Application of Static VAr Compensator in Entergy System to Address Voltage Stability Issues – Planning and Design Considerations

Sharma Kolluri, PE, IEEE Fellow

Entergy Services, Inc.
New Orleans, LA

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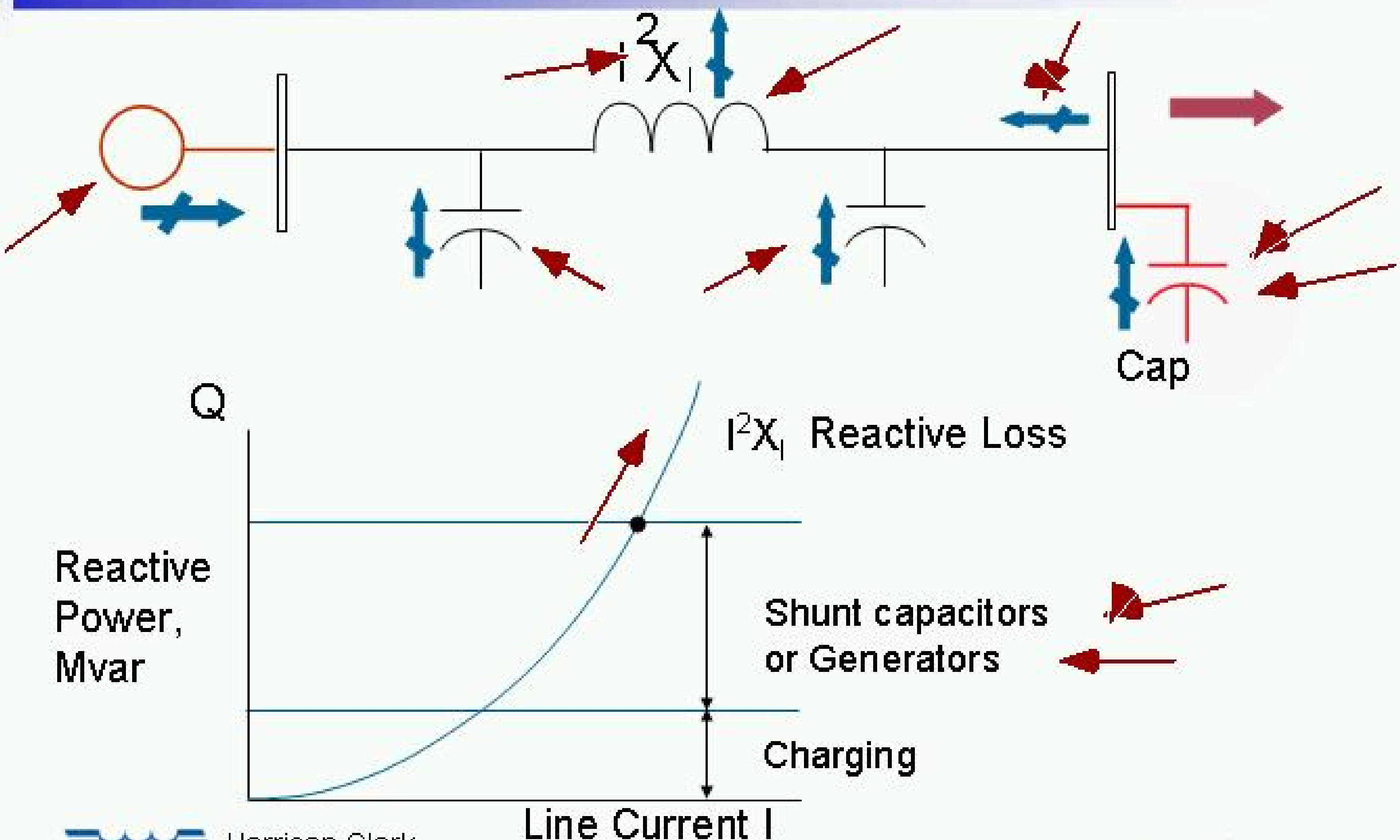
Presentation Outline

I. Introduction
   I. Reactive Power
   II. Voltage Stability
II. Study Methodology/Results
III. Solutions Considered
IV. Design/Protection Considerations
V. External Bank Control
VI. Conclusions

Reactive Power

Line Charging versus Reactive Demand (I2X)



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Reactive Power Management/Compensation

What is Reactive Power Compensation?

- Effectively balancing of capacitive and inductive components of a power system to provide sufficient voltage support.
    - Static and dynamic reactive power

- Essential for reliable operation of power system
    - prevention of voltage collapse/blackout

Benefits of Reactive Power Compensation:

- Improves efficiency of power delivery/reduction of losses.
- Improves utilization of transmission assets/transmission capacity.
- Reduces congestion and increases power transfer capability.
- Enhances grid reliability/security.

Static and Dynamic VAR Support

- Static Reactive Power Devices
  - Cannot quickly change the reactive power level as long as the voltage level remains constant.
  - Reactive power production level drops when the voltage level drops.
  - Examples include capacitors and inductors.

- Dynamic Reactive Power Devices
  - Can quickly change the MVAR level independent of the voltage level.
  - Reactive power production level increases when the voltage level drops.
  - Examples include static VAR compensators (SVC), synchronous condensers, and generators.

Voltage Stability

What is Voltage Instability/Collapse?

- A power system undergoes voltage collapse if post-disturbance voltages are below "**acceptable limits"**
  - voltage collapse may be due to voltage or angular instability
- Main factor causing voltage instability is the inability of the power systems to "**maintain a proper balance of reactive power and voltage control"**

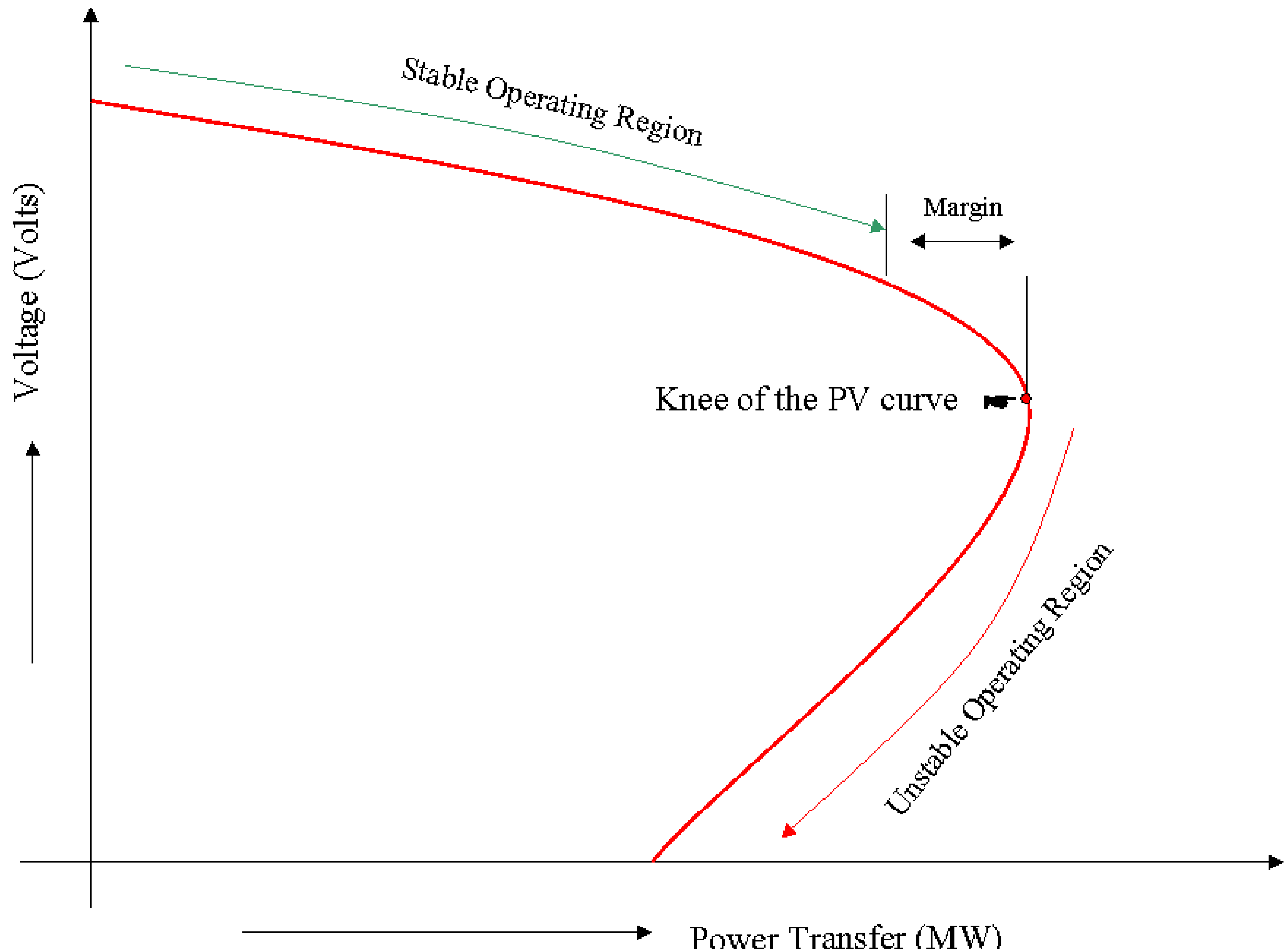
Voltage Instability/Collapse

- The driving force for voltage instability is usually the load
- The possible outcome of voltage instability:
  - loss of loads
  - loss of integrity of the power system
- Voltage stability timeframe:
  - transient voltage instability: 0 to 10 secs
  - long-term voltage stability: 1 – 10 mins

