Upgrading Transmission Capacity for Wholesale Electric Power Trade

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On April 24, 1996, the Federal Energy Regulatory Commission (FERC) issued a final rule, Order No. 888, (1) in response to provisions of the Energy Policy Act (EPACT) of 1992. Order No. 888 opens wholesale electric power sales to competition. It requires utilities that own, control, or operate transmission lines to file non-discriminatory open access tariffs that offer others the same electricity transmission service they provide themselves. The second final rule, Order No. 889, (2) issued on the same date, requires a real-time information system to assure that transmission owners and their affiliates do not have an unfair competitive advantage in using transmission to sell power. It is expected that Orders No. 888 and No. 889 and other actions taken by State Public Service Commissions to promote competition in the electric power industry will result in increased demands for transmission services.

EPACT states that when transmission capacity is constrained, an electric utility must offer to enlarge its transmission capacity, if necessary, to provide transmission services. However, obtaining approval to site and build new transmission capacity is becoming more difficult due to environmental concerns, potential health effects of electric and magnetic fields (EMF), special interest groups' concerns, and the concern that property values would decline along transmission line routes. Currently, 10,126.8 line miles of transmission additions are planned for the United States, Canada, and the northern portion of Baja California, Mexico, for 1995 through 2004 Table FE1. and are in different stages of planning and/or construction. Many of these lines may be delayed for many years or may never be constructed.

Due to the problems associated with constructing new transmission lines, it is important to examine .the possible options for increasing the transmission capability on present sites and making maximum use of existing transmission systems through upgrades. When feasible, upgrades are an attractive alternative, because the costs and leadtimes are less than those for constructing new transmission lines. This article describes to policy makers and regulators the bulk electric power system and identifies the thermal, voltage, and operating constraints on a system's capability to transmit power from one area to another. Some of the potential remedies for these constraints through upgrades are presented along with a comparison of the cost to upgrade compared to the costs for new transmission lines.

Description of the Bulk Electric Power System

The basic elements of an electric power system are shown in Figure FE1. (Note that the figure does not include all types of electric generation.) The electric generating plants or stations, transmission lines, and high voltage or bulk power substations that constitute the bulk power system are shown above the dashed line. Subtransmission and distribution systems and sites where the electricity is consumed is shown below the dashed line. Transmission lines and distribution lines are categorized by their voltage rating. Transmission lines are generally defined as 115 kilovolts (kV) and higher (765 kV is the highest installed). Subtransmission systems are 69 kV to 138 kV. Distribution systems, that furnish power to retail customers, are less than 69 kV.

The transmission system usually designates the highest voltage or voltages used on a given system and carries electric energy from the power plants to the distribution system. Most transmission systems use overhead alternating current (AC) lines; however, some overhead direct current transmission systems and underground and submarine cable exist as well. Power transformers are used in generating stations to raise the voltage of the produced power from the generation voltage to transmission voltage; in distribution substations to reduce the voltage of the power delivered to the distribution system voltage; and elsewhere to connect together transmission systems designed at different voltages.

The bulk-power substation supplies power to the subtransmission system, the part of the system between transmission and distribution systems. The distribution system carries the electricity to the residential and commercial customers and some of the smaller industrial customers.

Switching stations and substations are used to transform the electrical energy to a different voltage, transfer electrical energy from one line to another, and to redirect the flow of power whenever a fault occurs on the transmission line or other equipment in the system, so system operation can be preserved. Circuit breakers disconnect the flow of power from the faulted equipment protecting it from further damage.

A control center coordinates the operation of bulk power system components and is responsible for .operating the power system within a geographic region called a control area. One or more utilities make up a control area. A control center is connected to other control centers with transmission tie lines. Through proper communications (metering and telemetry), the control center is constantly informed of generating plant output, transmission lines and ties to neighboring systems, and system conditions. A control center uses this information to ensure reliability by following reliability criteria and to maintain its interchange schedule with other control centers.

For the bulk power system to operate reliably, it must be designed and operated based on the following principles:

- The total generation at any moment must be kept equal to total electricity consumption and losses on the system including transmission and distribution.
- The electricity is allowed to flow through the transmission system in accordance with physical laws and cannot be directed to flow through specific lines.
- The system must be designed with reserve capacity in generation and transmission to allow for .uninterrupted service when contingencies occur.

