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October 19, 2011

METHODS TO INCREASE EXISTING TRANSMISSION CAPACITY – A TECHNOLOGY ASSESSMENT AND APPLICATION GUIDE

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INTRODUCTION AND WELCOME

STEVE OXLEY, DEPUTY CHAIR WYOMING PUC, CHAIRMAN SPSC GRID UTILIZATION WORK GROUP (GUWG)

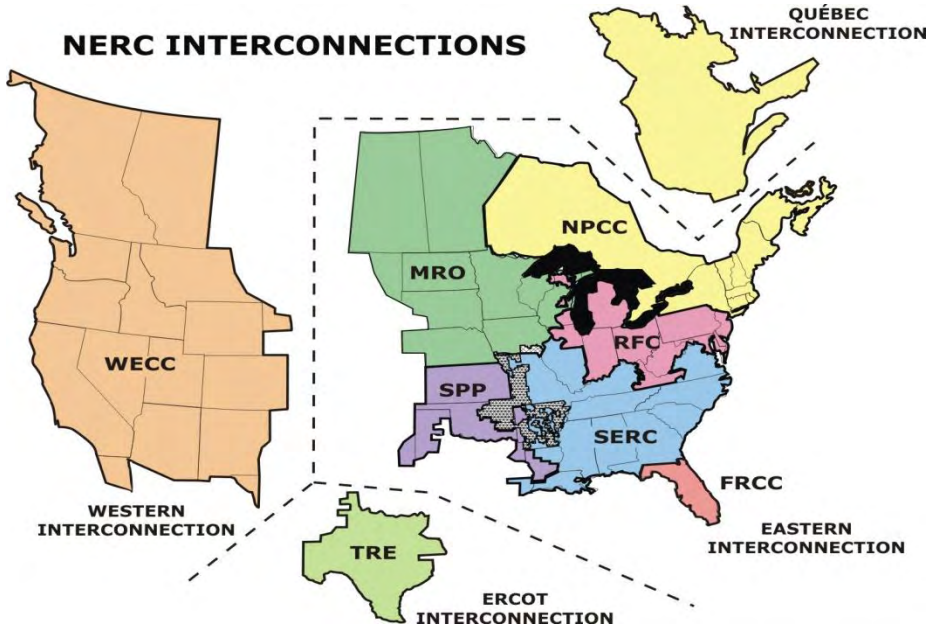
OBJECTIVE OF ASSESSMENT AND APPLICATION GUIDE

Jeff Hein, NREL

CURRENT STRUCTURE OF U. S. ELECTRIC POWER SYSTEM AND TRENDS

Steven Balser, Black & Veatch

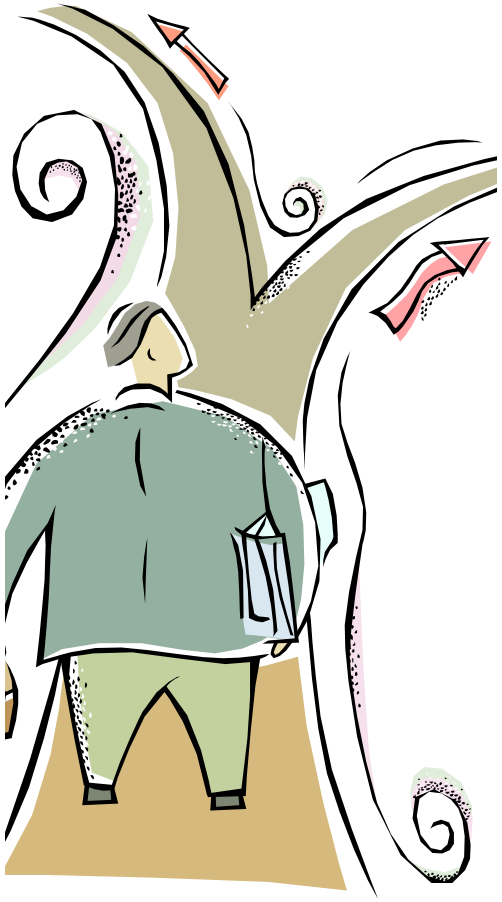
U.S. INTERCONNECTIONS AND NERC REGIONAL ENTITIES



- Three asynchronous systems with limited interconnections (HVDC back to back)
- Eight NERC Regional Entities with ability to enact more stringent reliability standards than NERC but not relax or loosen
- This report has been driven by Western Interconnection activities, but has national application(s).

