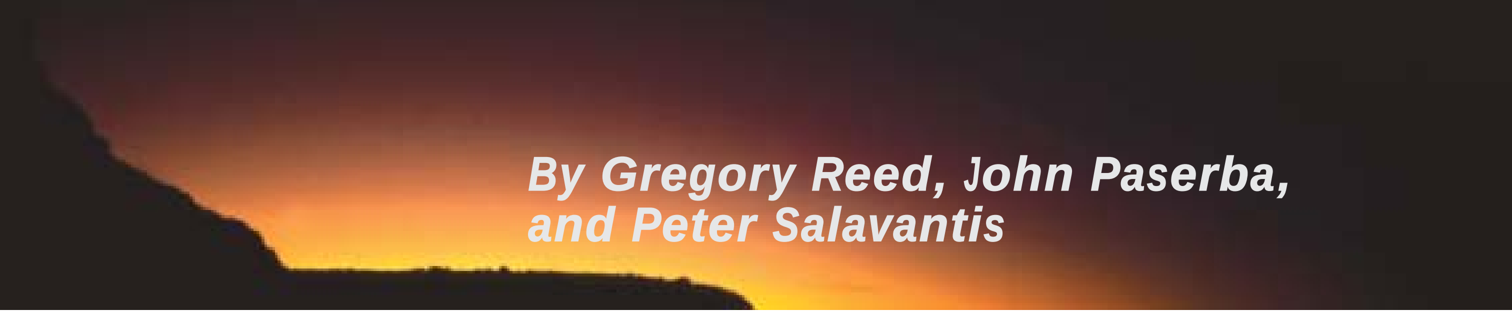


By Gregory Reed, John Paserba, and Peter Salavantis

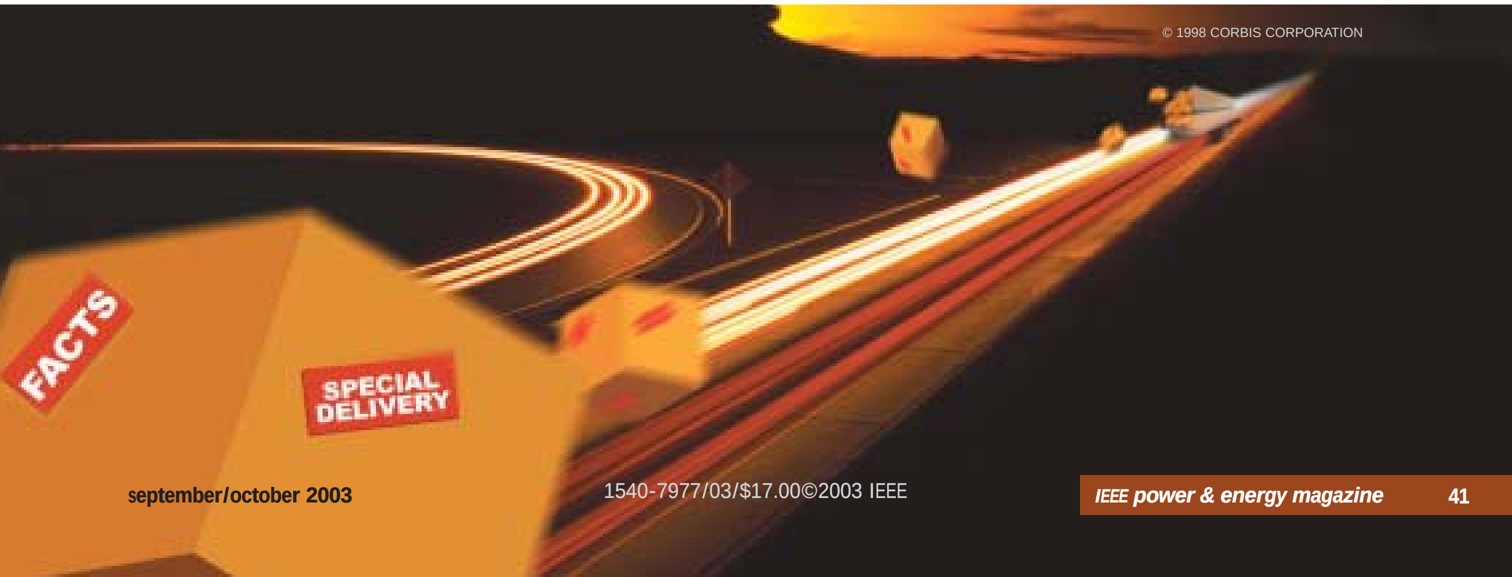
The FACTS on Resolving Transmission Gridlock

