Shaping the Future of Global Energy Delivery

By Thomas F. Garrity

1540-7977/03/$17.00©2003 IEEE

New developments in high-voltage power transmission technology for reliable and efficient system expansion

SINCE THE MID 1990s UPWARDS OF 100 GW OF NEW GENERATION CAPACITY HAS been added in the United States, with little to no increase in the transmission capacity to move that power across the electrical grid. Historically, the U.S. transmission grid was designed to serve native load and to support regional transfer of power between neighboring companies within the power pool. Since the onset of electric utility deregulation (or, more appropriately, re-regulation) sales of wholesale electricity from generators to the network have increased 100-fold. This aspect of dispatch by new participants in the electricity market has introduced some operating challenges due to the large volume of hourly transactions that must be scheduled. Since the rolling blackouts of 2001, the adequacy of the U.S. power transmission network has been questioned. From an investment standpoint, annual capital expenditures in the U.S. power transmission system have steadily fallen from a high of $5.5 billion in the 1970s to a level of about US$3-3.5 billion in the early 2000s.

The initial interest in the cause of the blackouts and proposed solutions created an excitement in power transmission that had not been seen in years. U.S. Vice President Dick Cheney's energy task force was commissioned, and talk of a new energy bill gave companies in the business of transmission solutions a reason to be optimistic that the boom was on. EEI reported that the U.S. transmission grid would require an investment of US$56 billion dollars over the next ten years to just maintain current levels of transmission reliability. The FERC issued order 2000, mandating the formation of regional transmission organizations and requiring all transmission-owning utilities to join one by the end of 2001. Siemens and Black & Veatch presented a proposal for a project they envisioned would shore up the nation's ailing grid. The TransAmerica Generation Grid (TAGG) would add new generating capacity in the form of wind power and low-emission clean coal-fired power plants and would connect to regional grids via new high-voltage dc transmission lines, creating a way to get electricity to areas that need it during peak demand. All of these proposals, seemingly bright at first, now appear to be stalled in various financial, legislative, legal, or regulatory quagmires, unable to satisfy the varied and numerous constituencies required to move forward.

Even globally, the increasing power demand is coupled with environmental constraints and strong competition that require advanced solutions for global power transmission. System reliability and congestion relief are imperative under dynamic market conditions to ensure that transmission systems provide a steady return on investment and cash flow as well as operate with the flexibility and security that will be required to serve future demand and load growth.

Given all of the factors that must be balanced, the one certainty is that new technology will be a key enabler to move transmission investment forward and increase capacity. The good news for the electric power industry is that technology exists or is being developed to solve a large number of the world's power transmission problems. When investments do begin to take shape and the hurdles are overcome, many of the transmission equipment companies will be ready to do what they do best—serve customers with innovative solutions to their power needs. A few of the innovations that have the potential to shape the future of the global power system are already available or will soon be commercially available. Some, but definitely not all, of these new technologies are briefly discussed in this article.

Flexible AC Transmission Systems (FACTS) and HVDC Transmission

FACTS (flexible ac transmission systems) and HVDC (high-voltage dc transmission) solutions for power transmission have existed for a number of years and have provided utilities around the world with important technical solutions to a wide range of transmission needs. FACTS installations take many forms and have given utilities the option to delay new transmission line construction by offering reliable and flexible solutions to increase capacity on existing lines. Included in the family of FACTS technologies is series compensation.

Series compensation has been installed around the world to increase power transfer capability across long transmission lines, particularly lines where power flow was limited by large power angle differences between the sending and receiving ends of the line (see Figure 1). Due to concerns over SSR (subsynchronous resonance) for large generating machines, total line compensation has generally been limited to values of 20% or less. There are some exceptions to the general guideline where specific mitigation steps have been taken at power plants to minimize the adverse consequences of SSR. However, the successful deployment of thyristor-controlled switching to a small portion of the total series capacitor bank offers new solutions to SSR and can have the beneficial effect of increasing the maximum level of line compensation to achieve more power throughput. This is a good example of how FACTS technologies can used to increase line loadings in a very economical way.

Static VAR compensators (SVCs) (Figure 2) and STATCOM devices are shunt-connected solutions that can solve a wide range of dynamic issues that can limit the maximum power transfer across the power system. Where large dynamic instabilities must be solved, fast-acting shunt compensation with thyristor controls can effectively restore system stability and allow the power system to quickly recover to predisturbance power transfer levels. New fast-acting storage technologies using superconducting magnetic coils for energy storage can also enhance power system dynamic performance. Application of the right technology to solve dynamic swing or instability in the power system must be determined through system studies and simulation of device response to the disturbance.

figure 1. Western Area Power Authority Kayenta Substation (165 MVAR TCSC/230 kV).

figure 2. A typical example of a static VAR compensation installation.

There are several other technologies in the FACTS family of devices that combine both series and shunt components with thyristor controls, such as a unified power flow controller (UPFC), to improve power systems performance. The important point to note is that FACTS devices can be configured in a variety of ways to solve many power system transmission limitations, and FACTS is a key technology for improving power transfer in an open market with a large number of generators all participating in the load supply.