TRENDS AND CURRENT SITUATION

- **Recent changes such as deregulation, markets, and shifts in generation portfolios have resulted in unplanned stresses on transmission design limits.**
- **Deregulation (EPRI Redbook, Third Edition)**
  - Lack of coordinated generation and transmission planning.
  - 10-year planning emphasis versus 20-year (operations versus planning emphasis).
  - Lack of transmission investment.
  - All of this is now changing (e.g., FERC Order 717, State electric rules, and WECC Long-term planning tool) but still impacts are felt today.



TRENDS AND CURRENT SITUATION

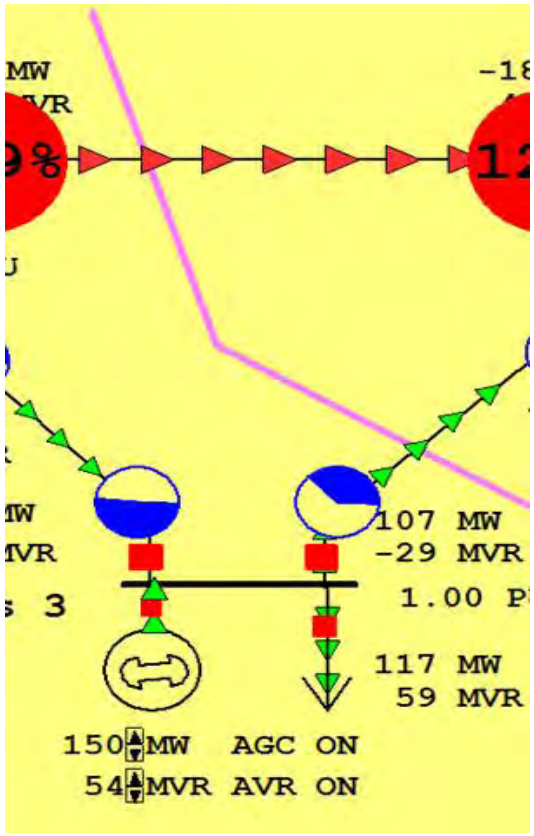
- **Cost recovery issues delay transmission capacity expansion.**
- **Right-of-way acquisition and permitting to expand transmission is time consuming and expensive in many parts of country (Eastern Interconnection in particular).**
  - Time to build new, incremental transmission capacity takes 7-10 years, but need capacity sooner than that (~ 5 years).
- **Time and expense to build new transmission places premium on ability to increase capability of existing transmission whenever possible.**

EXPANDING EXISTING TRANSMISSION CAPACITY –POLICY, RULES, AND PROCÉDURES

Steven Balser, Black & Veatch

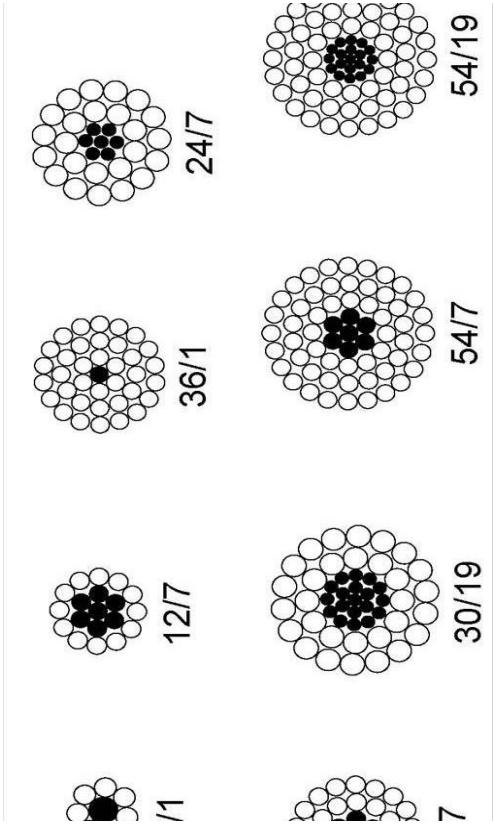
DRIVER FOR POLICY, RULES, AND PROCEDURES

- Existing transmission capability is limited by lines reaching design limits, applicable reliability rules, and/or local operating procedures.
- NERC rules are the minimum and may be difficult to change.
- Local rules may be less codified and more subject to modification, more stringent, and easier to change.
- Several examples are discussed, more exist.