The case for implementing power electronics control technologies to enhance reliability and upgrade capacity

THE CHALLENGES TO PROVIDING A RELIABLE AND EFFICIENT STREAM OF electricity to residential and commercial users in the digital age are great. Regulatory uncertainty, cost, and lengthy delays to transmission line construction are just a few of the barriers that have resulted in the serious deficiency in power transmission capacity that currently prevails in many regions of the United States. Solving these issues requires innovative thinking on the part of all involved. Increasing numbers of electricity stakeholders now recognize that low-environmental-impact technologies such as flexible ac transmission systems (FACTS) and dc links are a proven solution to rapidly enhancing reliability and upgrading transmission capacity on a long-term and cost-effective basis.

A Transmission System in Gridlock

While headlines of power shortages, rationing, and skyrocketing prices in California and other



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regions of the United States have faded from memory for much of the general public, energy professionals know that the state of the electrical transmission grid remains in crisis. The question is not whether but *when* the next major failure of the grid will occur absent government and private sector initiatives that enable significant infrastructure improvements to ensure reliable and affordable electricity. For the debate on electricity reliability and capacity to truly advance, however, electricity stakeholders must find solutions to the vexing problems of rapidly increasing demand, inadequate infrastructure, and the critical challenge of balancing energy growth with environmental protection.

Investment in new transmission facilities has declined steadily for the last 25 years while demand will grow by 45% over the next 20 years, according to U.S. Department of Energy (DOE) estimates. To meet these needs, it is estimated the United States must build between 1,300 and 1,900 power plants, yet there are no strategic plans to effectively deliver this amount of new generation to end users. As the DOE notes: "an antiquated and inadequate transmission grid prevents us from routing electricity over long distances and thereby avoiding regional blackouts, such as California's."

The costs of inaction are great. Recent EPRI studies reveal that direct economic losses attributed to transmission system stability and reliability deficiencies resulting in power interruptions and inadequate power quality in the United States conservatively exceed US$100 billion per year. Further, in order to reestablish adequately stable transmission system conditions nationwide, initial investments in overall transmission system infrastructure upgrades are estimated at up to US$30 billion in the western region of the United States alone. It is estimated that annual expenditures of up to US$3 billion or more would then be needed to maintain this condition in consideration of continued demand growth. Projecting these estimates conservatively nationwide yields an initial investment requirement in transmission facilities exceeding US$50 billion.

It is equally well documented that uncertainty about recovery of transmission system investments has played a major role in our current situation. Utilities and other owners of transmission infrastructure have little incentive to invest in new transmission assets given the present regulatory regime.

Finally, intense opposition to the construction of new power lines is often responsible for the interminable and often fatal roadblocks to new transmission capacity. NIMBY ("not in my backyard") challenges to needed transmission capacity amidst lacking infrastructure and growing demand round out the daunting mission of providing a reliable, efficient, and affordable stream of energy to complacent residential and industrial users of electricity.

Affects of Deferring Transmission Investment

It is universally recognized that to keep pace with present energy demand and to ensure reliability as electricity needs grow, the construction of new transmission lines must occur. Such modernization, however, presents a plethora of political, economic, and environmental issues that serve to indefinitely delay urgently needed upgrades of the U.S. transmission system. As the Federal Energy Regulatory Commission (FERC) notes, "the sluggishness of transmission construction is largely because siting transmission is a long and contentious process."

Indeed, the long-term trend of deferred investments in the electrical transmission grid continues to cause serious capacity and reliability issues that threaten the United State's economic security. Consider the case of the proposed Rainbow-Valley Transmission Project in Southern California. The proposal is for a 500-kV transmission line from Southern California Edison's Valley Substation to San Diego Gas and Electric's proposed new Rainbow Substation. The interconnect would greatly enhance system reliability in the area as well as provide 1,000 MW of import capacity into the San Diego region, which has had much in-city generation decommissioned in recent years. The case for the project not only entails transmission reliability and import capacity but is important for the continued economic growth and development of the region. Southern California-area businesses, industries, and residential customers alike have felt the adverse affects of the energy crisis in the region through periods of sky-rocketing prices and the potentially unstable supply during certain critical contingencies. Regardless, various NIMBY, political, and regulatory barriers continue to stifle the approval and development of this much-needed transmission corridor to provide electricity supply relief and increased reliability in the region. Further, citing absence of economic justification of the project, recent rulings have stalled all progress. Yet, no other adequate alternatives are available. Thus, this needed investment continues to be deferred at the expense of transmission system reliability and capacity deficits in one of the largest economic regions of the country. Both system and economic security remain exposed to risk under this current situation.