Constraints on the Transmission System

The amount of power on a transmission line is the product of the voltage and the current and a hard-to-control factor called the "power factor." (3) Additional power can be transmitted reliably if there is sufficient available transfer capability on all lines in the system over which the power would flow to accommodate the increase and certain contingencies or failures that could occur on the system. There are three types of constraints that limit the power transfer capability of the transmission system: thermal/current constraints, voltage constraints, and system operating constraints.

Thermal/Current Constraints

Thermal limitations are the most common constraints that limit the capability of a transmission line, cable, or transformer to carry power. The transmission line resists the flow of electrons through it, causing heat to be produced. The actual temperatures occurring in the transmission line equipment depend on the current, that is the rate of flow of the electrons, and also on ambient weather conditions, such as temperature, wind speed, and wind direction, because the weather effects the dissipation of the heat into the air. (4) The thermal ratings for transmission lines, however, are usually expressed in terms of current flows, rather than actual temperatures for ease of measurement.

Thermal limits are imposed because overheating leads to two possible problems: (1) the transmission line loses strength because of overheating which can reduce the expected life of the line, and (2) the transmission line expands and sags in the center of each span between the supporting towers. If the temperature is repeatedly too high, an overhead line will permanently stretch and may cause its clearance from the ground to be less than required for safety reasons. Because this overheating is a gradual process, higher current flows can be allowed for limited time periods. A "normal" thermal rating for a line is the current flow level it can support indefinitely. Emergency ratings are levels the line can support for specific periods, for example, several hours.

Underground cables and power transformers are also limited by thermal constraints. Operating undergroundcables at excess temperatures shortens their service lives considerably due to damage to their insulation. Power transformers are likewise designed to operate at a maximum temperature rise to protect insulation.

Voltage Constraints

Voltage, a pressure-like quantity, is a measure of the electromotive force necessary to maintain a flow of electricity on a transmission line. Voltage fluctuations can occur due to variations in electricity demand and to failures on transmission or distribution lines. Constraints on the maximum voltage levels are set by the design of the transmission line. If the maximum is exceeded, short circuits, radio interference, and noise may occur. Also, transformers and other equipment at the substations and/or customer facilities may be damaged or destroyed. Minimum voltage constraints also exist based on the power requirements of the customers. Low voltages cause inadequate operation of customer's equipment and may damage motors.

Voltage on a transmission line tends to "drop" from the sending end to the receiving end. The voltage drop along the AC line is almost directly proportional to reactive power flows and line reactance. (5) The line reactance increases with the length of the line. Capacitors and inductive reactors are installed, as needed, on lines to, in part, control the amount of voltage drop. This is important because voltage levels and current levels determine the power that can be delivered to the customers.

System Operating Constraints

The operating constraints of bulk power systems stem primarily from concerns with security and reliability. These concerns are related to maintaining the power flows in the transmission and distribution lines of a network. Power flow patterns redistribute when demands change, when generation patterns change, or when the transmission or distribution system is altered due to a circuit being switched or put out of service.

Power Flows in Networks

When one utility, or control area, transmits power to another, the resulting power flows along all paths joining the two areas, regardless of ownership of the lines. The amount of power flowing on each path of the transmission system depends on the impedance (6) of the various paths. The impedance of a transmission line depends on the line's length and design details for the line. A low impedance path attracts a greater part of the total transfer than a path with a high impedance.

When utilities enter into a wholesale power transaction with other utilities, nonutilities, or customers they designate a pro forma "contract path" of transmission lines or systems through which the power is expected to flow. The actual power flows from the transactions, however, do not necessarily follow the contract path but may flow through parallel paths in other transmission systems depending on the loading conditions at the time when the transfer occurs. These are referred to as "parallel path flows." When transmission systems are directly or indirectly interconnected with each other at more than one point, power flows can travel into the other systems' networks and return, thus forming "loop flows." Both loop flows and parallel path flows may limit the amount of power these other systems can transfer for their own purpose.

