The Advent Of Energy Storage For Transmission Voltage Stability Support Via Superconducting Magnetic Energy Storage (SMES) And Ultracapcitors (UCAP)

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The current status of the U.S. transmission system is discussed. The issue of increasing real power loading without increasing the investment in the transmission infrastructure has resulted in many points of transmission congestion because of potential voltage instabilities caused by overloading of lines and line outages. This has reduced the available transfer capacity (ATC) limiting the flow of power from low cost areas of generation to high cost areas of generation.

The merits of using AMSC's Distributed Superconducting Magnetic Energy Storage D-SMES technology for transmission voltage stability support is discussed along with a description of AMSC's D-SMES (distributed SMES) technology. TVA has ordered one AMSC D-SMES unit (with helium cooled niobium/titanium superconductor and power electronics based on the use of Insulated Gate Bipolar Transistors -IGBT), and is evaluating the installation of additional units for transmission voltage stability support, as TVA's transmission system is loaded routinely during peak periods to levels beyond the transmission system surge impedance loading (SIL).

It is shown that the requirements for additional dynamic sources of reactive power for transmission voltage stability support are increasing at a rapid rate in the future (>square of the increase in real power). A future, new concept using UCAPs for transmission voltage stability support (or TUCAP) is presented. The TUCAP is planned for development to use new advanced UCAPs, and the advanced high current density, high frequency Emitter-Turn-Off (ETO) Thyristors being developed by Virginia Polytechnic Institute. The UCAPs and ETOs will be mounted into a mobile trailer and integrated at the transmission distribution interface as a TUCAP for voltage stability control. Also, the TUCAP is shown as being configurable into an UPS for digital loads as well.

The problem of transmission congestion has been growing due to a decoupling between the increase in generation to meet an increasing load and a continued decrease in transmission investment. The margin in the transmission system no long exists. Major paths of transmission congestion have occurred due to potential voltage collapse under single contingency scenarios.

Next, the significant increase in reactive compensation is shown to keep the voltage constant for a 345 kV line as the transmission lines loads increase beyond the surge impedance loading (SIL). In the future, as lines are loaded up to the thermal limits, the increase in reactive compensation will continue at least at the square of the real power load increase. This is further complicated by a dramatic increase in the transfer of power from low cost to high cost regions of the country.

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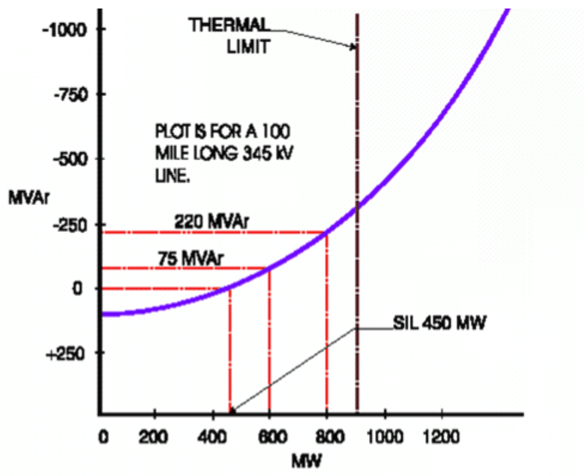
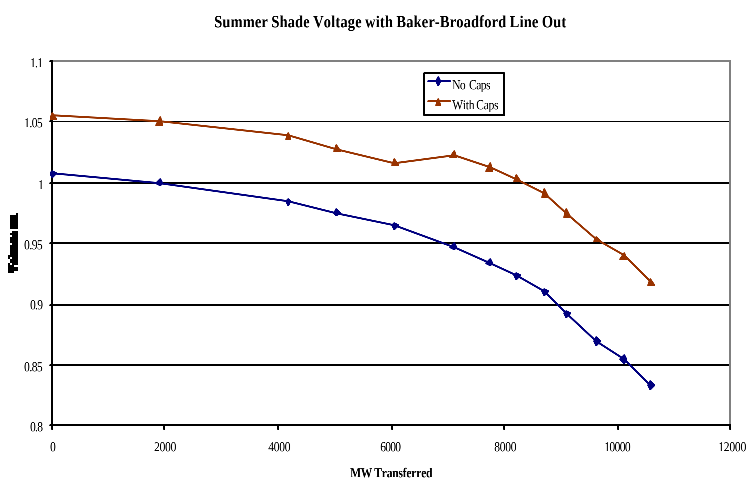
Real Power vs. Reactive Power and Explosion in Reactive Power Compensation