Transmission Gridlock Resolved

A solution to this stalemate is the availability of proven and low-environmental-impact infrastructure technologies that are sound alternatives to the protracted process of power line construction, such as those identified in the DOE's National Transmission Grid Study. Two of these technology areas, FACTS and certain configurations of high-voltage direct current (HVDC) systems, represent long-term solutions to upgrading electrical transmission infrastructure in situations where power line construction is not feasible or attainable on a reasonable time basis to accommodate our urgent present-day needs.

Compelling financial and performance case studies exist for the wide-scale implementation of advanced, low-environmental impact technologies such as FACTS and HVDC. HVDC configurations in such analysis come in the form of back-to-back (BTB) dc links. Although detailed study of each individual application is required, these technologies can play a key role in alleviating transmission system constraints (i.e., bottlenecks) and provide rapidly implemented, cost-effective relief to the very serious, yet commonly experienced, conges-

FACTS Installation at the San Diego Gas and Electric Talega Substation—by Terry Snow

The FACTS technology recently installed in the SDG&E system at the Talega 138-kV substation is being applied to relieve transmission system constraints in the area through dynamic VAR control during peak load conditions. The transmission constraints addressed are related to voltage stability and dynamic VAR supply. The FACTS installation is operating as a STATCOM system and has a rated dynamic reactive capacity of ±100 MVA. As shown in Figure 1, the STATCOM system, as it is now configured, consists of two groups of voltage-sourced converters (50 MVA each). Each 50-MVA converter group consists of four sets of 12.5-MVA modules plus a 5-MVAR harmonic filter (plus one spare filter switchable to either group), with a nominal phase-to-phase ac voltage of 3.2 kV and a dc-link voltage of 6,000 V. The two 50-MVA VSC groups are connected to the 138-kV system via two three-phase step-up transformers each rated at 55 MVA, 3.2 kV/138 kV (plus one "hot" spare switchable via the motor operated disconnects). Either 50 MVA VSC group or both can be connected to each of the 138-kV buses via the various automatically controlled motor-operated disconnects.

The system is also designed for future operation as a BTB dc link connecting the Talega East and West buses or as a unified power flow controller (UPFC). The BTB dc-link system would have a power transfer rating of 50 MW and would be able to deliver power bidirectionally between the east and west buses at Talega. The dc links are physically in place for this future option, which would essentially only require software-based control adjustments for BTB operation. The potential expansion to a UPFC is also facilitated by the in-place dc links. Other expansion requirements for UPFC operation would be the connection of one group of 50-MVA converters to a transformer in series with a line emanating from the Talega Substation. The UPFC configuration would also require software adjustments and would allow for the simultaneous control of real power flow (MW) and reactive power (MVAR) at Talega. This type of "flexibility" in the design and operation of FACTS technologies is imperative in its ability to adapt to system topology changes or new operational requirements in the future.

The main power semiconductor devices incorporated in the converter design are 6-in gate commutated turn-off thyristors (GCTs), rated at 6 kV, 6 kA. These devices are arranged in each module, forming a three-level converter circuit, which reduces the harmonic current as compared to a two-level design. The control of the converter is achieved with a five-pulse PWM (pulse width modulation), which further decreases the harmonics as compared to three-pulse or one-pulse PWM control. Because of these two aforementioned features, only the small harmonic filter is required on the ac side. As part of the overall reactive compensation scheme at the Talega substation, there are also three 69-MVAR shunt capacitors that are connected directly at the 230-kV system. The STATCOM system is able to control the operation of the voltage-sourced converters and the three 69-MVAR-capacitor banks. It can be remotely operated via SDG&E's SCADA system or manually operated from the control building. A one-line diagram of the Talega FACTS installation is shown in Figure 1.

Some of the main benefits of this FACTS design are as follows:

- ✔ rapid response to system disturbances
- ✔ smooth voltage control over a wide range of operating conditions.
- ✔ a significant amount of built-in redundancy (i.e., any one or more of the 12.5-MVA modules or 50-MVA groups can be out of service while all others remain in operation at their full rated capability)
- ✔ automatic reconfiguration to handle certain equipment failures (such as a transformer or filter) without shutting down the STATCOM
- ✔ expansion capability for future operation as a BTB dc link or UPFC system.