Preventive Operation for System Security

Constraints on the transmission capabilities also occur due to preventive operating procedures for system security. The bulk power system is designed and operated to provide continuity of service in the case of possible contingencies such as: loss of a generation unit, loss of a transmission line, or a failure of any other single component of the system. "Preventive" operating procedures means operating the system in such a way as to avoid service interruptions as a result of certain component outages. It is recognized as good utility practice and regarded by the North American Electric Reliability Council (NERC) as the primary means of preventing disturbances in one area from causing service failures in another. (7) NERC provides standards and operating guidelines for overall coordination of utility procedures in the United States, Canada, and parts of Mexico.

The NERC guidelines recommend making it an operational requirement that systems be able to handle any single contingency. The ability to handle multiplecontingencies should be an operational requirement when practical, according to NERC. The adoption of the NERC guidelines has increased the operating security of the interconnected systems and reduced the frequency with which major disturbances occur.

The NERC preventive operating requirements include running sufficient generation capability to provide operating reserves in excess of demand and limiting power transfers on the transmission system. The system then operates so that each element remains below normal thermal limits under normal conditions and under emergency limits during contingencies. The reserve capacity can then be used to handle contingencies. (8)

System Stability

Power systems stability problems represent other system operating constraints. Generally they are grouped into two types:

- Maintaining synchronization among the generators of the system
- Preventing the collapse of voltages.

In a synchronous, interconnected operating system, all generators rotate in unison at a speed that produces a consistent frequency. In the United States, this frequency is 60 cycles per second. When a disturbance (fault) occurs in the transmission system, the power requirements from the generators change. The fault may reduce the power requirements from the generator; however, the mechanical power driving the turbine stays constant, causing the generator to accelerate. Removing the fault alters the power flow and the turbine slows down. This results in oscillations in the speed at which the generator rotates and in the frequency of the power flows in the system. Unless natural conditions or control systems damp out the oscillations, the system is unstable. This is referred to as transient instability and may lead to a complete collapse of the system. To avoid transient instability, power transfers between areas are limited to levels determined by system contingency studies. (9) Steady-state instability can occur if too much power is transferred over a transmission line or part of a system to the point that the synchronizing forces are no longer effective. Steady-state instability is an unusual occurrence because it is easily preventable; however, it acts as a constraint on transmission power transfers. (10) Small-signal instability, also called dynamic instability, usually occurs when normal variations in generation or consumption are too small to be considered disturbances, but initiate oscillations at low frequencies. These conditions can lead to large voltage and frequency fluctuations, resulting in loss of overall system stability. (11)

Voltage instability occurs when the transmission system is not adequately designed to handle reactive power flows. Large amounts of reactive power flows on long transmission lines result in severe drops in voltage at the consumption end, causing the consuming entities to draw increasing currents. The increased currents cause additional reactive power flows and voltage losses in the system, leading to still lower voltages at the consumption end. As the process continues, the voltages collapse further, requiring users to be disconnected to prevent serious damage. Finally, the system partially or fully collapses. (12)

Upgrade Remedies for Constraints on the Transmission System

The constraints, that have been described, limit a system's ability to transfer power and, therefore, lower the utilization rates of the existing transmission network. This section of the report will discuss upgrade possibilities to increase the transfer capability of existing transmission lines so that additional power can be transmitted reliably from one area of a system to another, or from one entire system to another. Remedies for constraints related to thermal limits, voltage-related limits, other options to increase power transfer, and system operating procedures will be explained and the typical costs of these remedies provided. The typical cost of building a new transmission line Table FE2. is also included for comparison. Note that actual costs for a specific project could be somewhat higher or lower than those shownin the table. Right-of-way costs, that is the cost of land and the legal right to use and service the land on which the transmission line would be located, are not included in the table because they vary significantly depending on the location and the territory being traversed. New line costs are substantial, however, even without the inclusion of the costs of rights-of-way.