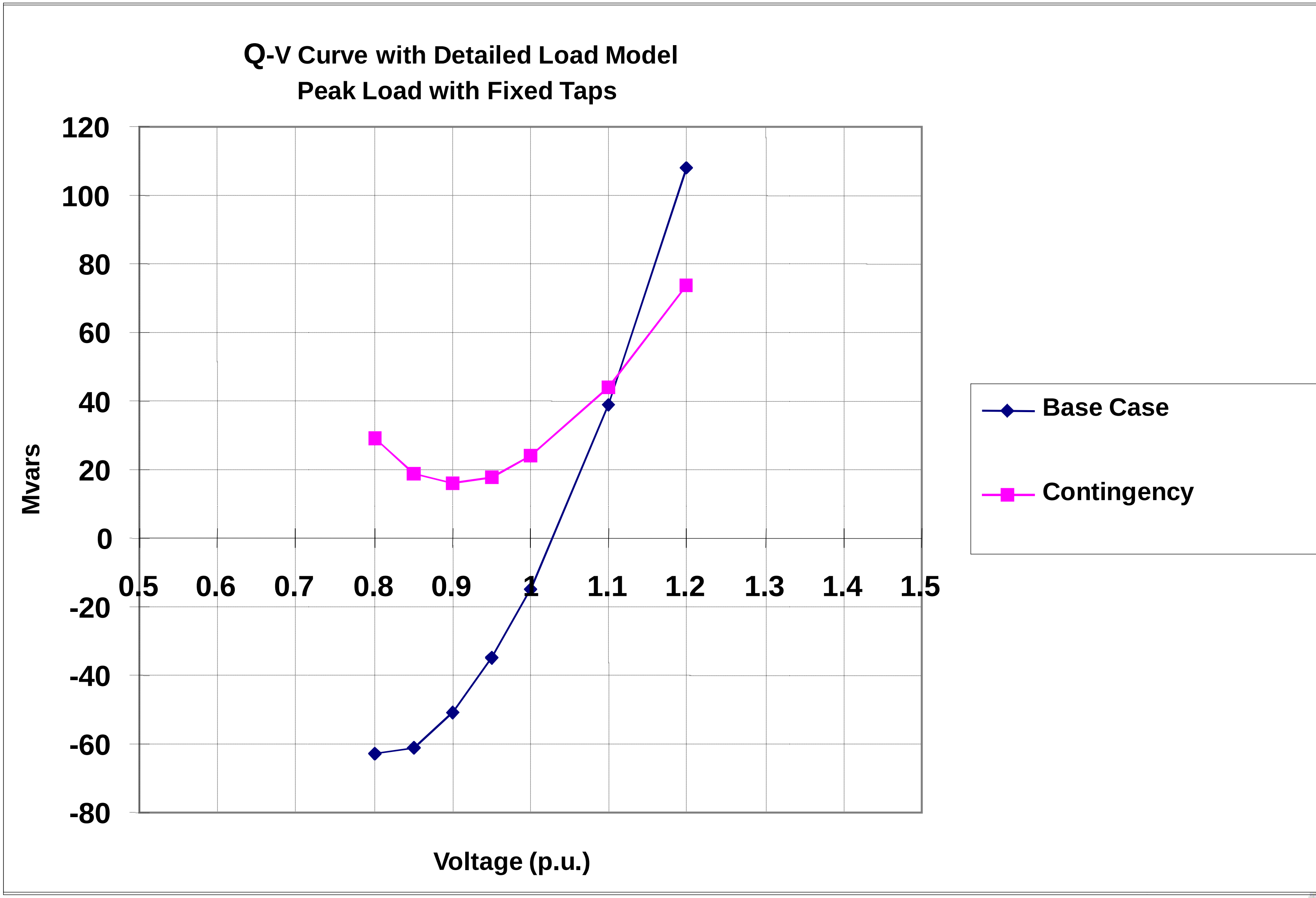
Voltage stability causes and analysis

- Causes of voltage instability :
  - Increase in loading
  - Generators, synchronous condensers, or SVCs reaching reactive power limits
  - Tap-changing transformer action
  - Load recovery dynamics
  - Tripping of heavily loaded lines, generators

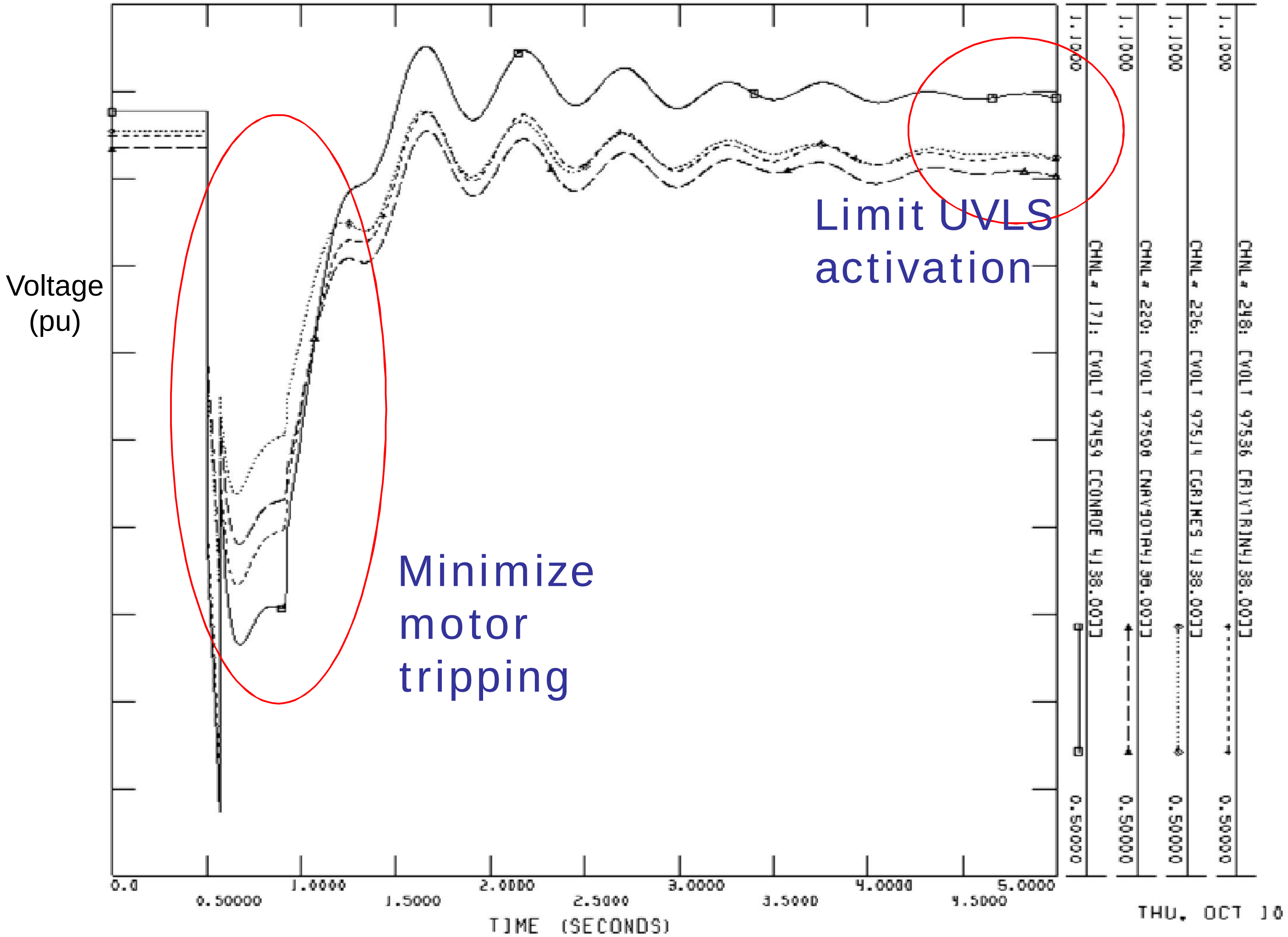
P-V Curve


Stable Operating Region
Margin
Voltage (Volts)
Knee of the PV curve
Unstable Operating Region
Power Transfer (MW)

Q-V Curve


Q-V Curve with Detailed Load Model
Peak Load with Fixed Taps
120
100
80
60
40
20
0
-20
-40
-60
-80
Mvars
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Voltage (p.u.)
Base Case
Contingency