HVDC solves the complex problems of connecting power sources to power users over long distances or across large bodies of water where underwater cables are used. HVDC back-to-back links have been installed to connect two power systems together where synchronous ties could not be used or where the systems operated at different frequencies (e.g., 50 and 60 Hz). Recently, HVDC has been examined as a form of pipeline system to bypass existing ac transmission grids for the purposes of moving power from generator to load. This could emerge as a very viable technical solution to meet the requirements for an open generation market system.

A New Type of FACTS— Short-Circuit Current Limiters

The available short-circuit current level of a network increases directly with generation additions in high load density networks and interconnections among adjacent systems. If the short-circuit current rating of the equipment in the system is exceeded, the equipment has to be improved or replaced, which is a very cost- and time-intensive procedure. Short-circuit current limitation offers benefits in such cases. Limitation by passive elements such as reactors is a well-known practice; however, it reduces the system stability and adversely affects load flow.

An innovation in FACTS technology is a new dynamic short-circuit current-limiting device, the short-circuit current limiter (SCCL) (Figure 3). This new device operates with zero-impedance in steady-state condition, and in case of short-circuit it is switched within a few milliseconds to the limiting reactor impedance. The SCCL is based on developments in series compensation, were the TPSC (thyristor-protected series compensation) has been applied successfully on three projects in the 500-kV transmission system at the Vincent substation in the Southern Californian Grid.

By combining the TPSC with an external reactor, which is determined by the allowed short-circuit current level, this device can now be used as an SCCL.

The design of the SCCL is focused on maximum reliability and availability:

- ✔ high-power, light-triggered thyristor—110 ka peak, self-cooling
- ✔ protection with a standard multiprocessor system being widely in use for HVDC, FACTS, and drive systems
- ✔ redundant measurements—optically powered transducers
- ✔ no auxiliary power supplies on the platform needed
- ✔ fail safe—thyristor will be shorted in case of malfunction
- ✔ backup by wafer-integrated over-voltage protection
- ✔ fast switch on—instead of switch off in other electronic solutions.

Overhead Transmission Lines

Around the world, the bulk power delivery system relies on overhead lines to transport power. Much of the transmission technology already discussed relates to improvements made at the terminals or substations to increase power flow, but there have been considerable developments in overhead lines, which have the potential to increase line ratings. New line designs employ technologies for compactness, which minimize requirements for new rights of way and can be installed on existing line corridors. These new designs optimize line capacity by utilizing new conductor designs, reducing the electric and magnetic fields at the edge of the right of way by innovative phase configurations, and increasing the surge impedance loading limits for the line. High phase-order transmission with six or more phases on a single structure represents another technology with potential to increase the total power rating across the line or corridor.

Recently, major innovations in conductor design have been introduced that permit an increase of 10-15% in current carrying rating using essentially the same conductor size as earlier wires. These new designs can be used to reconductor an existing tower or pole line with minimal structural changes to the existing steel or wood structures. This has been proven to be a very economical way to upgrade an existing line to increase line ratings.

Second-Generation Gas-Insulated Transmission Lines

Whenever overhead power transmission lines cannot be used, underground transmission systems can be installed very effectively. Typically, underground cable systems have not matched the overhead line current rating without installing several parallel cable systems to achieve the same overhead line rating. This is costly, and there are some system issues due to the lower line impedance of cables, line protection schemes to detect cable faults versus overhead line section faults, and line compensation to accommodate low loading conditions. Gas insulated transmission lines (GILs) offer an economic, environmentally friendly, and maintenance-free alternative (Figure 4). GILs are suitable for burying, running above-ground, or installing in tunnels. Low operating losses (which means that less heat is dissipated to the environment and operating costs are significantly lower) are one of the outstanding features of GILs.

Gas-insulated transmission lines are suitable for metropolitan areas with high energy ratings. A special advantage of the GIL is that it can be easily integrated in the overhead line network without changing the operation modes and protection configurations. GIL is available for applications in tunnels or for directly buried systems. The GIL can transmit high power ratings greater than 1,000 MVA without forced cooling.

The GIL link behaves very much like an overhead line and can be operated with automatic reclosing. This makes it possible to have very simple terminals without high-voltage switchgear, current and potential transformers, or separate electrical protection; only surge arresters are needed. In accordance with current technology and for security reasons, this equipment is fitted with synthetic silicone insulators.

Gas Insulated Switchgear

In addition to GILs, gas insulated switchgear (GIS) is uniquely suited for applications with strict space limitations. GIS ensures high levels of safety for operating personnel and is environmentally friendly with low noise emissions. With safety and security of plants and substations at the forefront of concerns, GIS satisfies an emerging need with highly reliable, compact installations that have ratings from 145 kV all the way up to 800 kV. Recent installations demonstrate the effectiveness of an aesthetically pleasing, enclosed building that can serve growing urban areas.