TRANSMISSION CAPABILITY INDICES

- **Key indices are inter-related by ATC = TTC – TRM-CBM where:**
  - ATC – Available Transfer Capability
  - TTC – Total Transfer Capability
  - TRM – Transmission Reserve Margin
  - CBM – Capacity Benefit Margin
- **CBM and TRM are margins which reduce the amount of transmission that can be scheduled. Overly conservative margins unnecessarily reduce the available transmission.**
- **FERC Order 890 – Consistent method of measuring ATC.**

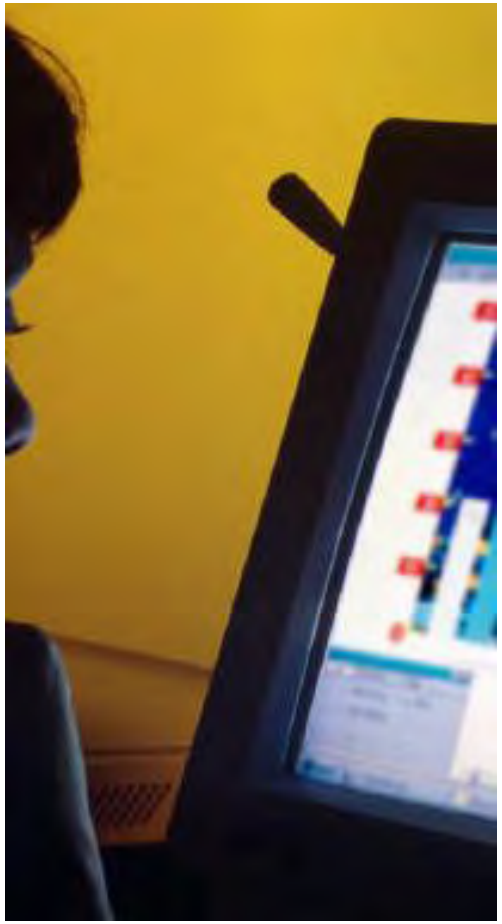


THERMAL RATINGS

- NERC FAC-08 provides flexibility for calculating ratings.
- Assumptions for ambient conditions are normally based on “worst day” that lead to very conservative ratings.
- Use of dynamic or real time ratings or more accurate past history could increase transmission capability much of the time.

WECC COMMON CORRIDOR DEFINITION

- WECC defines lines within greater of one span or 500’ as within a common corridor with more restrictive reliability rules than NERC standards.
- WECC committee looking at relaxing separation criteria to 250’ (approximately 500 kV tower height)
- Change could lead to more efficient use of existing or future transmission corridors.



MARKET BASED CONGESTION MANAGEMENT

- FERC Order 2000 requires RTO to establish market based congestion management.
- Transmission allocated day ahead or real time based on willingness to pay.
- Allows transmission users to hold financial rights to transmission rather physical rights
- Facilitates availability of unused transmission but compensates those with transmission rights.

CONDITIONAL FIRM TRANSMISSION/REDISPATCH

- FERC added Conditional Firm transmission as bridge between Firm and market based congestion management.
- Makes transmission available at least some of the time based on history of constraints.
- More TO/TOPs should adopt Conditional Firm if market based congestion management is not available.
- FERC Order 890

EXPANDING EXISTING TRANSMISSION CAPACITY – TECHNOLOGY

S. Sankar , Black & Veatch

UNDERSTANDING POWER FLOW

- Power flow is a function of system topology and non-equipment related aspects such as system stability.
- Any increase in maximum allowable power flow through any component or circuit element, does not necessarily yield a higher rating.
- Power flow capacity / limit is both equipment and system related.