Figure 2 shows the FACTS installation, with various equipment and systems identified.

tion problems that occur throughout the grid.

FACTS technologies can essentially be defined as highly engineered power-electronics-based systems, integrating the control and operation of advanced power-semiconductor-based converters (or valves) with software-based information and control systems, which produce a compensated response to the transmission network that is interconnected via conventional switchgear and transformation equipment. FACTS technologies provide dynamic control and compensation of voltage and power flow and can be designed to coordinate the control of other transmission compensation devices, such as capacitors, reactors, and transformer tap changers, in order to establish greater overall system operation improvements. In effect, FACTS "builds intelligence" into the grid by providing this type of enhanced system performance, optimization, and control.

FACTS are available in both "conventional" forms such as static VAR compensators (SVCs) and thyristor controlled series capacitors (TCSCs), as well as in "advanced" forms that

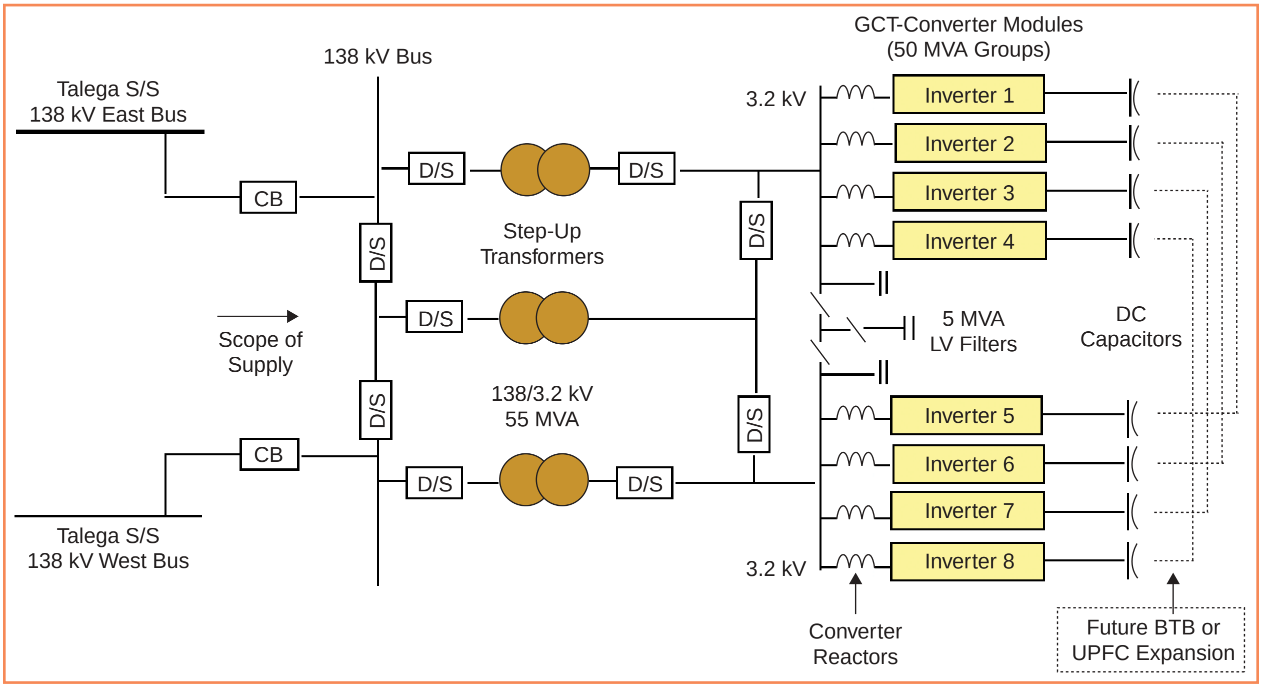

figure 1. One-line diagram representation of Talega ±100-MVA, 138-kV STATCOM system (50 MW, 138 kV BTB dc-link or UPFC future expansion capability).