Key Concerns

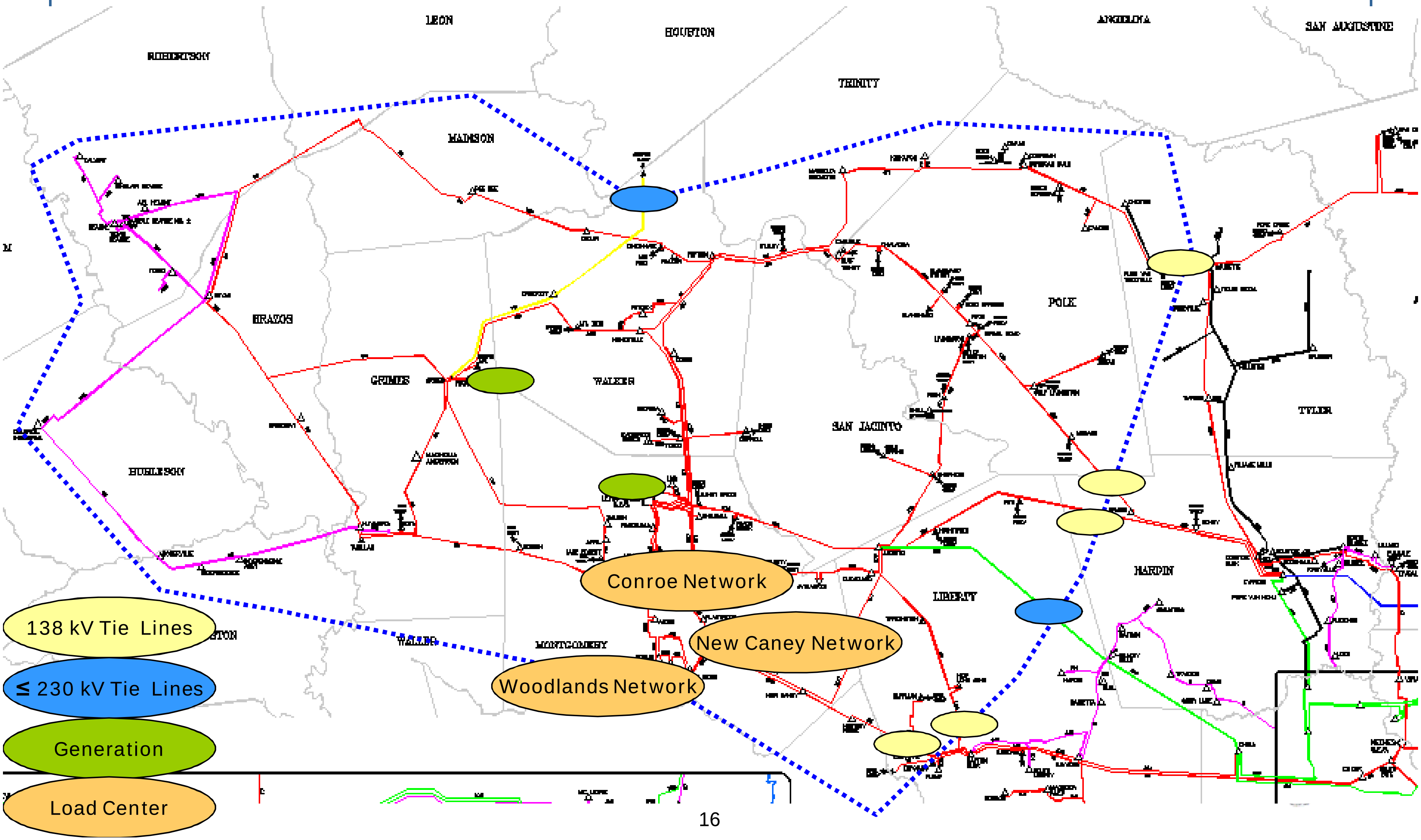


Possible Solutions for Voltage Instability

- Install/Operate Shunt Capacitor Banks
- Add dynamic Shunt Compensation in the form of SVC/STATCOM to mitigate transient voltage dips
- Add Series Compensation on transmission lines in the problem area
- Implement UVLS Scheme
- Construct transmission facilities

Voltage Stability Study for Western Region

Western Region – Overview

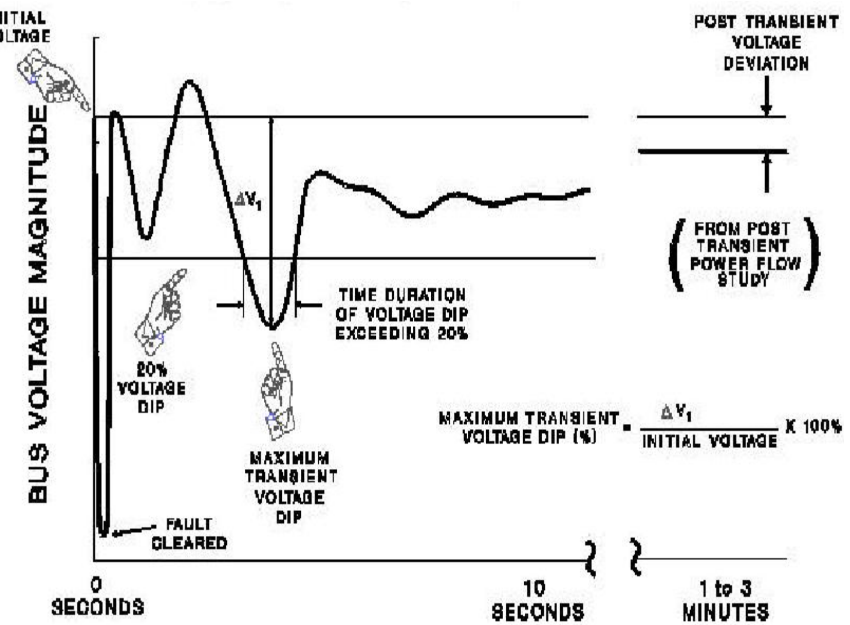


Study Objective

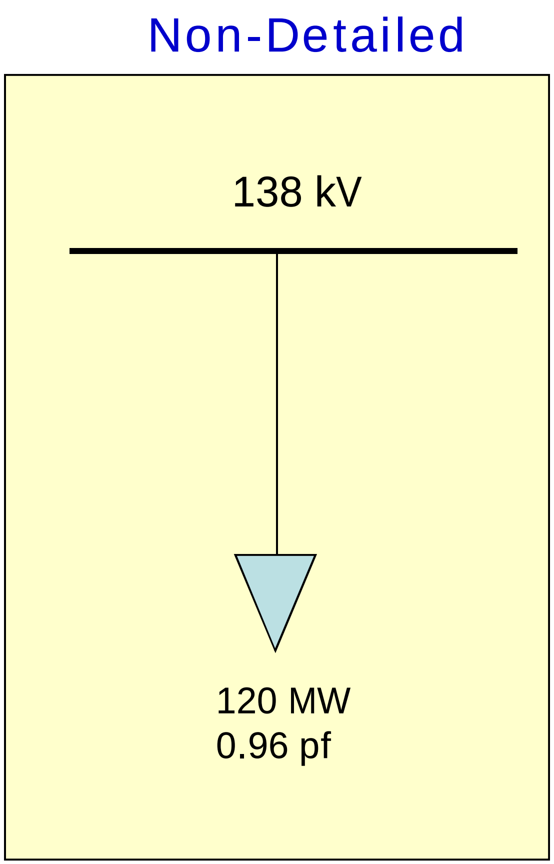
- Assess the nature of the Western Region voltage instability problem
- Analyze and recommend reactive compensation measures (size, type, location) to mitigate system problems

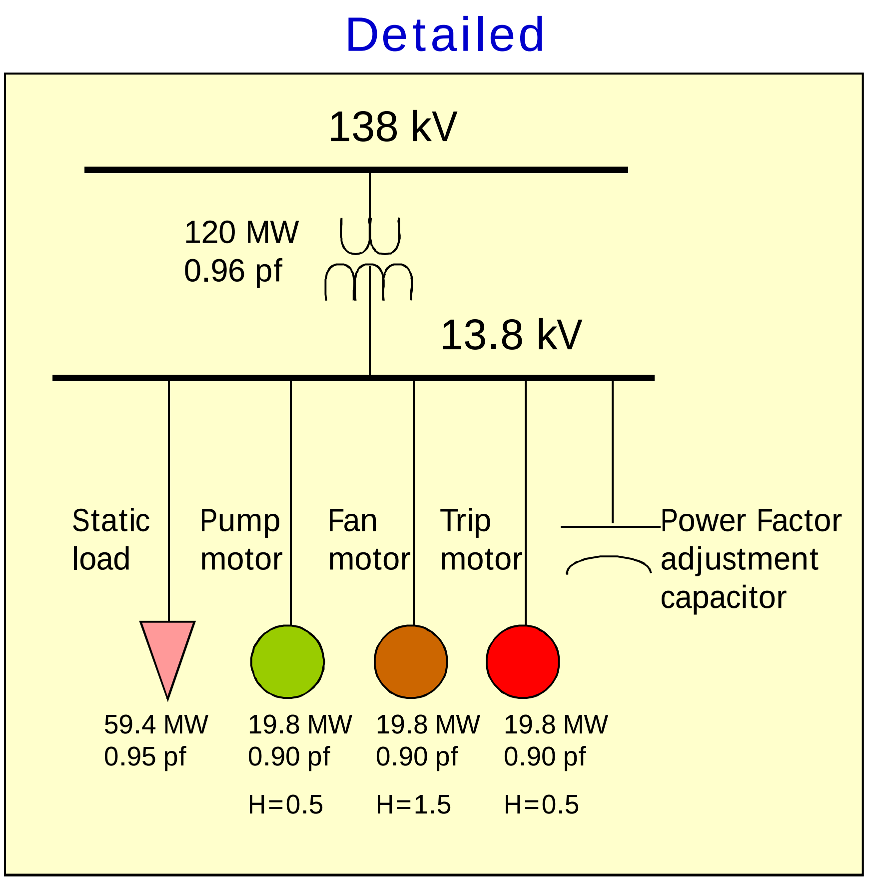
Key Concerns

- Transient Problem
  - Minimize motor tripping
- Steady State Problem
  - Return 138 kV buses post contingency to voltages above 0.92 pu
- Thermal Issues
  - Avoid thermal violations