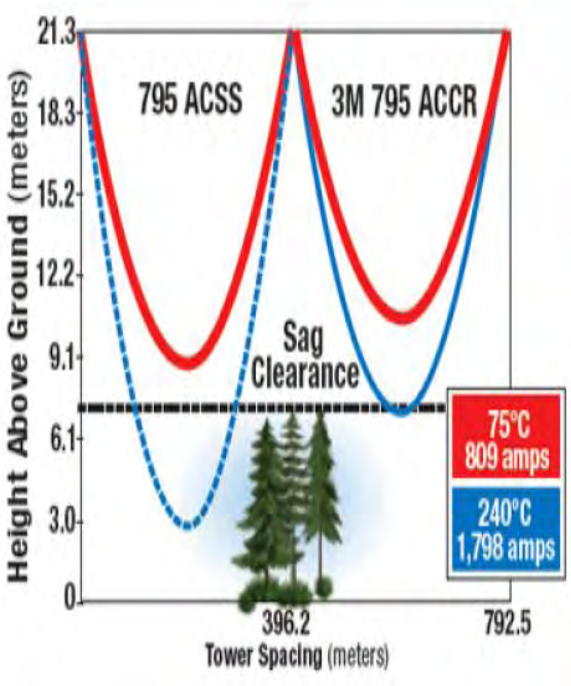
POWER FLOW LIMITS

- **Thermal Limits – depends on conductor type, conductor bundles, ambient temperature, wind speed, ice loading, span length etc.**
  - Characteristic limit in Eastern Interconnection
- **Stability Limits (Steady state, Transient) – depends on electrical characteristics such as system impedance and reactive power sources.**
  - Characteristic limit in Western Interconnection

TECHNOLOGIES AVAILABLE TO INCREASE THE POWER FLOW LIMITS

- Next-generation conductors (i.e. high capacity cable) – **Improve Thermal Limits**
- Enhanced system and equipment monitoring – **Improves Thermal Limits**
- "Mature" (i.e. well-established, non-power electronics-based) technologies (e.g. phase shifting transformers, series capacitor line compensation) – **Improve Stability Limits**
- High-Voltage Direct Current (HVDC) converters and transmission – **Improve Stability Limits**
- Flexible Alternating Current Transmission Systems (FACTS) based devices – **Improve Stability Limits**

NEXT GENERATION CONDUCTORS



- Traditional conductors are ACSR and AAC.
- The strength of aluminum starts to degrade under sustained usage above 95°C.
- New conductors, High Temperature Low Sag (HTLS) Conductors, can operate over 100°C, some up to 200°C.
- ACSS and ACSS/TW (Aluminum Conductor Steel Supported) - 200°C
- ZTACIR (Zirconium alloy Aluminum Conductor Invar steel Reinforced) - 150°C
- GTACSR (Gap Type heat resistant Aluminum alloy Conductor Steel Reinforced) - 150°C
- ACCR (Aluminum Conductor Composite Reinforced) - 210°C (3 – 6 X cost/2-3 x capacity)
- CRAC (Composite Reinforced Aluminum Conductor) - 150°C
- ACCFR (Aluminum Conductor Composite Carbon Fiber Reinforced) - 210°C

DYNAMIC CIRCUIT RATINGS

- The actual thermal capacity of a transmission circuit is determined by the conductor temperature at that point in time
- Weather Data Monitors
- Conductor Temperature Monitors
- Tension Monitors
- Sag Monitors
- The data from each monitor is relayed to the utility's operations center where software calculates a dynamic circuit rating
- Example: Idaho Power, Prometheon, ONCOR System in Texas, and many others

THERMAL LIMITS IMPROVEMENT - OTHERS

- Terminal Equipment Replacement – switches, wave traps, connectors etc.
- Voltage Uprating – Insulator and tower replacements (MW increase with square of voltage)