Remedies for Thermal Constraints on Components

Many options are available for reducing the limitations on power transfers due to the thermal rating of overhead transmission lines. Available measures are much more limited for underground cables and transformers. A review of the process used to set the present thermal rating for a transmission line may reveal ways to increase the rating at little or no cost. In the past, it was common practice to use approximations and simplifications to determine thermal ratings for lines, with the result that the lowest possible rating and greatest reliability were selected. Modern methods for computing thermal ratings for different conditions may allow higher ratings without any physical changes to the line. (13)

In addition, power flow limits for lines based on reaching a maximum temperature can be calculated in real-time using data on the ambient weather conditions on the line and power flow information available to the control center. Some utilities measure the temperature of the line using detectors located on the transmission lines and transmit it to the control center. One estimate for such a system, including sensors and ground installation, was $70,000 per location. (14)

Since the thermal limit of a transmission line is based on the component that would be the first to overheat, a substantial increase in the overall thermal rating of the line can sometimes result from replacing an inexpensive element. The replacement of a disconnect switch or circuit breaker is much less costly than major work to replace a line or to build a new line. The parts being replaced can often be used somewhere else on the system.

It may be acceptable to increase allowable temperatures and plan for a decrease in the life of the lines. This approach may produce sags in the line such that the allowable clearance to the ground is not maintained. If inadequate clearances occur at a limited number of spans on the line, it may be economically justifiable to rebuild the towers, increasing their height to restore sag clearances, or to fence the affected parts of the right-of-way to make them inaccessible. If the excessive sag occurs throughout the line, however, increasing the height of towers would be very expensive. Sometimes it is possible to re-tension the line or span to increase the clearance to the ground.

It may also be possible to increase the transfer capability of the line by monitoring the line sag to allow higher temperatures/currents. There are two possible approaches one direct and another indirect. The direct approach involves calculating the actual sag of the line at its mid-span using actual information provided by special sensors on the towers about the horizontal tension and ambient temperature. Using this method, the control center calculates the actual limit on the current that the line can handle under actual conditions. The indirect method entails transmitting temperatures and wind velocity and locations of the critical sag sites to the control center by radio or telephone. With this information, the control center calculates what the sag is and determines any dangerous trend.

The most obvious, but also most expensive method for alleviating the thermal constraints on a line is to replace the lines with larger ones (conductors) through "restringing" or to add one or more lines, forming "bundled" lines. This approach requires consideration of the tower structures that support power lines. The towers are designed to hold the weight of the existing lines and the weight of any possible ice formations. They require lateral strength to withstand the sometimes very substantial forces of winds blowing perpendicular to the direction of the line. Replacing lines with larger ones, or bundling them, usually requires substantial reinforcement of the tower structures and, possibly, the concrete footings of the towers. Restringing or bundling lines to increase the transfer capability also requires enhancing substation equipment so that it does not become a limiting factor. Substation enhancements cost approximately $600,000 per substation. (15)

Other typical cost estimates for restringing transmission lines with larger conductors are:

- 60 kV line, to 397.5 kcmil: (16) $40,000 per mile
- 115 kV line, to 715.5 kcmil: $80,000 per mile
- 230 kV line, to 1,113 kcmil: $120,000 per mile.

The normal thermal ratings of the restringed lines would be approximately 55 MW, 150 MW, and 400 MW, respectively.

Some typical costs of bundling lines are:

- 115 kV line, 715.5 kcmil: $130,000 per mile
- 230 kV line, 1,113 kcmil: $200,000 per mile
- 230 kV line, 2,300 kcmil: $260,000 per mile.

Bundling these lines would approximately double their normal thermal ratings, for an increase of approximately 150 MW, 400 MW, and 500 MW, respectively. (17)

Remedies for Voltage Constraints for Individual Lines

The standard voltages for electric utility lines in the United States are currently 34.5 kV, 46 kV, 69 kV, 115 kV, 138 kV, 161 kV, 230 kV, 345 kV, 500 kV, 765 kV, and 1,100 kV (not yet commercially installed). Each of these line types can carry 5 percent more or less voltage for normal operation. Upgrades to change line voltages can be divided into two categories: increases within a voltage class and changes to a different voltage class.

Increasing the operating voltage within a voltage class is a technique that has been used for decades. If the system does not reach the upper voltage limit during light loads under normal operation, normal operating voltage can be increased without major configuration changes to the lines. It is necessary, however, to increase the voltages of the generators, and to make some adjustments to the settings of the transformer, or possibly some transformer replacements, in order to produce the new operating voltage. Coordination with neighboring systems is required to prevent additional reactive power flows because of the increased voltage into the neighboring system.