Load Modeling





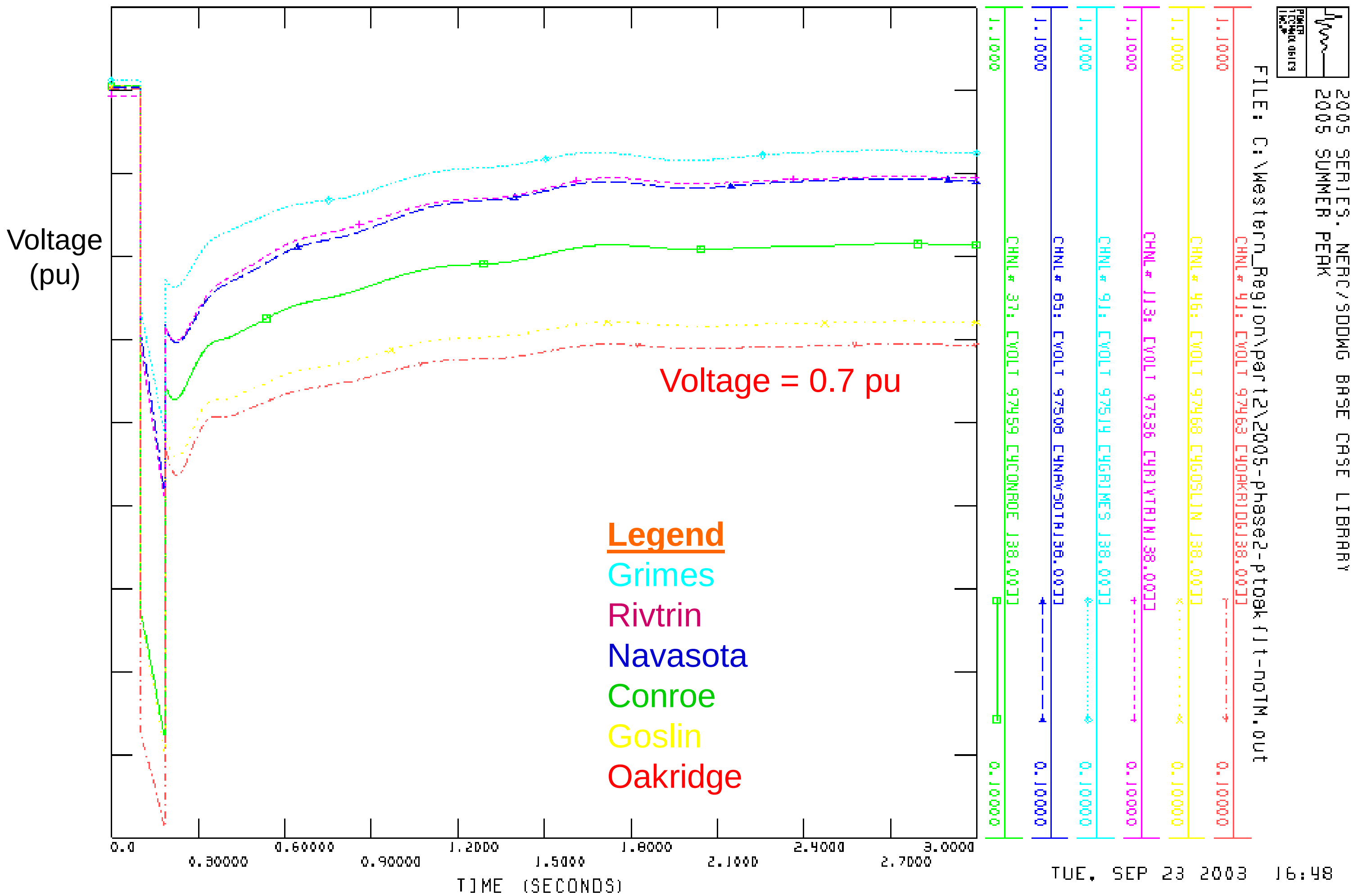
Critical Contingencies Studied

- Lewis Creek Unit 1 out-of-service
  - Fault and trip
    - China – Jacinto 230 kV line
    - Grimes – Crockett 345 kV line
    - Lewis Creek Unit 2
    - Oakridge – Tamina 138 kV line
    - Jacinto – Peach Creek 138 kV line

Results

Without motor tripping being simulated

Oakridge - Tamina Fault



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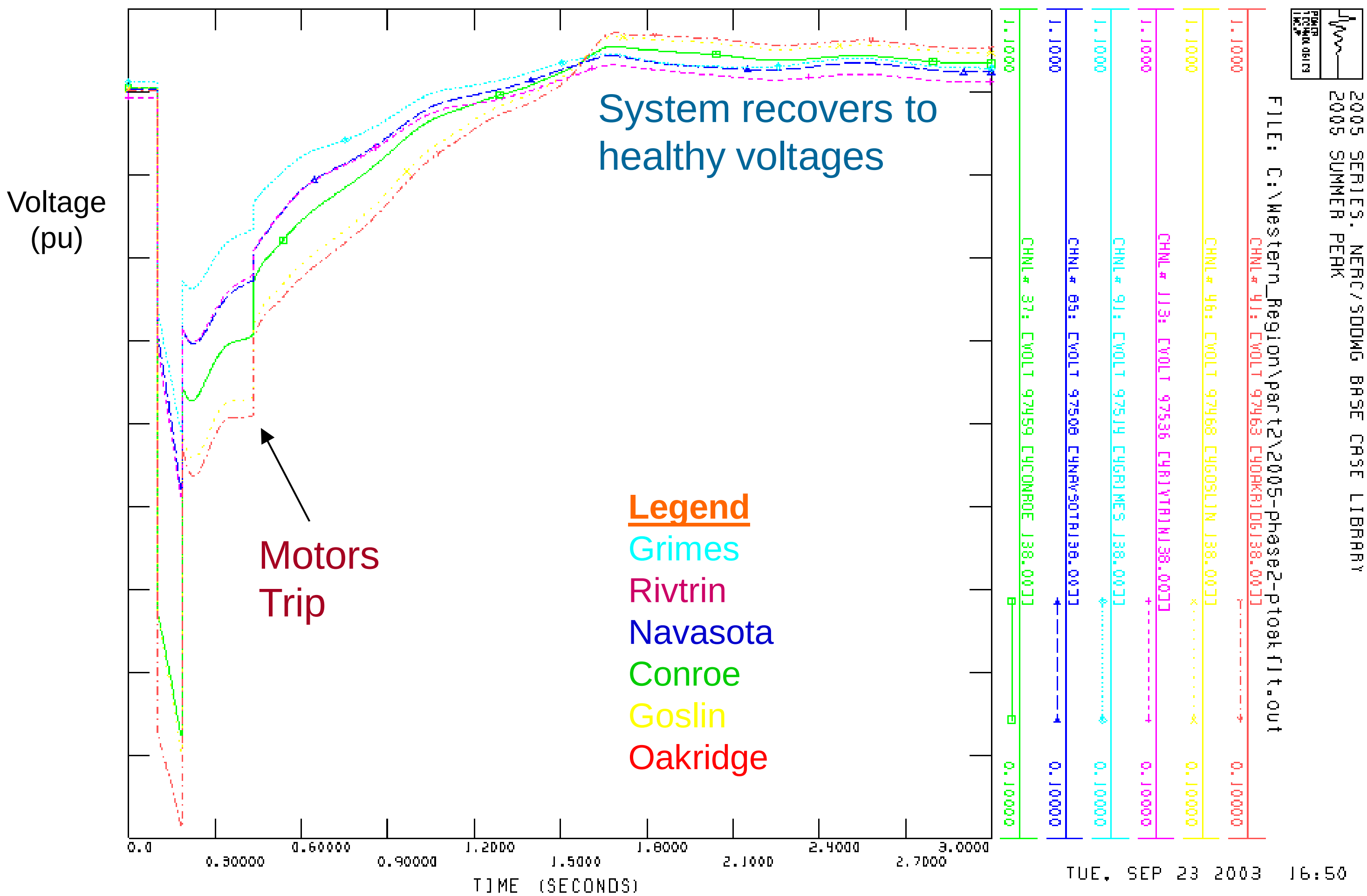
Results

With motor tripping being simulated

Oakridge - Tamina Fault

- Criterion for motor trip : Voltage < 0.7 pu for > 20 cycles

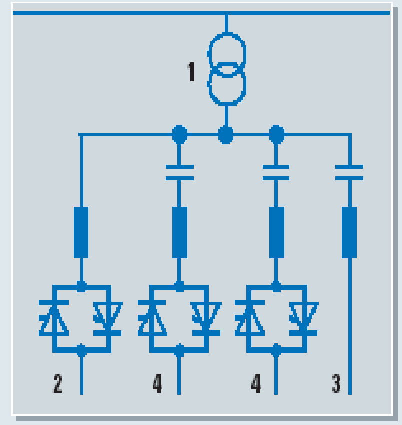


Solutions Considered

- System reinforcements to mitigate the voltage instability with the proposed China-Porter 230 kV series compensated line were:
  - SVC
  - STATCOM
  - Distributed VAR

What is a SVC?