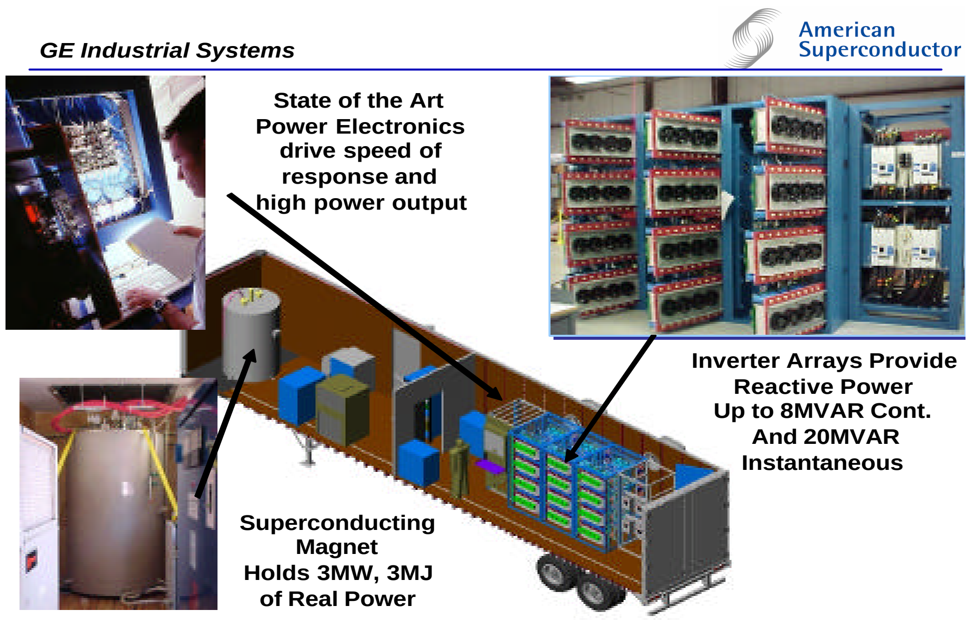


In the past, and today, the reactive compensation beyond the SIL is met using switched capacitors. However, as the following example shows, using capacitors is a mixed blessing, for a contingency occurs; the voltage can begin to drop and the reactive power provided by a capacitor will decrease as the square of the voltage. This is where capacitors help the voltage at equilibrium, but “flatten” the nose curve of the V versus P curve, thus hastening the potential for voltage collapse.

Impact of Adding Capacitors on Voltage Collapse

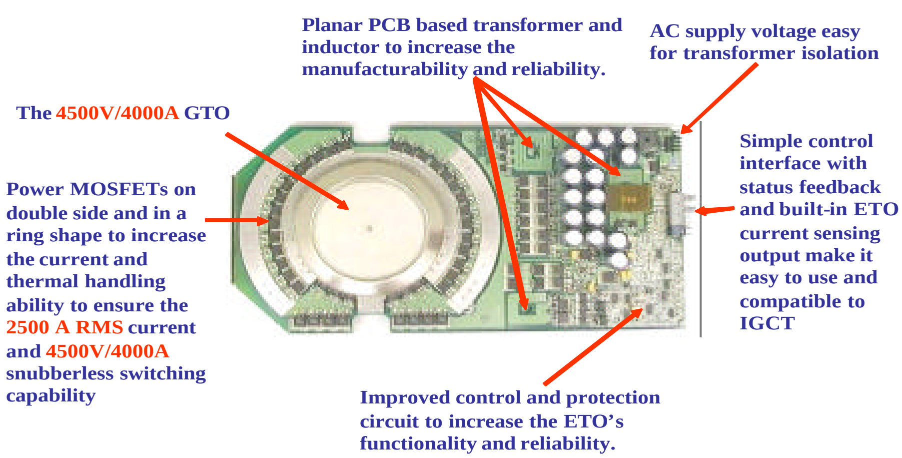


Options for increasing the ATC and mitigating voltage collapse are shown below:
A key option is the D-SMES (thanks to Chuck Stankiewiz of AMSC) shown below:



The potential competitive benefits of D-SMES versus SVCs and STATCOMs have been documented by and for Entergy in West Texas where the D-SMES solution to eliminate voltage collapse is 20% to 40% cheaper in total cost than SVC or STATCOM solutions:

The performance of the D-SMES can be further improved by going from a low voltage device using Insulated Bipolar Gate Transistors (IGBT) to advanced power electronics using Virginia Polytechnics' (Dr. Alex Huang and Bin Zhang) Emitter-Turn-Off Thyristor (ETO) that can handle high current, at high voltages, and has a high switching frequency for improved power quality as shown in the following slides:

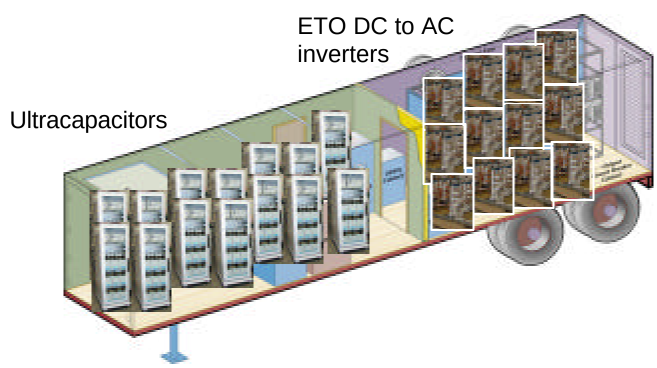


Further improvements can be obtained by replacing the SMES in the D-SMES with high energy density, rapid discharge, and asymmetric ultracapacitors like those shown below by Tom Geist of EPRI PEAC:

- No moving parts
- Modular design
- Easily custom configured
- Compatible with existing voltage source inverters
- Long life
- Low cost for pulse power
- 1 MJ capacity: 100 kW for 10 seconds
- Complements ETO: High pulse-power capability with good energy density

The integration of the ETO and UCAPs into a mobile system to eliminate voltage collapse results in the following Transmission UltaCAPacitor (TUCAP) configuration:

UltraCAPcitor (TUCAP) with ETO Power Conversion

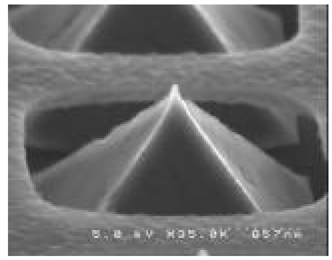


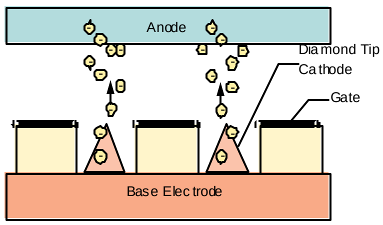
- 30-75% lower total cost than other options
- Transmission voltage stability control
- Sub-cycle reaction time
- Possible use at premium power parks
- Real power storage: 3 MW instantaneous for 1.5 seconds
- Dynamic reactive power: Up to +/-60 MVAR instantaneously

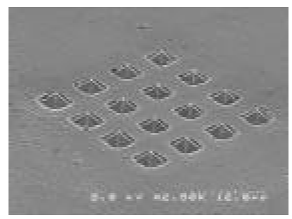
And in the long term, the TUCAP performance and cost can be more improved by using chemical vapor deposition of diamond tips in a vacuum creating a field effect transistor as shown below:

Gated Diamond Tips

- Self aligned grid structure
- Triode device
- Very low-loss switching
- Fast switching







With an impact on Transmission and Distribution systems as shown below:

CVD Diamond devices will . . .

- Operate at line voltage w/o additional transformers
- Provide high current circuit switching (circuit breakers and transfer switches) for large and/or digital loads
- Reduce cost of power electronic devices* by more than 50%
- Allow 500-kV (+/-) DC lines to be built economically over existing 161-kV lines

*High-voltage DC terminals, power conversion systems, flexible AC transmission devices, fast switches & circuit breakers, TSMES, and TUCAPs.

Thanks to Dr. Alex Huang & Bin Zhang of Virginia Polytechnic Institute, AMSC & General Electric Industrial, Steve Lee of EPRI GOP, Dr. Jim Davidson of Vanderbilt University and Susan Morris of GridSouth