Other remedies for voltage problems that limit transfer capabilities involve controlling reactive power flows. There are two types of reactive power sources, capacitors, and reactors, which generate and absorb reactive power flows, respectively. The installation of capacitors or reactors at strategic locations of the transmission or distribution system, is a remedy often used to control reactive power flows and therefore increase power transfers. Shunt capacitor installation costs are shown below:

- 115 kV, 50 megavolt amperes reactive (MVAR): New installation, $1,000,000; additional step (more capacitors)

in existing installation, $500,000
- 230 kV, 63 MVAR: New installation, $2,000,000; additional step, $700,000
- 500 kV, 100 MVAR: New installation, $3,000,000
- 500 kV, 200 MVAR: New installation, $5,000,000.

Typical costs of shunt reactors on the transmission line are:

- 230 kV, 87.9 MVAR: New installation, $2,000,000
- 500 kV, 100 MVAR: New installation, $3,000,000. (18)

Voltage changes to a higher voltage class usually require substantial reconstruction of the transmission lines. Higher voltages require greater clearances between the lines, and between grounded objects including the towers. Increasing the string of insulators and making other changes drive up the weight and transverse loadings of the towers. These changes require additional strength in the construction of the towers and their footings. Typical estimates for converting steel tower transmission lines from one voltage class to another are:

- 60 kV to 115 kV: $50,000 per mile
- 115 kV to 230 kV: $500,000 per mile
- 230 kV to 500 kV: $800,000 per mile.

Voltage class conversions increase normal thermal ratings which depend on the conductor size. The following are typical values of increases that can be achieved:

- 60 kV to 115 kV, 397.5 kcmil conductors: from 56 MW to 108 MW; 115 kV to 230 kV, 715.5 kcmil .conductors: from 151 MW to 302 MW; and
- 230 kV to 500 kV, 1,113 kcmil conductors: from 400 MW to 865 MW. (19)

Rebuilding a line to higher voltage requires further expense for substation equipment. If the connected networks remain at the older voltage, rebuilding a line to higher voltage would require a transformer at either end to provide connection to the rest of the system. Rebuilding a line for higher voltage class is not cost-effective unless a number of circuits are converted at the same time.

Other Options to Increase Power Transfer

Other methods of mitigating power transfer constraints due to individual components include: converting single circuit towers to multiple-circuit towers and converting alternating current (AC) lines to high-voltage direct current (HVDC) lines. Most transmission circuits for 230 kV and below are built on two-circuit tower lines. Circuits for higher voltages are generally built on single-circuit towers. Substantial increases in either right-of-way width or in tower height are required for conversion of a single-circuit line to a double-circuit line. Estimates of the costs of conversion are given on Table FE3.

The conversion of an AC line to HVDC, or the replacement of an AC line, is a consideration when large amounts of power are transmitted over long distances. HVDC lines are connected to AC systems through converter systems at each end. The power is converted from AC to DC at the sending end and back to AC at the receiving end. HVDC circuits have some advantages over AC circuits for transferring large amounts of power. HVDC circuits can be controlled to carry a specific amount of power without regard to the operation of the AC circuits to which they are connected. If HVDC lines are operating in parallel with AC lines, the outage of a parallel AC line does not overload the DC line. However, the outage of the HVDC line does increase the loading on the parallel AC lines. HVDC circuits have resistance but do not have reactance associated with AC, so they have less voltage drop than AC circuits. HVDC circuits have a major disadvantage as they require converter stations at each end of the circuit that are very expensive, making HVDC uneconomical except when power is transmitted for long distances. HVDC circuits also do not have the system instability problems that AC circuits have.

Remedies for System Operating Constraints

Changing Power Flows

As previously mentioned, the distribution of power flows through a transmission network depends on the impedance of the different lines. If the power flows over the system can be changed so that the loading on a critical line is reduced, larger power transfers can be permitted. Sometimes the power flows through a transmission system can be improved by changing the connections of lines at various substations to increase power flow through some lines and reduce it in others. Some reconfigurations, such as closing some circuit breakers and opening others, require no investment. Other reconfigurations require small investments such as the addition of some circuit breakers or the reconnection of a line from one bus in a substation to another.