- The SVC typically consists of a
  - Coupling Transformer
  - TCR (Thyristor Controlled Reactor)
  - TSC (Thyristor Switched Capacitor)
  - ACF (AC Filters)
- TCR continuously controls reactive power by varying the current amplitude flowing through the reactors
- TSC switches the capacitors on and off
- AC filters provide fixed reactive power and absorb the harmonic current generated by TCR

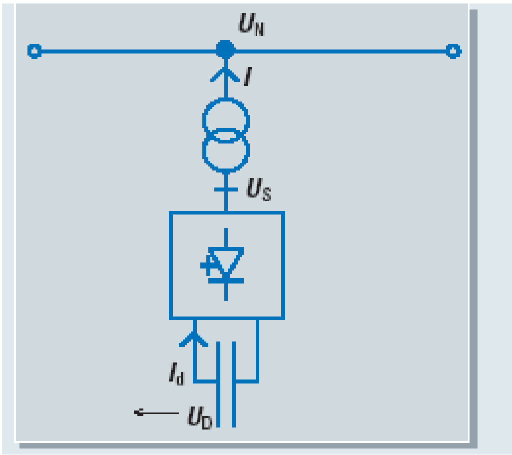


1 Transformer
2 Thyristor-controlled reactor (TCR)
3 Fixed connected capacitor/filter bank
4 Thyristor-switched capacitor bank (TSC)

- Output can be asymmetric, e.g. +300 MVAR, -100 MVAR
- TCR+ACF is the most basic configuration of the SVC
- TCR+TSC+ACF, the more advanced configuration, can be tuned to minimize the losses at the most frequent operation point
- Reactive power control is fast

What is a STATCOM?

- STATCOM consists of
  - Coupling Transformer
  - Inverter Bridge
  - DC capacitor
- Output is always symmetric, e.g. ±100 MVAR



- Reactive power control is fast and continuous from inductive to capacitive through the adjustment of the inverter AC voltage output

What are Distributed VARs?

- They are smaller size of SVC or STATCOM at the distribution level
  – DVAR: Distribution level STATCOM
  – AVC (Adaptive VAR Compensator): Distribution level SVC
- Distributing VAR support where it is needed – closer to loads

Recommendation

- SVC was the most suitable solution for the problem in the Western Region
- Reasons
  - Total dynamic and steady state VAR requirement for this area is very large
  - Traditionally SVCs are applied to address voltage problem in large area whereas distributed solutions are applied to provide local voltage support
  - SVC has a proven track record (> 1,000 installations) – matured technology
  - SVC is capable of damping power system oscillation
  - SVC can be used under light load conditions for voltage regulation, thereby avoiding capacitor switching

Details of SVC Solution

- Full dynamic range required
  - SVC must be normally at zero output during peak load conditions
- Size
  - Dynamic: 300 MVAR
  - Steady State: 210 MVAR
- Location – Porter 138 kV station

Typical SVC Configuration

① Step-down transformer

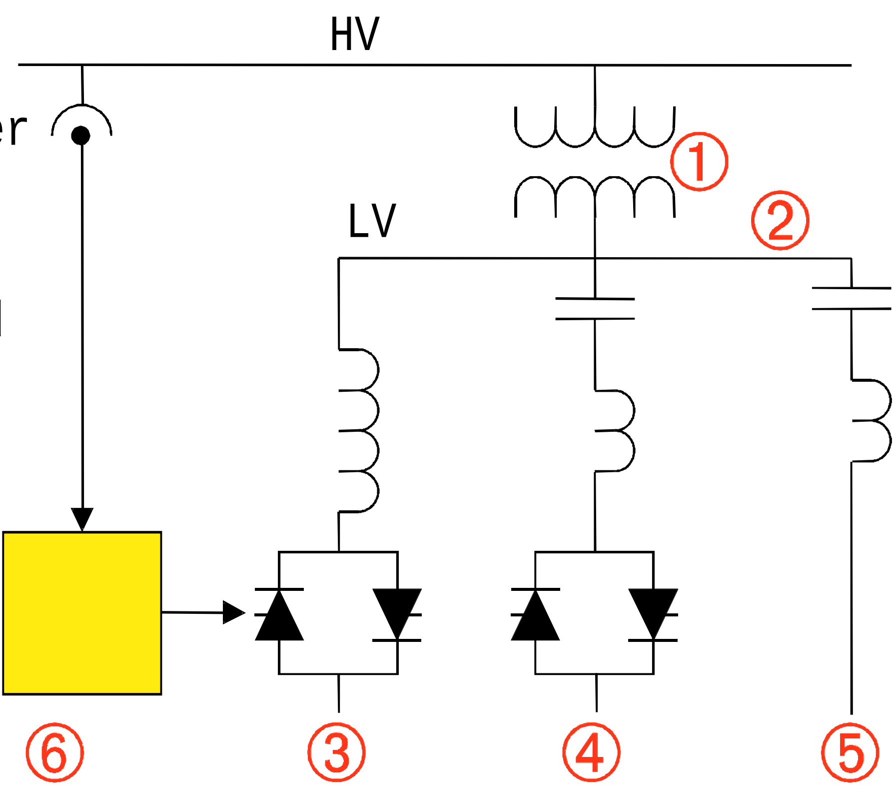
② LV bus bar

③ Thyristor controlled reactor

④ Thyristor switched capacitor

⑤ Fixed filter circuit

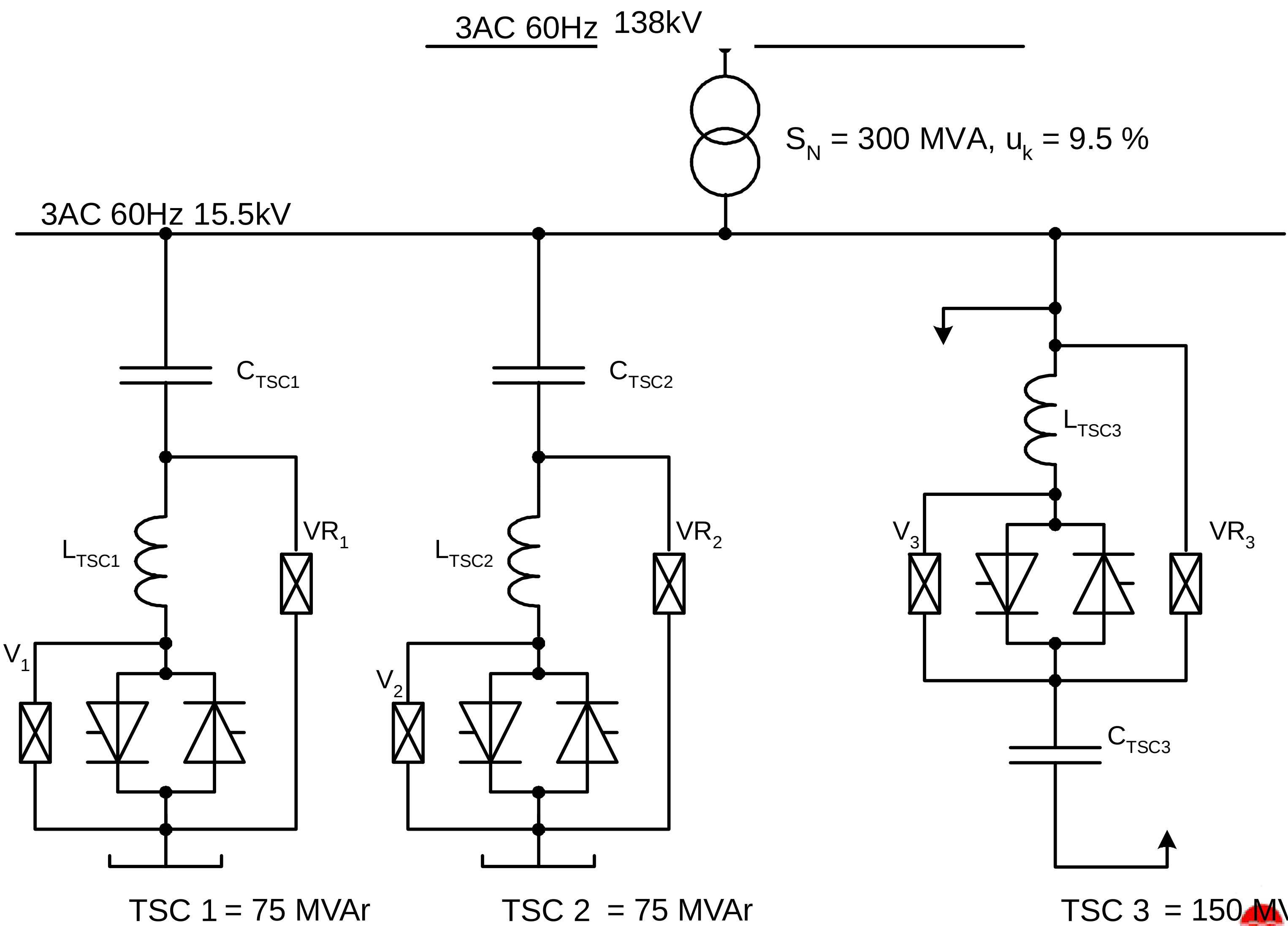
⑥ Control



Porter Static VAR Compensator (SVC)

- Main Components
  - Step Down Transformers
  - Capacitors
  - Cooling System
  - Thyristors
- Switching Logic
  - Voltage Control
  - Reactive Power Control
- Coordinated Remote Capacitor Switching
  - Issues
  - Implementation