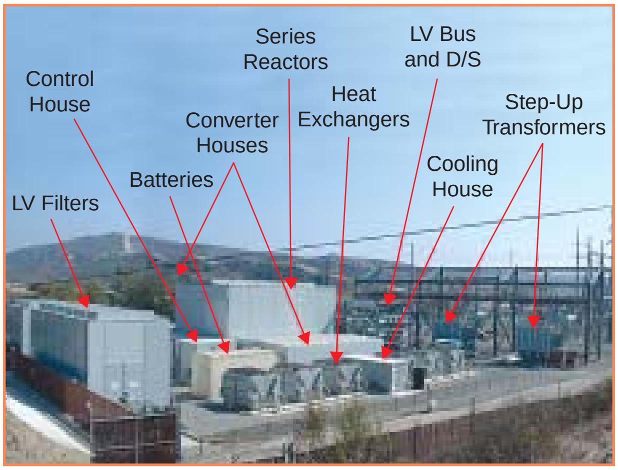

figure 2. Photograph of the Talega ±100-MVA, 138-kV STATCOM (future BTB or UPFC) system.

are categorized as voltage-sourced converter (VSC)-based systems. The main VSC-based FACTS configurations are know as static reactive compensators (STATCOMs), static series synchronous compensators (SSSCs), unified power flow controllers (UPFCs), and VSC-BTBs.

The SVC and STATCOM designs are applied as shunt-connected devices providing dynamic reactive compensation for voltage control, system stabilization, and power quality improvement. The TCSC and SSSC designs provide dynamic real power flow control. The UPFC is an advanced configuration that combines the simultaneous operation of STATCOM and SSSC in one controller to allow increased power flow and dynamic voltage control and stability within the same device. The BTB systems are implemented to provide dc links for seamless interconnections as well as improved inter-tie reliability and control. All of these configurations of FACTS solutions allow for increased transmission capacity through the elimination of transmission system constraints (such as extending transient stability limits, improving power system damping, enhancing short-term and long-term voltage stability limits, providing loop flow control, etc.).

Numerous recent applications of FACTS in the United States and other parts of North America that have addressed localized issues have proven to be cost-effective, long-term solutions. Applying FACTS on a broad-scale basis for both local and regional solutions would result in numerous operational advantages.

Benefits of FACTS and BTB DC-Link Technologies

When implemented on a broad-scale basis, FACTS technologies deliver the following benefits.

- ✔ **Rapidly Implemented Installations**: FACTS projects are installed at existing substations and avoid the taking of public or private lands. They can be completed in less than 12 to 18 months—a substantially shorter time-frame than the process required for constructing new transmission lines.
- ✔ **Increased System Capacity**: FACTS provide increased capacity on the existing electrical transmission system infrastructure by allowing maximum operational efficiency of existing transmission lines and other equipment.

- ✔ **Enhanced System Reliability**: FACTS strengthen the operational integrity of transmission networks, allowing greater voltage stability and power flow control, which leads to enhanced system reliability and security.
- ✔ **Improved System Controllability**: FACTS allow improved system controllability by building “intelligence” into the transmission network via the ability to instantaneously respond to system disturbances and gridlock constraints and to enable redirection of power flows.
- ✔ **Seamless System Interconnections:** FACTS, in the form of BTB dc-link configurations, can establish “seamless” interconnections within and between regional and local networks, allowing controlled power transfer and an increase in grid stability.
- ✔ **Fiscally Sound Investments:** FACTS are less expensive solutions to upgrading transmission system infrastructure as compared to conventional solutions such as the construction of new transmission lines. Strategic implementation of FACTS on a nationwide basis could reduce transmission system infrastructure expenditures by an estimated 30% overall. FACTS also provide transmission owners greater opportunity to realize profits through more efficient operation of existing networks.

A Recent FACTS Application in North America

A project overview of a recent FACTS installation at the San Diego Gas and Electric Company’s (SDG&E) Talega Substation, which was recently placed online, is described in the sidebar. The Talega FACTS project implements the advanced VSC-based technology, which provides superior performance along with design and control flexibility. The SDG&E FACTS project provides dynamic VAR support and control in order to compensate for transmission system needs arising from operational conditions due to deregulation, and it is the first of several other potential FACTS projects that SDG&E may complete in the future. The system is currently operating as a STATCOM, but it is also designed for future expansion to either a BTB dc link or a UPFC.

FACTS and Renewable Energy Sources

In addition to transmission applications and the benefits offered by FACTS for gridlock resolution and improved system operations, these technologies are also extremely beneficial when implemented for the interconnection of certain renewable energy sources to the grid, and they also have tremendous worth for industrial applications.

In the case of renewable energies, FACTS are especially advantageous when applied for wind generator interconnections. An increasing percentage of the United State’s total generation supply is being produced from wind farm developments. However, wind generation, although beneficial in many aspects such as it pertains to economics, renewable sources of energy, and the environment, does not universally provide a steady and continuous interconnection to the electric power transmission grid.

