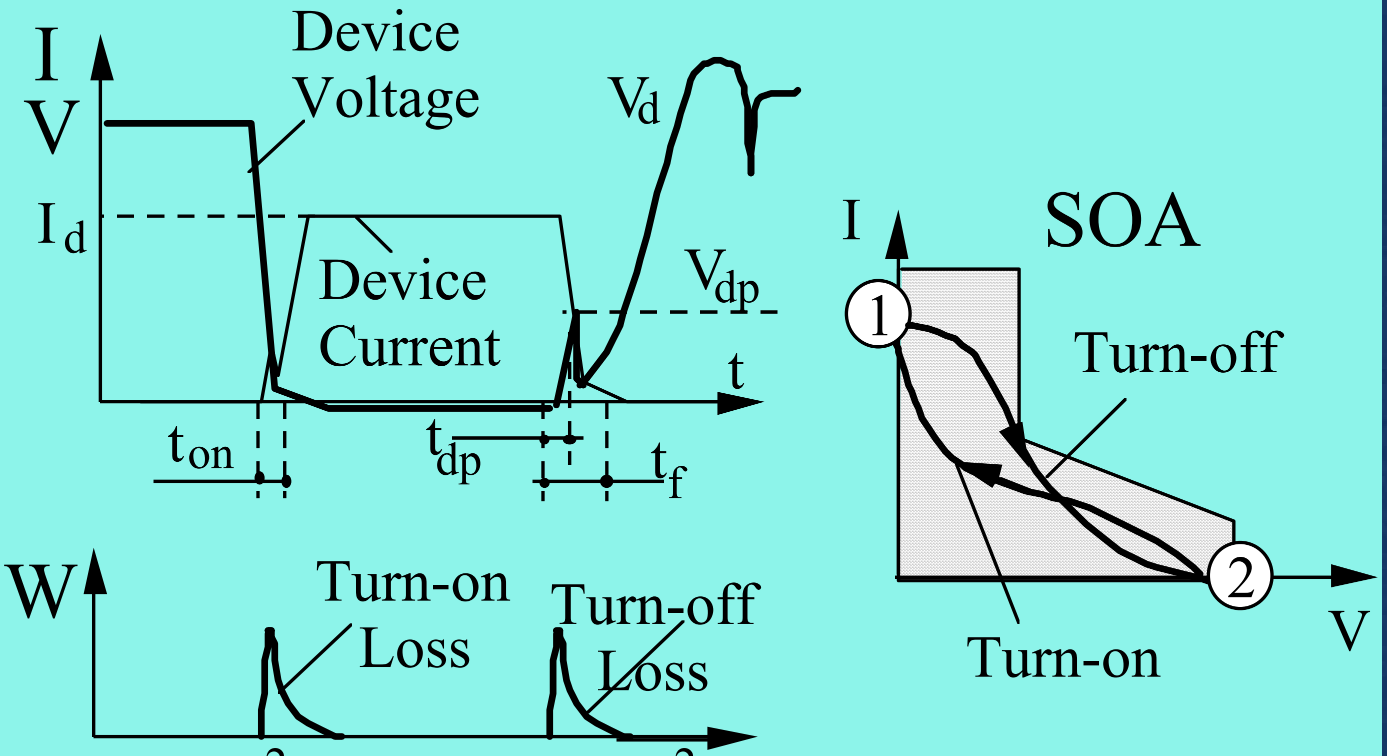


Hardswitching Converters



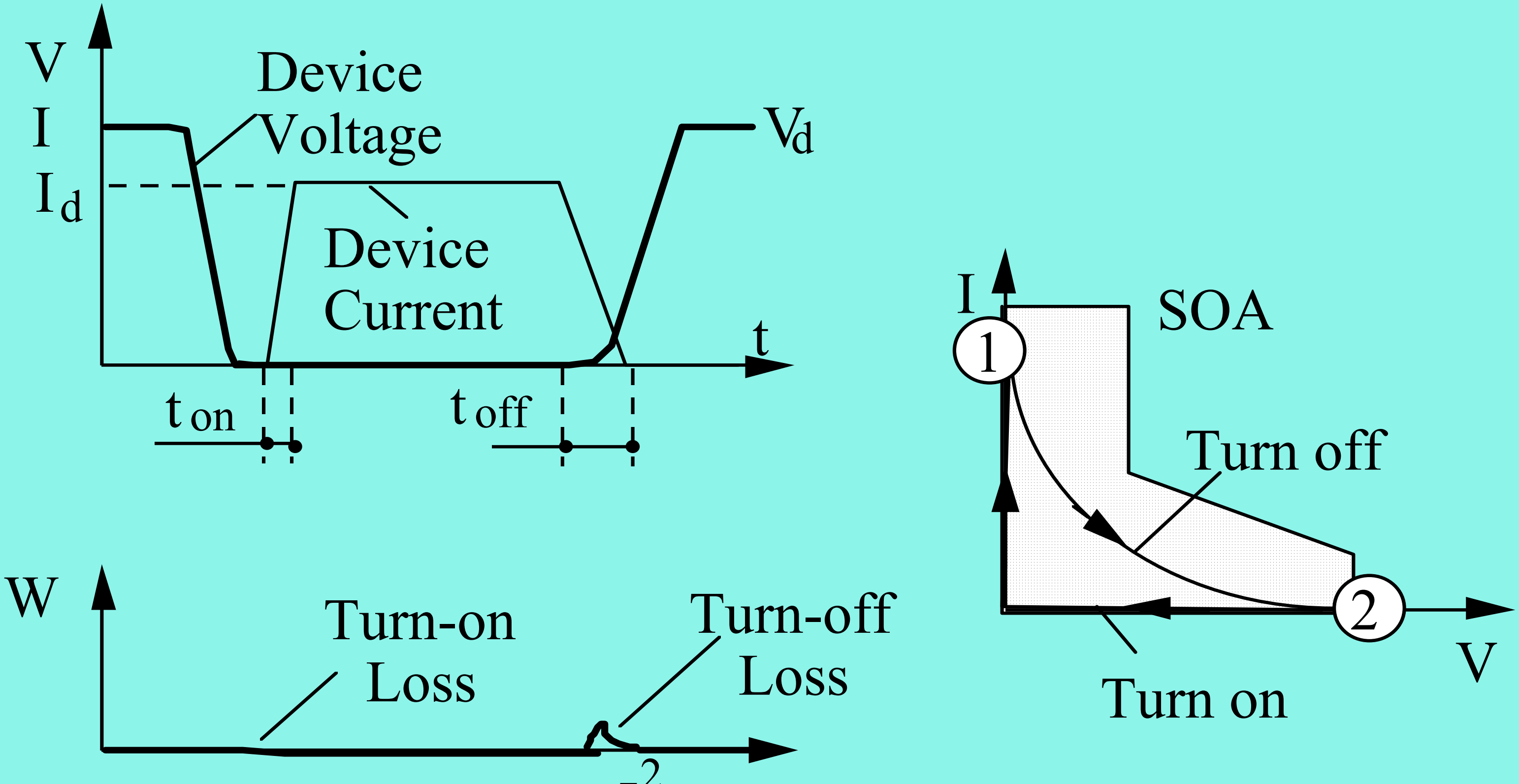
$$E_{on} = \frac{V_d I_d}{2} t_{on} \qquad E_{off} = \frac{V_d I_d}{2} t_{off}$$

Snubber Performance



$$E_{on} = \frac{V_{dc}^2 \, t_{on}}{48\, L_s} \qquad E_{off} = \frac{I_{off}^2}{24\, C_s} t_f^2 + I_{off} V_{dp} t_{dp}$$

Softswitching Converter



$E_{on} = 0$ $\quad E_{off} = \frac{I_{off}^2}{24\, C_r} t_f^2$

TSC, TCR & Statcom

	TSC	TCR	Statcom
Rating	Q_c	$\leq Q_r$	$Q_c \leq Q \leq Q_r$
@ limit	impedance	impedance	I_q= const
ST load limit	device	device	Safe turn-off
Losses	Thyristor conduction	Thyristor switching and conduction	GTO or IGBT switching and conduction
Transformer	$S=Q_c$	$S= Q_r$	S=Q; special
Filter	none	needed	small
Reliability	N-modules	2-modules; 6-pulse	Partial operation?