Porter SVC Configuration



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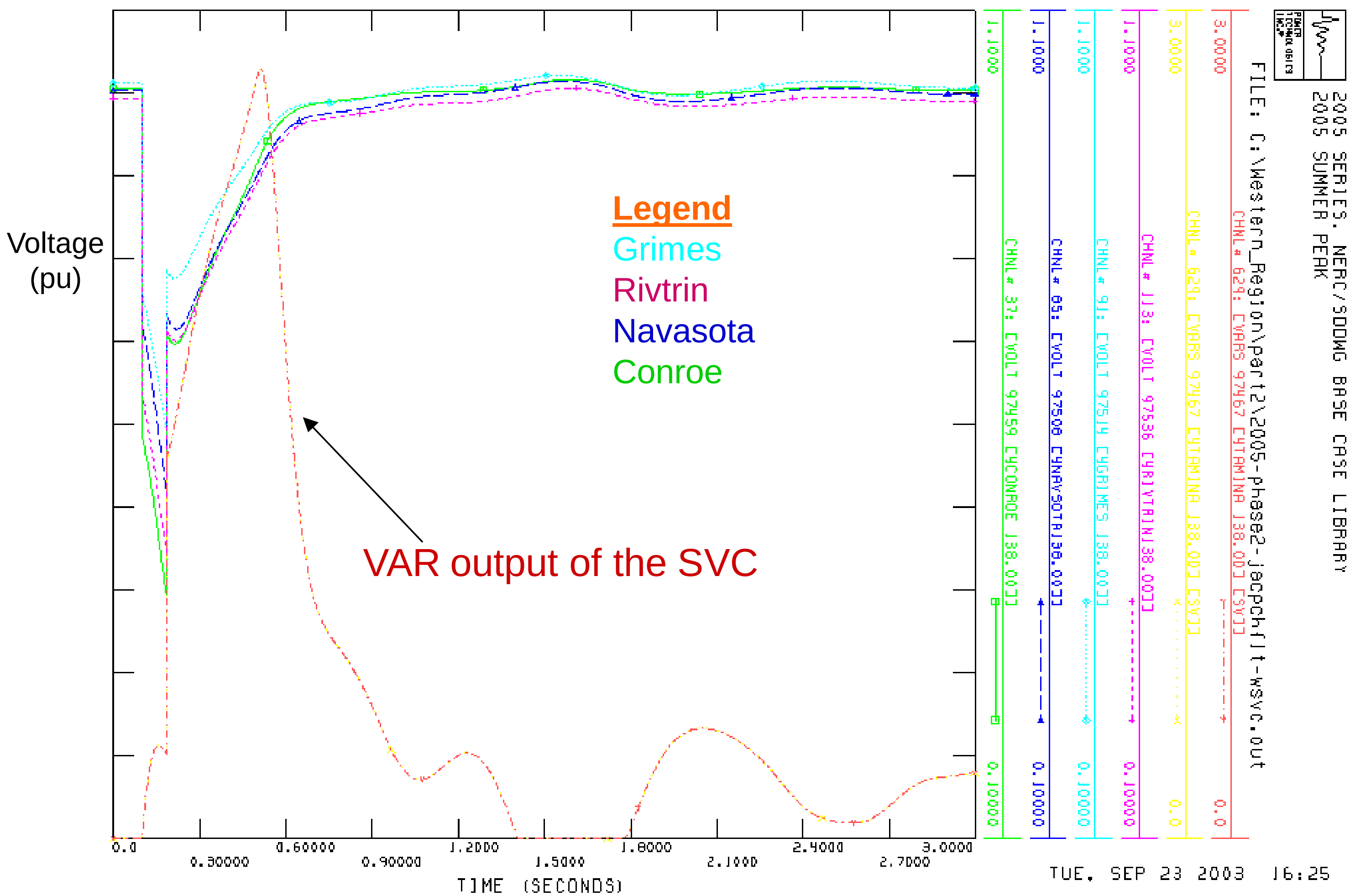
SVC Performance