There frequently are multiple paths between sections of the transmission system. A single line often becomes overloaded before the others. Some devices can also be used to address this problem and change the power flows; the phase-angle regulator (PAR) is the device most often used. PAR is also referred to as a power-angle regulator, or phase shifter. A PAR looks like atransformer and induces a circulating power flow through the regulated line and back through all lines that are more or less in parallel with it. The distribution of the current flows over the lines is changed, but the total power transfer is not. The use of PARs has increased in recent years; however, their installations are relatively costly. A 230-kV, 300-MVA PAR with a phase angle capability of plus or minus 60 degrees is estimated at $30,000,000. (20)

The power flow can also be altered by reducing the impedance of the line by inserting a series capacitor or increasing the impedance by inserting a series reactor (actually a coil). Series capacitors are often used on long transmission lines to reduce impedance, thus reducing the voltage drop along the line and decreasing the amount of losses due to reactive power. Capacitors increase the flow of power on the line on which they are inserted and reduce the power flow on other parallel lines. A 500 kV, 570 million volt amperes reactive (MVAR) capacitor installation was recently estimated at $10,000,000. (21) Series reactors reduce the power flowing through a line which otherwise would be overloaded, but are used less often than capacitors. Series reactors are often used to limit short circuit currents. They have one disadvantage in that they increase the voltage drop on the line reducing power transfer capability.

Change in Operating Philosophies

The "preventive" operating procedure, discussed under system operating constraints, ensures that no action is required in the event of a system contingency other than clearing the fault. When contingencies arise, the system is capable of responding without lines overheating, voltage problems, and instability. This approach is different from "corrective" operation, which requires immediate action, such as switching circuits or other actions, after a contingency occurs, so the system performance will be adequate. Corrective operation is less reliable than preventive operation, but allows greater power transfers during normal operations. Corrective measures between systems sometimes become so complex that when a certain contingency occurs, the system fails.

Changing the power flows over the system to reduce the loading on the critical line after a contingency occurs increases the power transfers that can be made under normal conditions. The improvement in the power flows must be compared against the cost of system failures when the corrective measures do not work. Technologies are being developed to move toward corrective, rather than preventive methods. Technologies, developed as a part of a Flexible AC Transmission System, (FACTS), can be used to help mitigate current preventive system operating constraints. The FACTS concept uses new power-electronics switches and other devices to provide faster and finer controls of equipment to change the way the system power flows divide over the system under normal conditions or during contingencies. A FACTS device can be used to reduce the flow on the overloaded line and increase the utilization of the alternative paths excess capacity. This allows for increased transfer capability in existing transmission and distribution systems under normal conditions. Some FACTS applications are presently feasible and in service while others are in various stages of development.

Increasing Stability Limits

Various schemes are available to increase the ability to withstand power system transient instability. These measures reduce the power mismatch between generation and consumption levels in different regions of the power system. The following describes some technologies for generators and their controls that influence the transient stability performance of the power system.

The new relatively small simple cycle and combined-cycle turbines, which are dispersed throughout the power system, can improve the stability of the system because of their fast response. These generators have little inertia and fast-acting mechanical drives, allowing them to change their generation level rapidly compared with older fossil-fuel steam plants. Dispersed generation usually reduces both power transfers between regions of the power system and power imbalance in each region. Dispersed generation also allows for a more uniform distribution of overall system inertia. Finally, the faster response of the generators can better follow demand variations in their region.

Transient stability can also be maintained by two generator control systems. The automatic voltage regulator (AVR) control system is responsible for maintaining a fixed voltage from the generator regardless of demand levels. AVR's contribute to keeping the power system within stability limits in the face of faults. The governor control system regulates the mechanical power outputof the generator's mechanical drive or turbine. If the generator rotor speed drops in a steam power plant, the governor increases the steam flow to the turbine, which increases the mechanical power delivered to the generator. Conversely, an increase in rotor speed is countered with a reduction in steam flow and turbine mechanical power. The control systems help to maintain the synchronous speed of generators in a region and improve the stability performance of the overall system.