PAR, TCSC & UPFC

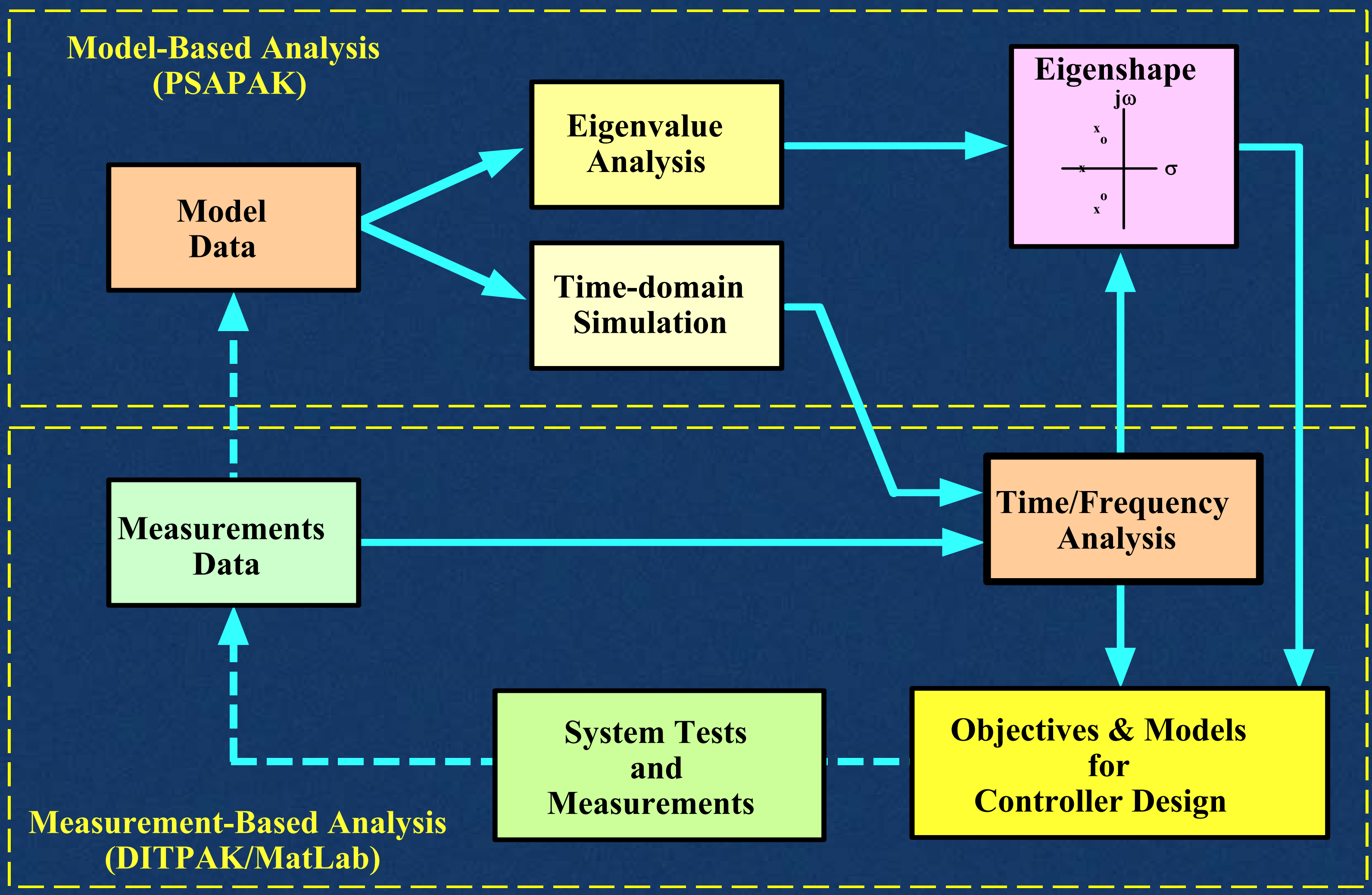
	PAR	TCSC	UPFC
Control range	+/-Ø	Q_c; Q_r	+/- Q_{shunt} +/- Q_{series} $S \geq P$
ST load limit	device	device	Safe turn-off
Application	Low angles	Higher angles	
ST load limit	device	device	Safe turn-off
Losses	Thyristor conduction	Thyristor switching and conduction	GTO or IGBT switching and conduction
Transformer	$S=Q_c$	$S= Q_r$	S=Q; special
Filter	none	none	small
Reliability	1 module	1 to N modules	Common dc link