The TransAmerica Generation Grid: An Innovative Solution to a Growing Problem

The TransAmerica Generation Grid (TAGG), a forward-thinking energy initiative from Black & Veatch and Siemens, is a break-

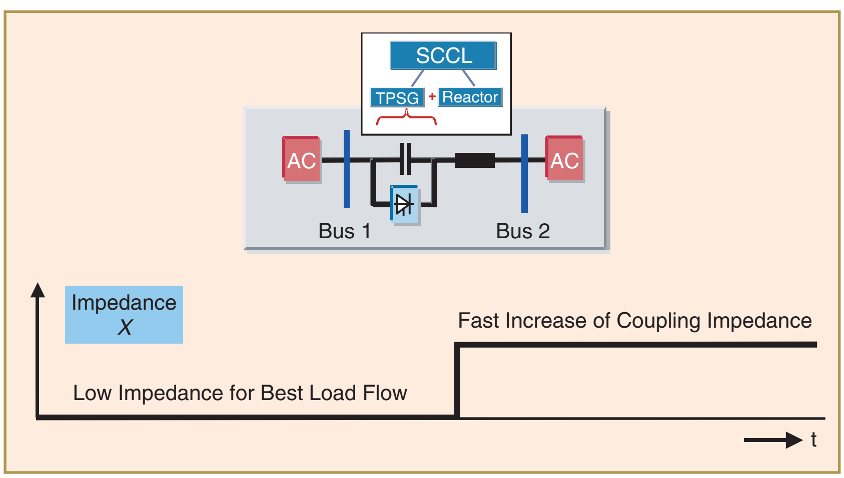

figure 3. SCCL: Fast short-circuit current limitation with high-power thyristor.

through concept to build a high-capacity energy backbone across America. TAGG will connect the existing eastern and western transmission grids to transport bulk electrical energy to regional load centers between Illinois and California.

New generation facilities using the upper Midwest's abundant wind and solid fuel resources will supplement existing energy sources. TAGG will decrease America's dependence on foreign energy, encourage development of power from renewable resources, contribute to national security through electrical reliability, and promote new commerce and economic development.

The solution proposed by TAGG supplements the existing ac system with a high-capacity, high-voltage dc backbone that permits inter-regional transfers of bulk energy. TAGG relieves congestion of the existing grid by rerouting flows on a dedicated circuit.

figure 4. A gas insulated transmission line tunnel in Switzerland.

The total reserves of the overall Powder River Basin (Wyoming–North Dakota) are enormous, constituting the coal equivalent for the United States of world oil reserves to the Middle East. The total reserve base is conservatively estimated to be in excess of 141 billion tons, of which about 58 billion tons are projected as being readily and economically capable of extraction by present-day surface-mining technologies. The 58 billion tons represents over 50 years of the total United States coal consumption compared to only nine years of natural gas reserves for North America. The Dakotas possess a wind generation potential that is as robust as anywhere in the United States and are an ideal location for power aggregation and injection.

Transmission Technology for the Future—Connecting Wind Generation to the Grid

Renewable energy, especially wind energy, has become the option for emission-free, renewable power generation of the future. As the TAGG proposal points out, there is great wind potential in the United States between the mountains, the Great Plains, and offshore capabilities. Grid access technology (GAT) in the form of high-voltage ac or HVDC can connect the wind farm parks to the grid and transmit the power securely and efficiently to the load centers. The selection of the right transmission technology improves the economics of the wind farm investment as well as allows the grid operator/owner to give access to the new generating member. Three-phase high-voltage ac transmission ensures minimal current losses but requires a reactive power device such as an SVC be installed for power factor correction and power quality improvements. The merits of HVDC transmission systems versus ac transmission systems are the principally unlimited route length and stable operation. The dc voltage does not cause reactive currents in the cables. Further, the HVDC system separates the two ac systems (one offshore, one onshore) and prevents any short-circuit current impact from one system to the other one.

Technology to Power the Future

High-voltage power transmission research and development continues to make advances in new technologies and applications that give transmission owners and operators the flexibility, security, and stability they need to continue to expand their systems reliably and efficiently. As the electric power infrastructure expands and global demand for power grows, suppliers and customers alike will have to cooperate to assure that the appropriate technologies are developed and deployed in ways that continue to maintain the reliability and security of the energy delivery system, provide a dependable and affordable source of electricity to the consumer, and ensure the highest standards of public welfare and safety.

Biography

Thomas F. Garrity joined Siemens Power Transmission and Distribution in Raleigh, North Carolina, in April of 2003 as vice president, sales and business development. Prior to joining Siemens, Tom spent 14 years with General Electric Company in various leadership positions in their Power Systems and Industrial divisions. Garrity has been a member of IEEE for 33 years and was elected a Fellow of IEEE in 1989. He received the IEEE Millennium Medal in 2000. He has served on the IEEE Standards Board from 1995 to 1997, the IEEE Foundation Board from 1996 to 2002, the IEEE PES Governing Board from 1994 to 2000, and previously served on a number of IEEE PES Technical Committees. Tom is a member of CIGRE and was the US representative to the CIGRE International Administrative Council from 1995 to 2000. He has published over 60 technical papers in IEEE, CIGRE and various industry technical journals. Garrity previously worked for the Department of Energy in the Ford and Carter administrations, and he held the title of director, electric power delivery systems. He is a graduate of the City College of New York with a B.S. in electrical engineering.