Due to the nature of the source of wind power, a continuous and steady supply from a wind generation unit or wind farm is difficult to achieve. As such, the inherently unsteady nature of this type of generation source requires measures of stability and control on the interconnecting power transmission system. In addition, due to issues associated with voltage control, as well as both real power (MW) and reactive power (MVAR) dispatching, measures must be established for power system operators in order to adjust to wind generation output as base load, peak load, or other dispatching criteria.

As wind farms become a larger part of the total generation base and as the penetration levels increase, issues related to integration such as transients, stability, and voltage control are becoming increasingly important. In addition, due to the stochastic nature of wind, the integration of such renewable sources of generation into the transmission system is significantly different than conventional types of generation.

For wind generation applications, FACTS can be implemented for voltage control in the form of the shunt-connected SVC or STATCOM configurations. In addition to voltage support and control, there are also benefits that can be realized for allowing generating units to increase real power output by relieving the reactive power requirements through the application of these dynamic compensation technologies.

Even more advantageous, perhaps, is the application of the BTB dc link form of FACTS for wind interconnections. Such applications provide a seamless interconnection to the transmission system, allowing power flow control and at the same time providing the voltage control and stability required. In addition, wind generation facilities that are interconnected to the grid through dc links do not contribute to increased short circuit capacity on the transmission system, allowing for greater flexibility in the size and output range of wind generation, while allowing maximum real power output from the generating units.

By implementing FACTS technologies in coordination with wind generation applications (and other renewable applications), a reliable, steady, and secure interconnection to the power transmission grid is ensured. In addition, maximum output of wind capacity and efficient operation of wind generating units are realized through interconnection with FACTS controllers.

Advancing FACTS Through Energy Policy Initiatives

As indicated by the application areas described above, FACTS can provide significant enhancements to overall transmission system performance and at the same time are environmentally friendly and cost-effective solutions.

Government policies can assist in providing the vision and incentive for stakeholders to reap the significant benefit of lower-profile technologies such as FACTS that frequently compete for acceptance in a marketplace dominated by a traditional but problematic solution (i.e., power transmission lines).

Congress, the Department of Energy, and the Federal Energy Regulatory Commission have begun to recognize the solutions that low-environmental-impact technologies like

FACTS afford in providing for rapid and reliable upgrades to transmission infrastructure. FERC has proposed incentives for utilities that invest in (currently undefined) "technologies that can be installed relatively quickly," bypass the "long siting process for procurement of new rights-of-way," and may be "environmentally benign." The proposed policy is presently structured such that these incentives apply to utilities that join a regional transmission organization (RTO).

Energy legislation approved by the U.S. House of Representatives includes a provision that directs FERC to undertake a rulemaking to encourage the deployment of economically efficient transmission technologies that increase the capacity and efficiency of existing transmission facilities. And in its National Transmission Grid Study, the DOE cites FACTS systems as a technology that increases electricity flows through existing transmission corridors without having to construct new transmission lines.

In light of the significant advantages that FACTS and certain HVDC technologies can provide for enhancement of transmission grid reliability, capacity, and control, regulatory policy should be structured to establish an environment with incentives for implementing FACTS and HVDC solutions. Such policy should put into place similar regulation and incentives that have previously been established for generator interconnections. FACTS technologies are indeed "generators" of reactive power (VARs) as applied on transmission networks, and BTB dc links are "controllers" of real power (megawatts).

Establishing policy that brings incentives toward a "merchant plant" approach for these technologies, with appropriate value given to VARs and controllable megawatts, would spawn the wide-scale applications that are critical to the future of transmission grid reliability. As such, regulatory policy should consider the following key points:

- ✔ Accelerated depreciation for investments in technologies that are, from a public policy and technical perspective, clear alternatives to the protracted process of power line construction.
- ✔ Increased rate of return on investment. The rate of return for transmission investment should be commensurate with the value to the system of having adequate transmission capacity. Compared to the costs of outages, congestion, and lack of access to low-cost electricity, the cost of this upgrade is minimal.
- ✔ Consistency between the regulations and incentives that have been established for generator interconnections with respect to var and megawatt value.

Conclusions

Over the past several years, FACTS and BTB dc-link applications have increased significantly as compared to the previous decade. There are now numerous FACTS applications, including recent installations in California and Texas, as well as in the New England region of the United States and in some areas of Canada. As more electricity stakeholders recognize the technical and public policy advantages that these technologies confer, additional applications will emerge. Advancements in the state of the art of FACTS technologies will continue and will further advance the case for breaking transmission gridlock with these innovative and proven systems.

Acknowledgments

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