PHASE SHIFTERS

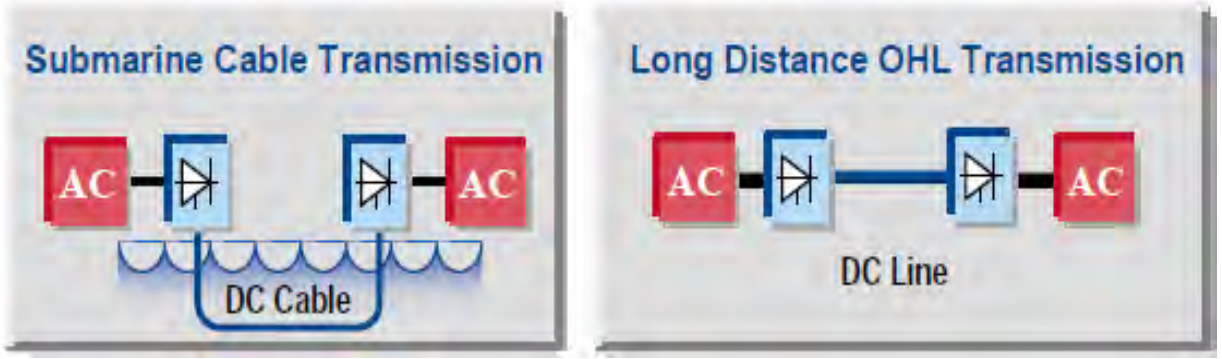
- Phase Shifters are similar to transformers in construction.
- Using this device, the flow through heavily congested lines can be reduced and shifted to adjacent transmission lines with spare capacity.
- There are a number of phase shifters in operation in US, mainly between two different control areas.

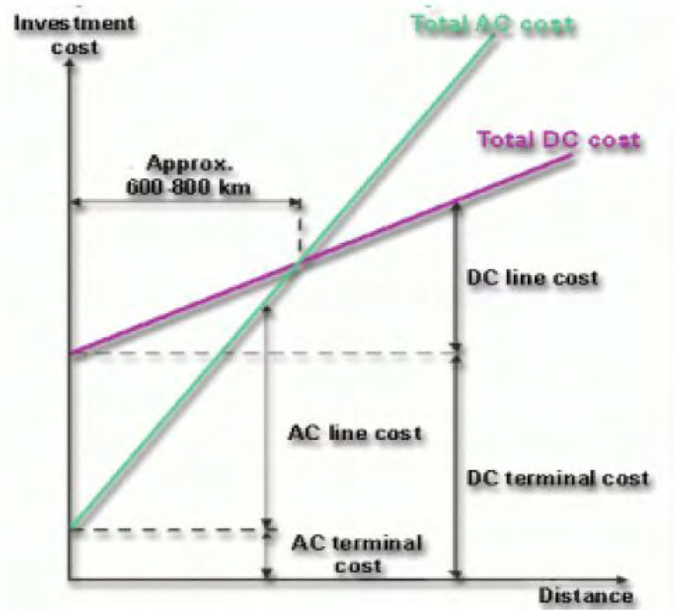
FIXED SERIES CAPACITORS

- Adding a series capacitor reduces line impedance and thereby increases power flow capacity.
- Increase in power transfer capacity could be about 10% to 30% depending on the network topology.
- Typically the cost of installing a series capacitor is about 10% of a cost of its overhead line for which it is applied.
- Example: New series capacitors were put in service in 2006 on 500 kV lines at Eldorado substation by SCE in order to increase the power transfer between Arizona / Nevada and Southern California.
- Colstrip (Path 8) Upgrade– recent example

HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION

- HVDC Transmission Systems have been in use since 1950's.
- Convert ac to dc, transmit and then convert dc to ac.
- HVDC transmission systems are used in long distance overhead transmission application primarily for economic reasons and stability considerations and in under ground / under water applications as a only technical viability in certain instances.



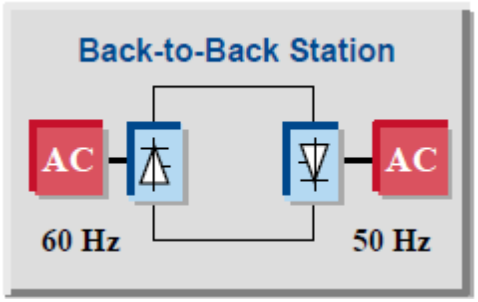


HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION (CONT'D)

- HVDC transmission systems can deliver more power than an AC transmission system for the same amount of right-of-way.
- AC lines have more flexibility for intermediate taps
- HVDC line costs are less than AC but terminal equipment is more expense; see breakeven distance at left