Security with FACTS

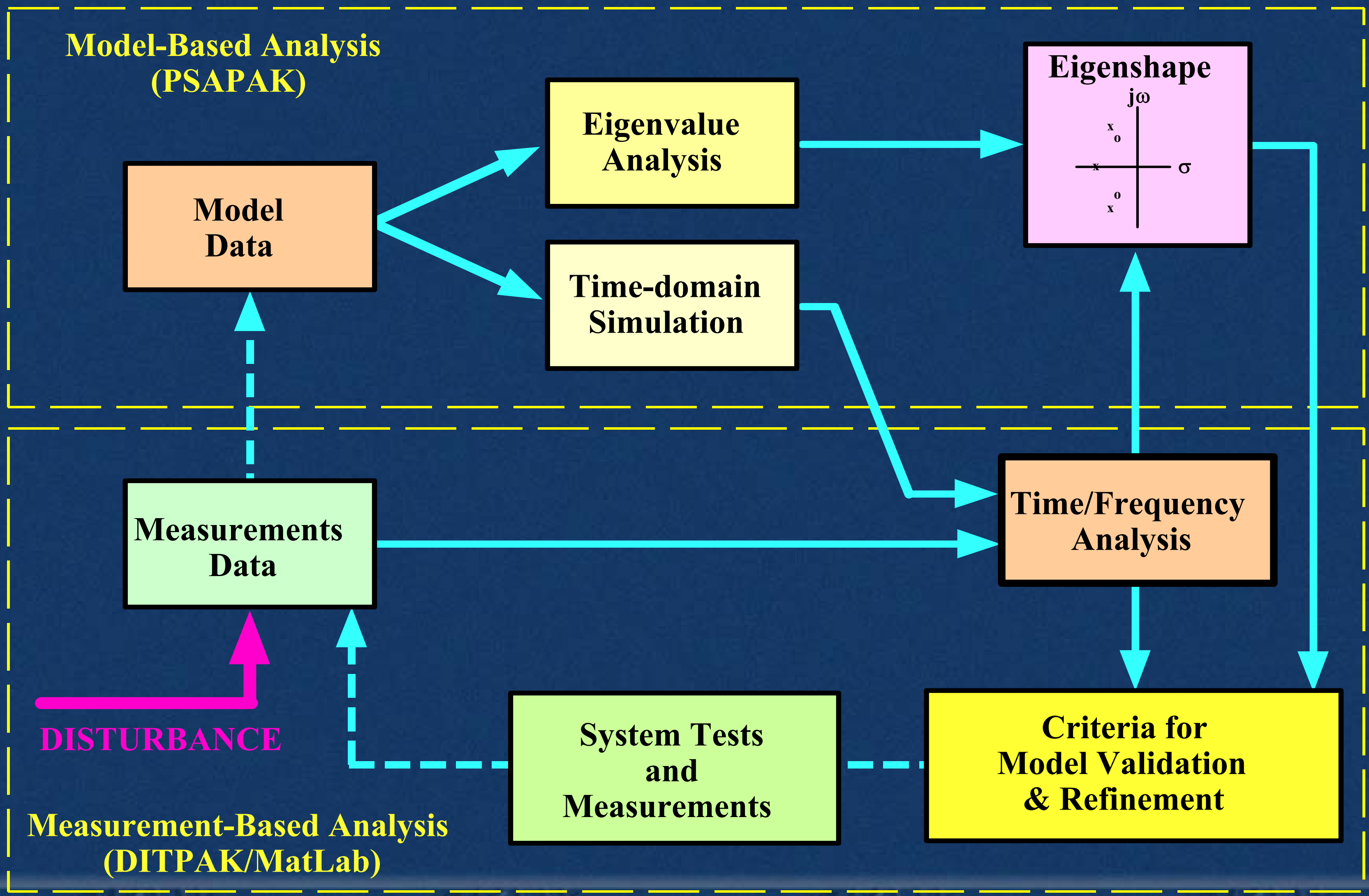
- Failure of FACTS Device
  – N-1 leading to N-2
- System Disturbance
  – N-1 leading to N-2
- Interactions Among FACTS Controllers

"I have seen the future and it is much like the present, only longer - Dan Quisenberry, Kansas City Royals"

Systems analysis for control of power system dynamics



Systems analysis for model validation & refinement



FACTS Concerns

- Method to get maximum power through a line
  - Extreme loading has no experience base
- Losses will increase
  - Balance between efficient lines and less efficient lines possible
  - Losses gives return in 10 to 15 years
    - Are we able to forecast loading that far into the future?

Power Electronics Considerations

- Speed of response
  - less than 1 cycle
  - some performance benefits from higher switching frequency
- SSR
  - all active control systems capable of exciting resonances as well as providing system damping
- Losses
  - Higher line loading equals higher losses
  - Savings potential from better load flow
  - FACTS system losses offset by optimized line losses

Economics of Power Electronics

- Comparison between fixed/switched and dynamic compensation alternatives can not be made on a steady state basis
- Least cost for small power flow increases probably from use of fixed/switched compensation alternatives
- 100 % power electronics probably always highest cost alternative but may be needed for maximum power transfer increase alternatives
- Most likely a combination of fixed/switched and dynamic compensation will be best investment alternative

“Running for money does not make you run fast, it makes you run first - Ben Jipcho, runner.”

CONCLUSIONS

- FACTS is being applied
- Results are encouraging
  - experience better than with most other new technology
  - minor teething problems
  - TCSC alternative to HVdc; facilitates serving loads along the line
  - Brazil & China have applied or are planning to apply TCSC systems
- Transmission access rules not yet clear in the US
  - Delays applications
- No FACTS wars yet

“If fans don’t want to come to the ballpark, nobody can stop them - Yogi Berra, NY Yankees catcher (baseball)”.

“It is what you know after you know it all that counts - John Wooden, UCLA basketball coach.”