Transmission Enhancement Technology Report

WESTERN

AREA POWER
ADMINISTRATION

UPPER GREAT PLAINS REGION
Transmission System Planning

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1. EXECUTIVE SUMMARY

Western Area Power Administration (Western), was directed to conduct a study pursuant to the following language in House Report 107-148, the Conference Report for the Supplemental Appropriation Act, 2001, Pub. L. 107-20, :

“Non-reimbursable funding of $250,000 is provided to conduct a planning study of transmission expansion options and projected costs in Western’s Upper Great Plains Region. Existing Western transmission capacity is insufficient to support the development of known energy resources that could support new electric generation capacity in the Upper Great Plains Region. The directed study will require assumptions as to future generation locations. Western is directed to solicit suggestions from interested parties for the sites that should be studied as potential locations for new generation and to consult with such parties before conducting the study. Western is directed to produce an objective evaluation of options that may be used by all interested parties.”

Additionally, House Report 107-258, the Conference Report for the Energy and Water Development Appropriations Act 2002, Public Law 107-66, states, “Within the amount appropriated, not less than $200,000 shall be provided for the Western Area Power Administration to conduct a technical analysis of the costs and feasibility of transmission expansion methods and technologies. These funds shall be non-reimbursable. Western shall publish a study by July 31, 2002 that contains a recommendation of the most cost-effective methods and technologies to enhance electricity transmission from lignite and wind energy. “

As per the requirements of the above-referenced Congressional direction, Western conducted a public workshop on October 19, 2001, and also accepted written comments. Based on the Congressional directive and input from all the interested parties, a detailed study scope was formulated. By using funds appropriated in Fiscal Year 2001, and some of Fiscal Year 2002, Western was able to expand the study scope. The "Montana-Dakotas Regional Transmission Study" (East Side and West Side) evaluates potential locations for new generation on Western's east and west transmission systems in fulfillment of the above-reference Congressional directive.

This report was prepared by SSR Engineers, Inc. and contains a review of methods and technologies with potential to enhance electricity transmission capability to integrate lignite and wind energy into the transmission grid.

Western has used both traditional and non-traditional methods and technologies to increase the capacity of the high voltage electric power transmission system in the Upper Great Plains Region. Western has also been a leader in providing funding and staff to participate in research of new technologies that may eventually prove to be valuable. Reconductoring existing lines along with the installation of state-of-the-art Static Var Compensators, HVdc technology, and phase-shifting transformers have been used successfully to increase the reliability and transfer capability of Western's system.

Although much of the new technology currently being evaluated by Western is not yet commercially viable or may not directly increase the transfer capability of the system, Western will continue to utilize existing technologies to provide requested transmission service to new electric power resources interconnecting to the Federal transmission system. Western will continue its leadership role in the development and review of new technology applications to the power system and will recommend the use of innovative technologies to generation developers for their consideration.

The "Montana-Dakotas Regional Transmission Study" evaluated several of the traditional technologies in the various transmission alternatives studied, as outlined in Section 7.

2. INTRODUCTION

There have always been challenges associated with moving large amounts of power over a transmission system, however, recent requests for transmission service has resulted in new limitations of the system because of the desire to buy and sell energy into different market locations. This has resulted in heavy transmission utilization in certain areas that was not considered when the system was initially constructed. This has also increased the need for improvements in transfer capability while maintaining the historically high level of reliability. These improvements must be done in a cost-effective manner, however. This challenge has increased interest in creating a more robust power system through the use of new technologies applied to the existing grid.

Western continually evaluates new and better practices to improve system operation and optimize and increase the use of the transmission system. All new technologies are evaluated on a case-by-case basis and are used when the new technology is cost effective and can provide benefits to the system.

The purpose of this report is to summarize and compare "newer" technologies with some of the existing technologies and methods used to increase transmission capability. Section 3 documents existing technologies used in the industry today. Section 4 involves discussion of new technology to improve existing equipment. Section 5 describes some of the new transmission equipment technologies with potential to improve transmission capability. Section 6 documents recent research into practices to more efficiently use different aspects of the existing system. Finally, Section 7 summarizes those technologies that have potential application to the Western's Upper Great Plains Region transmission needs.