	800 kV AC	500 kV DC
Capacity	2000 MW	3000 MW
RoW	75 m	50 m

HVDC BACK-TO-BACK SYSTEMS

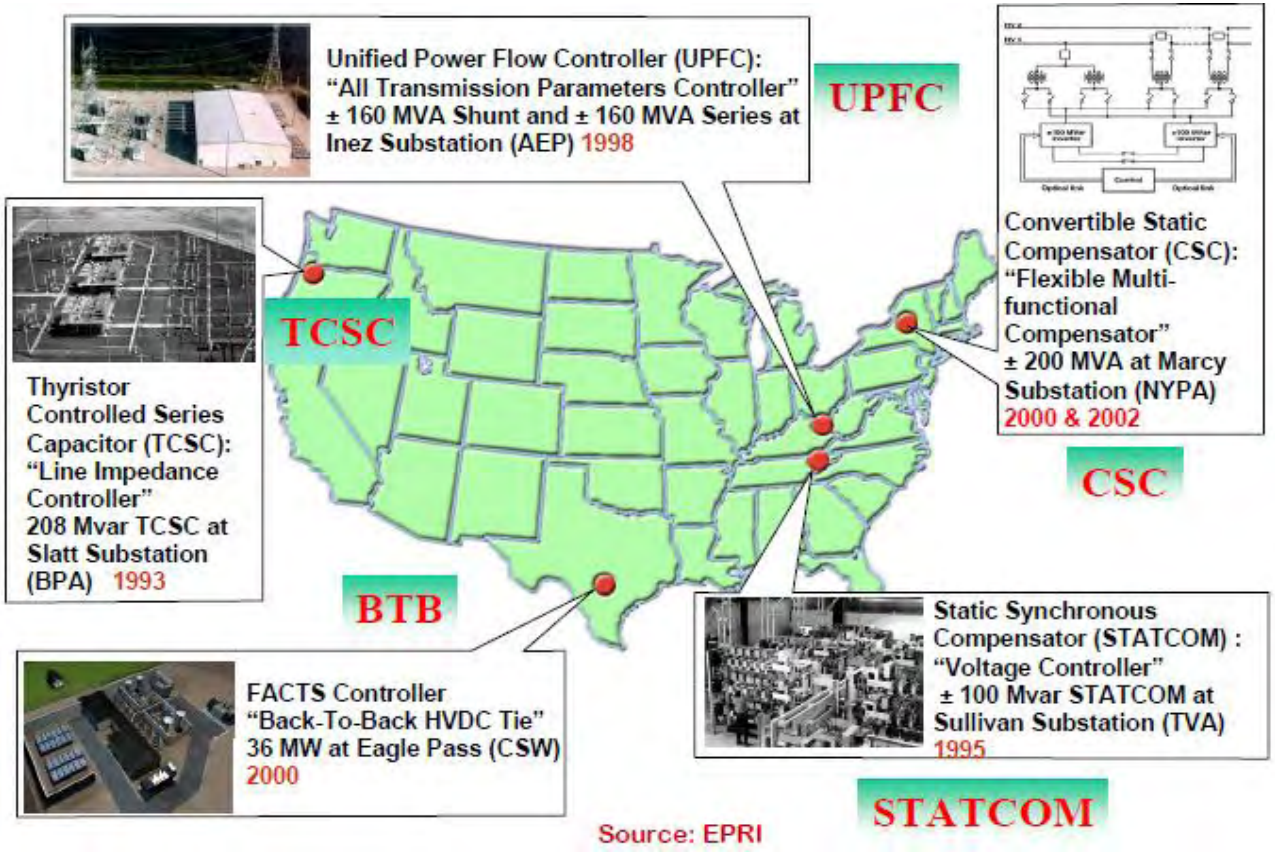


- AC to DC and DC to AC converters are located next to each other.
- Suitable for connecting two asynchronous systems such as WECC and ERCOT.
- Can be used for grid segmentation.

FLEXIBLE AC TRANSMISSION SYSTEM (FACTS) DEVICES

- Flexible AC Transmission System (FACTS) technology refers to a broad class of power electronics-based devices used to enhance the operation and control of the electric power grid.
- FACTS devices use power electronic components and conventional equipment which can be combined in different configurations for switching or controlling reactive power and/or for active power conversion / control.