Dynamic Rating

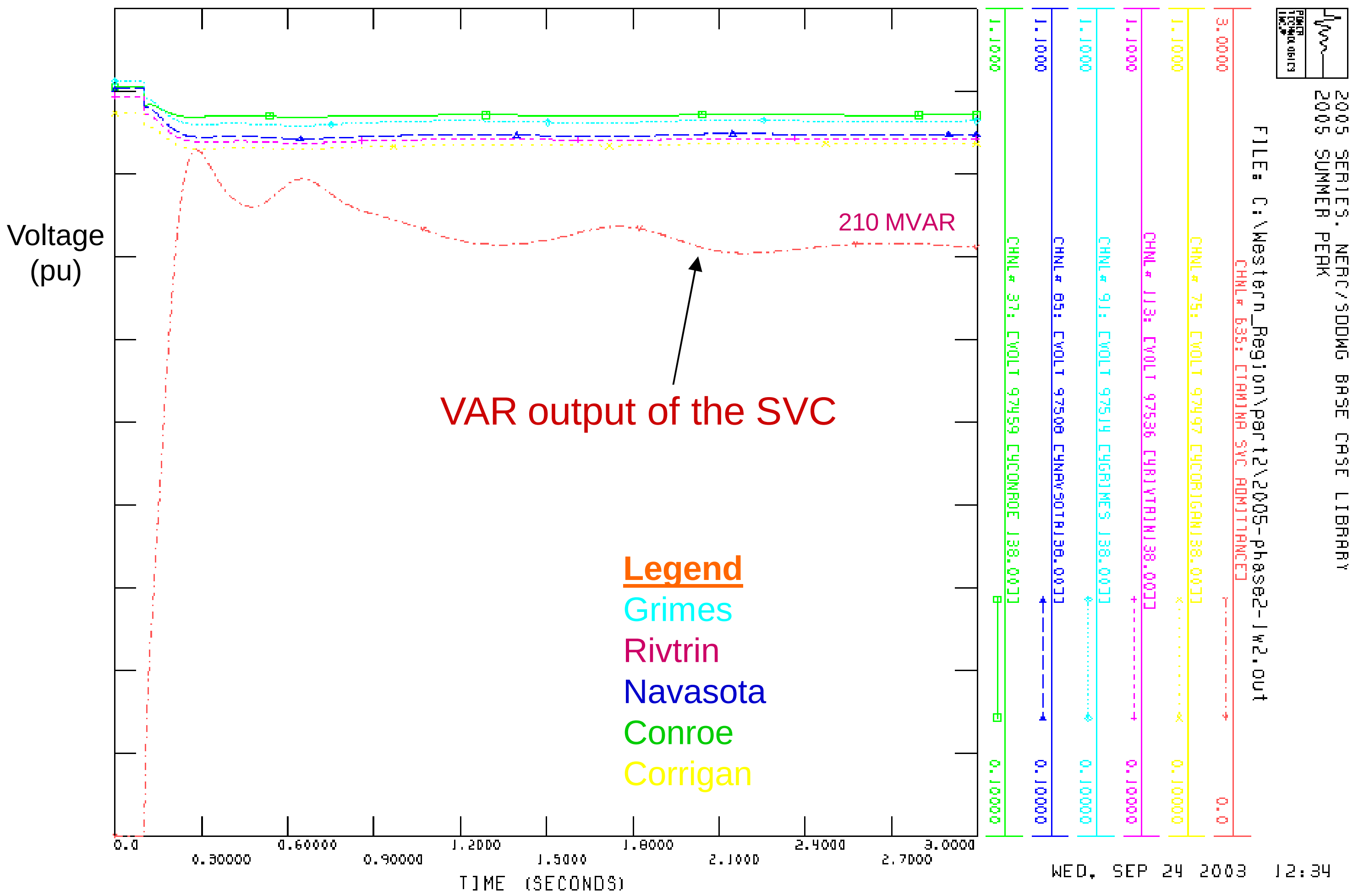
Jacinto – Peach Creek Fault



SVC Performance

Steady State Rating

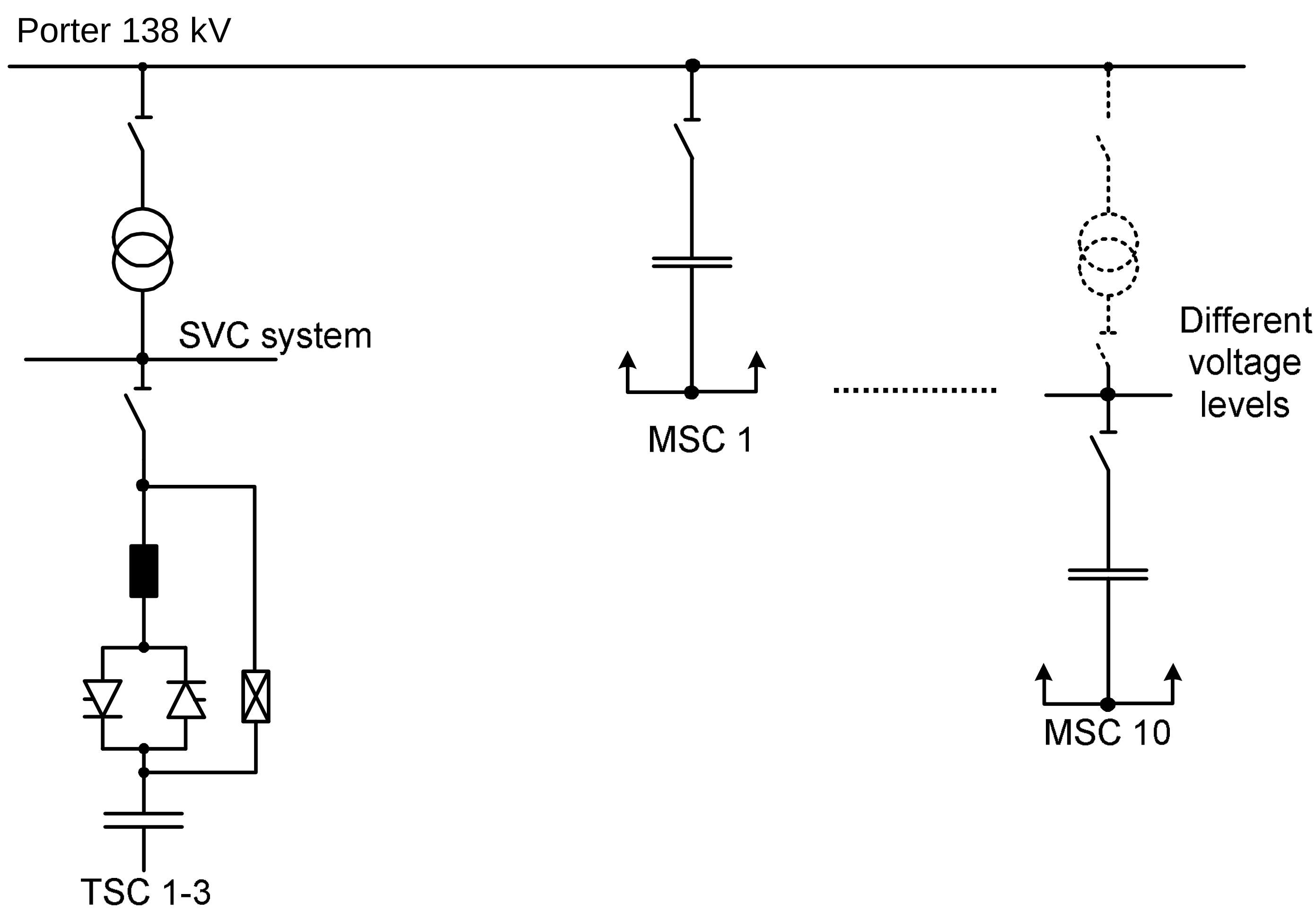
Two Lewis Creek Units Out



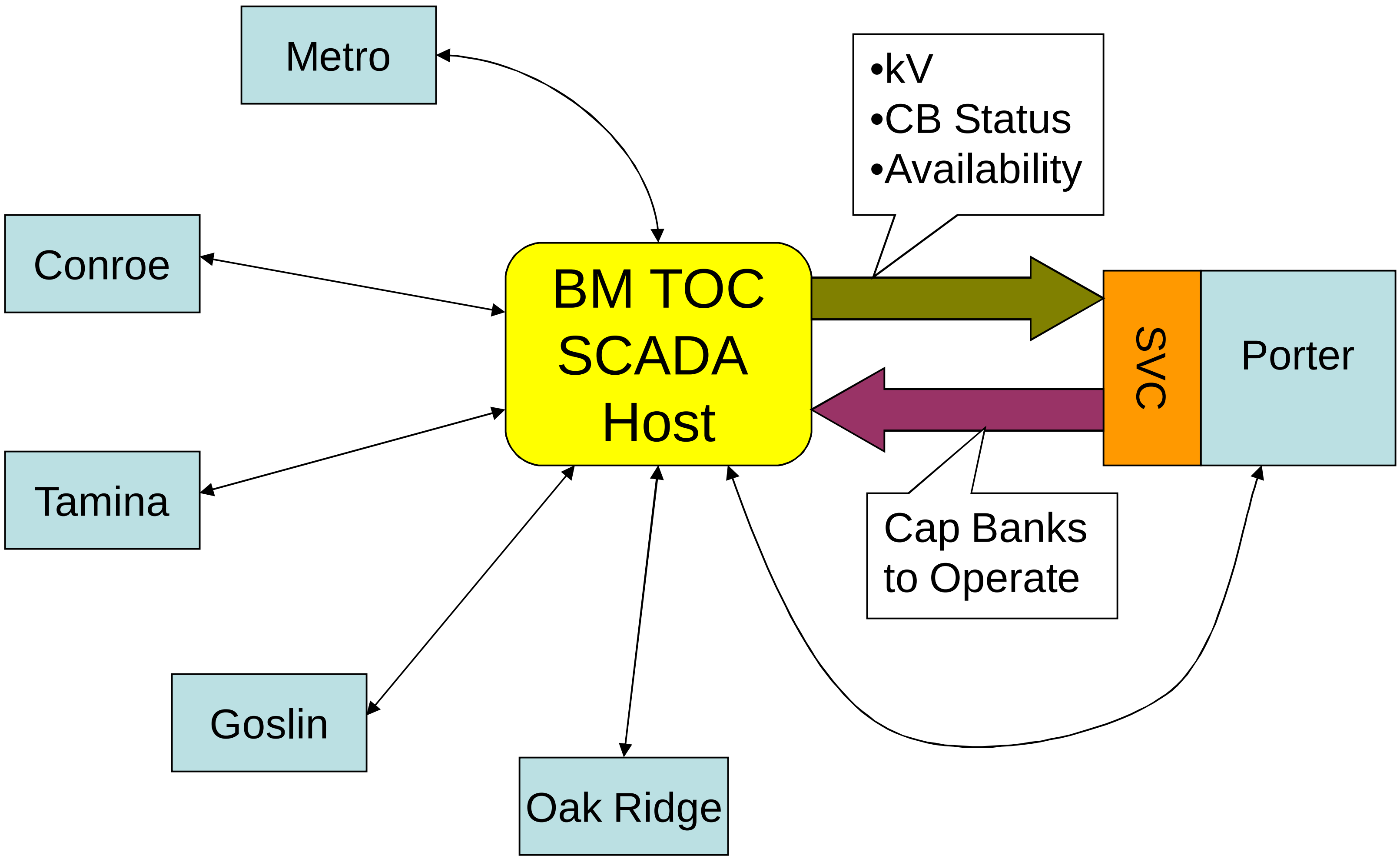
Switching Steps of the SVC

Operation Mode				
#	TSC 3	TSC 2	TSC 1	Reactive Power (Q)
8	0	0	0	0 MVAr
7	0	0	1	75 MVAr
6	0	1	0	75 MVAr
5	0	1	1	150 MVAr
4	1	0	0	150 MVAr
3	1	0	1	225 MVAr
2	1	1	0	225 MVAr
1	1	1	1	300 MVAr

External Device Control
Single line diagram of SVC and MSC



Coordinated Cap bank Control



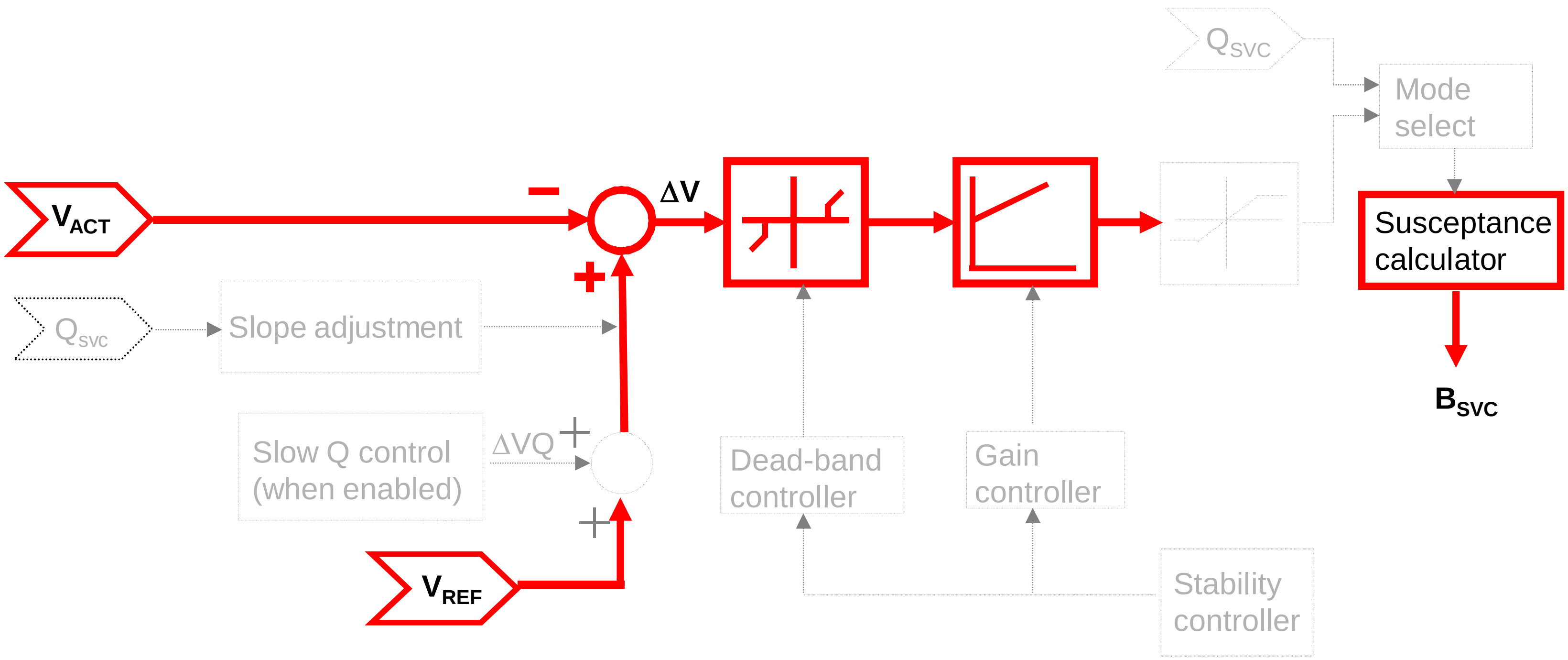
SVC Operation Modes

- Manual Mode or Fixed Susceptance mode (FS mode) - Q_{reg} is given by the fixed susceptance reference setting FS_{ref}
- Automatic Mode
  - Reactive Power control mode (Q mode) - Adjust the voltage reference (Vref) setpoint to maintain the $Q_{reg} = Q_{ref}$
  - Voltage mode (V mode) - **fast voltage control mode** that can override the Q-control mode