Transient stability in systems with more than one long transmission line can be increased by inserting one or more switching stations. For example, if one of a pair of long lines is lost due to a fault, the path of these two lines now has an impedance twice (200 percent) what it was before one line failed. This can have a serious effect on the stability of the system. If a switching station is installed on both lines and a fault occurs on one line, the two lines will now have 150 percent of the original impedance when the fault is cleared. This is a substantial contribution to the stability of the system and allows a substantial increase in the transfer of power.

Transient instability is a major concern of system operators because it is the most common source of instability and because changes in operating conditions produce the greatest variation in stability constraints. If system limitations can be calculated for actual conditions rather than off line, the system can be operated closer to actually needed limitations. These calculations require on-line data that provide immediate measurements of actual loading, generation, and transmission system status. Some utilities perform their off-line dynamic security studies every day based on the operating conditions forecast for the next day. The results of these studies, which are usually performed overnight, are provided to the control center for operating the power system the next day. On-line dynamic security assessment eliminates all conservative assumptions about future operating conditions because actual data on system operating conditions are used. This on-line assessment can increase the actual transfer capability of a power system. (22)

Conclusion

Utilities are expecting increased competition in the future and are looking for ways to lower their costs. The option to increase transmission capacity by upgrading the existing lines is of interest because it can be done at considerably less cost than constructing a new transmission line and with a shorter lead time. Also, constructing new transmission lines is becoming more difficult with environmental concerns, potential health effects of EMF, and possibly declining property values over transmission line routes. The transfer capability of a system may be increased if the thermal, voltage, or system operating constraints of the existing transmission lines can be removed with some of the upgrade remedies described herein. As restructuring of the electric power industry for increased competition continues, along with increases of wholesale trade, it is expected that the future operators of the transmission system, whether they are independent system operators (ISOs), regional transmission groups (RTGs), power pools, or utilities, will be interested in increasing the utilization rates of the existing transmission lines using some of the options described in this article.

Endnotes

(1) "Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities," Docket Nos. RM95-8-000 and RM94-7-001, Order No. 888, April 24, 1996. Return to Text

(2) "Open Access Same-Time Information System (formerly Real-time Information Networks) and Standards of Conduct," Docket No. RM95-9-000, Order No. 889, April 24, 1996. Return to Text

(3) The ratio of real power (kilowatt) to apparent power (kilovoltampere) for any given load and time. Return to Text

(4) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), pp. 12-13. Return to Text

(5) Reactive power is a phenomenon associated with AC power characterized by the existence of a time difference between voltage and current variations and depends on the power dispatch and the power requirements of the system. Reactance is a characteristic of the design and length of the line. Return to Text

(6) Impedance is the opposition to the power flow on an AC circuit. Return to Text

(7) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 17. Return to Text

(8) Power Technologies, Inc., "Technical Background and Considerations in Proposed Increased Wheeling, Transmission Access and Non-Utility Generation," (Schenectady, New York, March 30, 1988), pp. 4-25 to 4-26. Return to Text

(9) Power Technologies, Inc., "Technical Background and Considerations in Proposed Increased Wheeling, Transmission Access and Non-Utility Generation," (Schenectady, New York, March 30, 1988), pp. 4-23-24. Return to Text

(10) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), pp. 20-21. Return to Text

(11) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 21. Return to Text

(12) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 21. Return to Text

(13) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 26. Return to Text

(14) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 30. Return to Text

(15) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 28. Return to Text

(16) One kcmil is 1,000 circular mils, a measure of wire cross-area. Return to Text

(17) CSA Energy Consultants, "Existing Electric Transmission and .Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 28. Return to Text

(18) CSA Energy Consultants, "Existing Electric Transmission and .Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 32. Return to Text

(19) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 34. Return to Text

(20) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 42. Return to Text

(21) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), p. 43. Return to Text

(22) CSA Energy Consultants, "Existing Electric Transmission and Distribution Upgrade Possibilities," unpublished report prepared for the Energy Information Administration (Arlington, VA, July 18, 1995), pp. 49-50. Return to Text

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Tables:

Figures:

- **Figure FE1. Basic Elements of a Modern Power System Showing Several Types of Electric Generation**

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