OVERVIEW OF EPRI SPONSORED FACTS PROJECTS



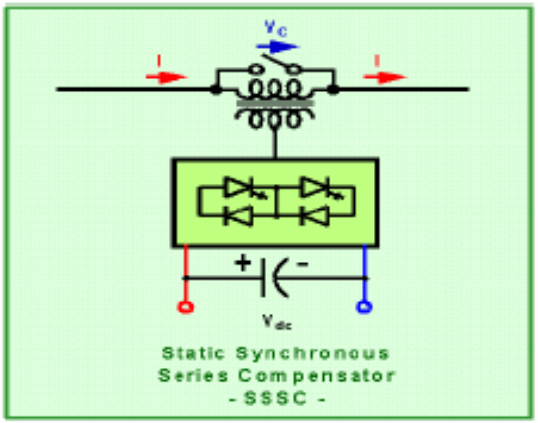
STATIC VAR COMPENSATOR (SVC)

- Static VAR Compensator (SVC) was one of the first technologies classified as a FACTS device.
- These are electronically controlled / switched reactors and capacitors.
- SVCs improve system voltages under various operating conditions and thereby improve system power flow limits.
- Hundreds of SVCs are in operation.
- Recently installed SVC at Devers, California to increase the CA import from AZ, is shown below:

STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

- STATCOMs are shunt-connected reactive-power compensation equipment capable of generating and/or absorbing reactive power, so as to control the specific parameters of an electric power system.
- STATCOMs appear as a voltage source without any rotating parts and are very fast acting voltage controlled devices.
- STATCOMs improve system voltages under various operating conditions and thereby improve system power flow limits.
- Recently installed SVC at Essex, Vermont is shown.

SERIES STATIC SYNCHRONOUS COMPENSATOR (SSSC)



SSSC

- Like the STATCOM, the Series Static Synchronous Compensator appears (to the system) as an adjustable synchronous voltage source.
- Unlike the STATCOM (and as the name implies), the SSSC is connected in series with a transmission line.
- This device varies the effective line impedance by injecting voltage and thereby controlling the power flow.

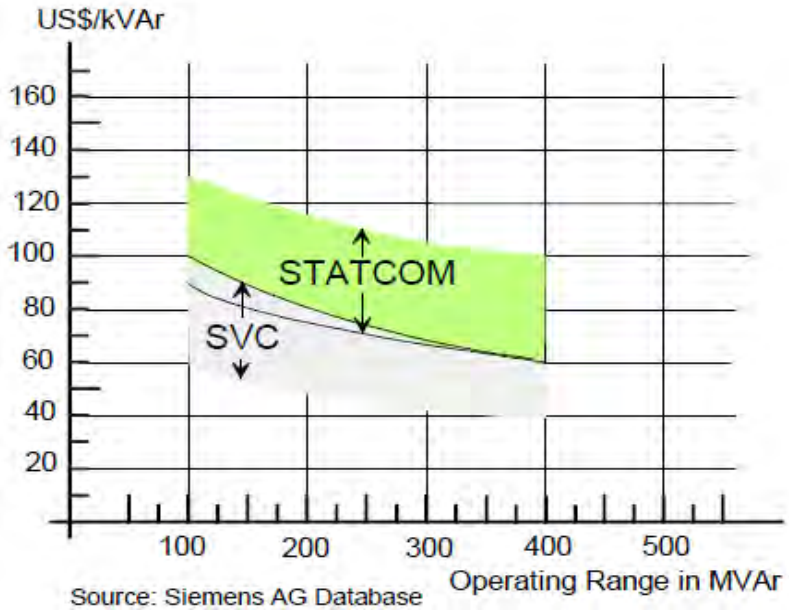
UNIFIED POWER FLOW CONTROLLER (UPFC)

- Most versatile FACTS device developed so far.
- Can be designed to control power flow on only one line or multiple lines and in which case they are called Interline Power Flow Controller (IPFC).
- UPFC / IPFCs are combination of STATCOM and SSSC devices.
- These devices act as voltage controller, impedance controller and a power flow controller.
- An example is the UPFC installed at Marcy, NY which increased the NY State interface transfer without adding any additional transmission lines.
- The first UPFC project, sponsored by EPRI, installed at Inez, KY is shown below:

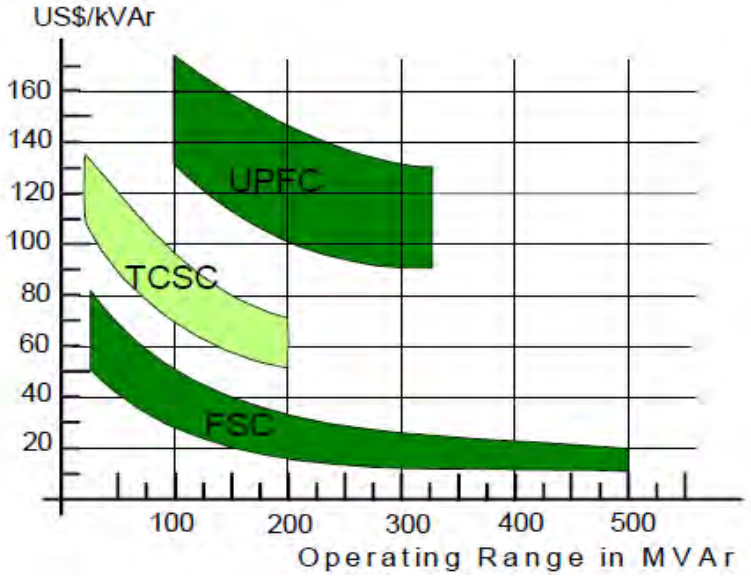
THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

- Extension of fixed series capacitor concept, except that the series capacitor impedance is controlled by electronic circuits.
- By controlling the series capacitor impedance, power flow is controlled / varied.
- The first TCSC project installed at Kayenta, AZ, which increased the power transfer between New Mexico and Arizona, is shown.

FACTS DEVICES COST COMPARISON



Source: Siemens AG Database



OTHER EFFORTS TO EXPAND UTILIZATION OF TRANSMISSION

- EPRI
- RMATS
- CDEAC
- Many others to be named in TAAG report

SUMMARY

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Jeff Hein, NREL

DRIVERS

- Deregulation, lines reaching design limits, markets, and generation portfolios have challenged conventional planning horizons and existing transmission
- Right-of-way acquisition and permitting are delaying new transmission.
- Immediate need to increase capability of existing transmission whenever possible.

POLICY, PROCEDURES, STANDARDS

- Reliability must be maintained
- Through review of margins in calculating Available Transmission Capability (ATC)
- Better management of congestion such as market based or conditional firm
- More efficient utilization of existing transmission corridors
- Increased use of dynamic/real time ratings rather conservative static ratings

Pellet of
GTO / IGCT

TECHNOLOGY

- High temperature conductors.
- Better flow control to balance flows on under utilized lines.
- FACTS devices to improve system performance where flow limits are the result of underdamped systems or dynamic limitations in voltage and frequency.
- Maximize the power transfer capacity within the available ROW by adopting higher voltages, compact tower designs or HVDC transmission.

SUMMARY OF RESULTS

Technology	ROW Utilization	Unused Capacity	Thermal	Voltage	Stability
Dynamic/Real Time Rating		×			
High Temperature, Low Sag (HTLS) Conductor			×		
Financial Congestion Management		×			
Changes to WECC Reliability Criteria	×	×			
Conditional Firm Transmission (CFT)		×			
Static Var Compensator (SVC)				×	×
STATCOM				×	×
Series Static Synchronous Compensators (SSSC)		×		×	
Unified Power Factor Control (UPFC)		×		×	×
Independent Power Factor Controller (IPFC)		×		×	×
Thyristor Controlled Series Capacitor (TCSC)		×			
High Voltage Direct Current Transmission	×				×
Back to Bach HVDC Link					×
System "shock absorbers"					×
Phase shifting transformer (PST)	×	×			
Series capacitors	×	×			
Real time monitoring		×	×	×	×

QUESTIONS & ANSWER AND GENERAL DISCUSSION

All Participants

CONTACT LIST

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