SVC Operation

- SVC operates in the automatic mode
- Vref of the SVC set at 141 kV (1.02 pu)
  - This enables the SVC to dispatch itself so that the voltage doesn't drop much below the Vref (remember 2% slope)
- Qref will be a function of the western region load
  - This will let the SVC switch the externally controlled capacitor banks and maintain adequate VAr reserve at the SVC

Simplified Primary Voltage Controller Schematic



SVC Control

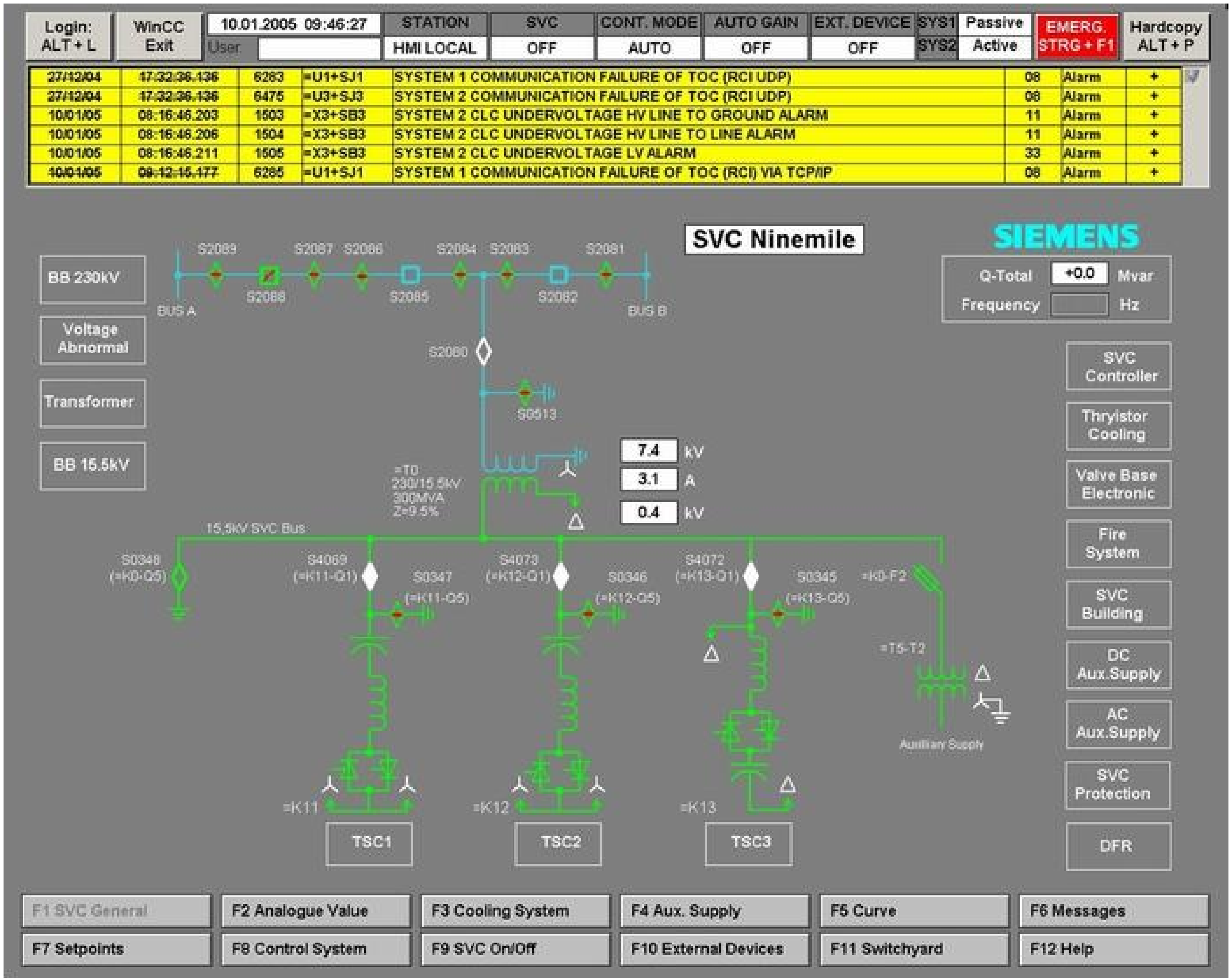
- Voltage Control
  - Responds to voltage fluctuations
  - Fast response, restoring voltage within 3 cycles
  - Employs stability controller
  - Unaffected by the QREF setting

SVC Control

- Q Control
  - Used to maintain the dynamic range of the SVC and to maintain an efficient operating point
  - Unaffected by the V_{REF} Setting
  - Slow response
  - Controls the operating point of the SVC
  - Controls the coordinated switching of the remote capacitor banks

Porter SVC

SVC Panel HMI



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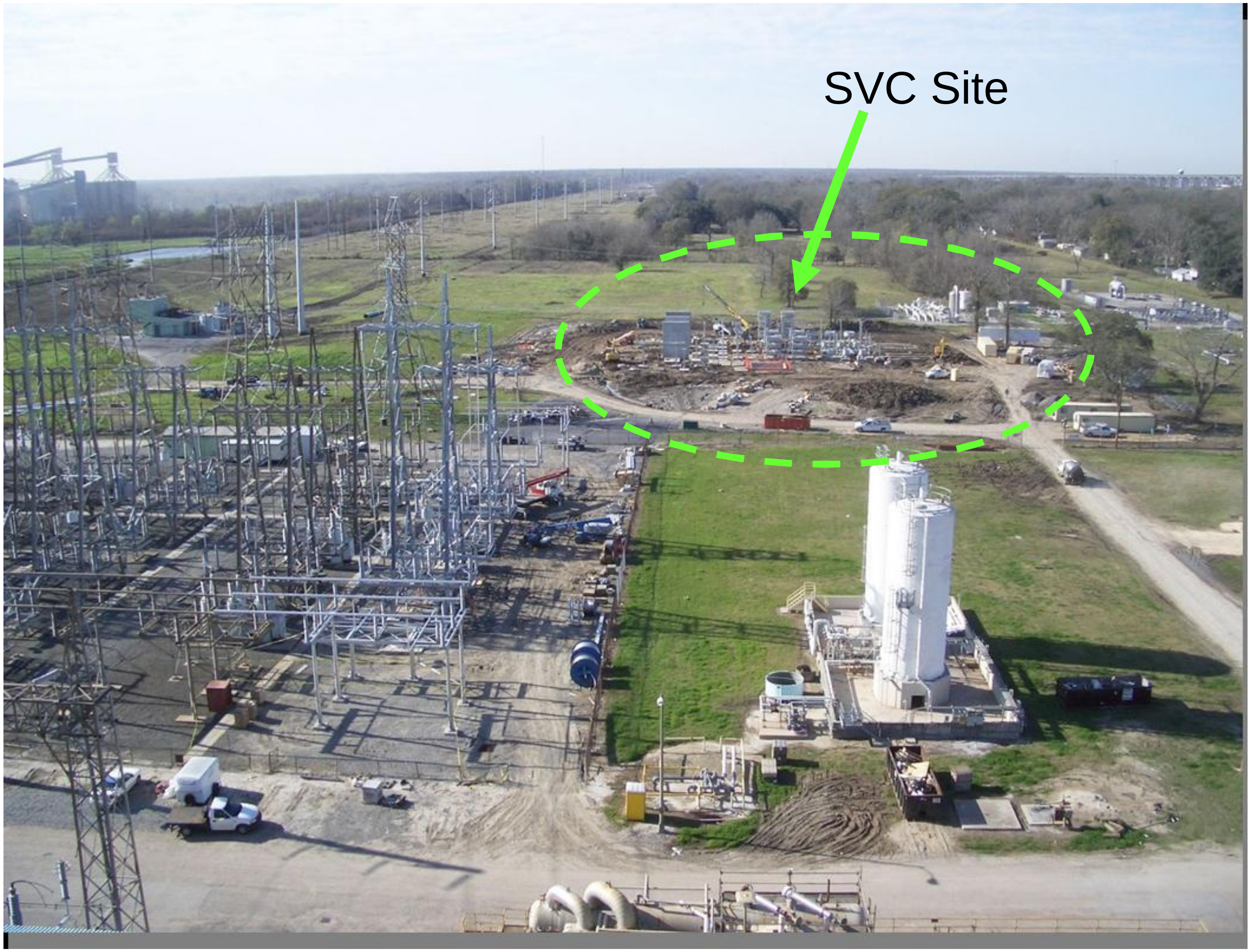
Ninemile SVC



Ninemile Switchyard

Ninemile SVC

Coupling Transformers

Ninemile SVC

Thyristor Switched Capacitor Bank

Ninemile SVC

Questions?