3. EXISTING TRANSMISSION IMPROVEMENT METHODS AND TECHNOLOGIES

When improvements and additions to the transmission system have been required in the past, several methods to increase Available Transmission Capability (ATC) have been used. This section discusses the traditional types of design alternatives used by Western and the electric industry.

The primary system improvements involve upgrades or replacements to the existing transmission lines, or installation of new transmission lines. Typically when more power carrying capability is required between areas in the power system, several traditional options exist for providing this increase in transmission capability.

1. Reconductor Transmission Line/Terminal Equipment Replacements: If the original transmission line conductor is inadequate to carry expected power flows, the line can be reconductored with a larger conductor with more power carrying capability. This can be an economical solution provided that the transmission line towers do not need to be significantly altered to support the heavier conductor. In addition, some transmission line ratings may be limited by terminal equipment that can be upgraded as needed to increase the transfer capability of the line to the thermal limits of the conductors.

2. Voltage Upgrade: Another option is to increase the operating voltage of the transmission line. For example, increasing the voltage from 230 kV to 345 kV. In this instance, for example, the nominal rating of the line may be increased by 150% while using the same conductor. This type of improvement may require upgrading the transmission towers to meet National Electric Safety Code (NESC) clearance levels. In addition, the switching stations and substations must also be upgraded with higher voltage circuit breakers, switches, transformers, and other related equipment.

3. New Transmission Line Installation: A third option is to build new transmission lines to help alleviate overloading by providing additional paths for power flow. Construction of new transmission provides many benefits by increasing the reliability of the transmission system. However, construction of new transmission may be difficult due to environmental requirements, right of way issues, and landowner objections.

4. Conversion from single circuit to double circuit: A fourth option is to double circuit an existing single circuit line. This involves modifying the existing transmission tower and adding a second transmission line to the structure. This may require that the transmission structures have to be extensively modified or replaced. If a new parallel line can be built within the existing

right-of-way, this option can eliminate costly routing studies and land acquisition problems.

5. Series Compensation: A fifth option to increase the power carrying capability of the system is to install series capacitors in adequately rated long distance transmission lines. Due to the length of the lines, the impedance (or resistance to electrical flows) may be restricting flows across the system. The addition of series compensation reduces the electrical impedance of the line and therefore increases the power flows across the line. This can be an effective and economical means of increasing the transmission capability as a whole, by taking advantage of transmission lines that can carry more power.

In addition to transmission line upgrades and replacements, additional methods exist and are currently utilized to increase transmission capability. These include the addition of shunt reactive devices to increase the system voltages to support additional power transfers, and phase shifting devices to better control the power flows on the system to optimize the existing transmission capability by better distributing the flows across the transmission lines.

Improved system voltages will allow additional power transfers, and reduce the transmission system losses. Voltage support is provided by generation, shunt reactive devices such as capacitors, and recently developed technologies including Static Var Compensators (SVCs). If the power transfer capability is limited by the lack of dynamic voltage support at various locations, well placed SVCs can provide voltage support necessary to increase operating transfer limits. This in turn allows the transmission system to be better utilized yet remain reliable. A SVC works by adjusting the overall reactive power flow through the system as the transfer levels change and can also help the transient response of the system during contingency situations.

Additional benefits to the system could be realized by upgrading some of the existing control functions at these SVC installations. For example, a programmable controller that modulates the SVC output in response to system conditions could be used to increase the transfer capability of the system. Western (UGPR) has installed SVCs at its Fargo and Watertown Substations to improve voltage stability and enhance transfer capability of the Federal transmission grid in the Dakotas.

Phase shifting transformers can also be used to increase the power flow transfer capacity and to help improve the stability of the system. This is achieved with a phase shifter by forcing flows down certain transmission lines, or constraining the power flows to prevent unacceptable impacts to neighboring parties' systems that would limit transfer capability on Western's system. Western (UGPR) has installed a phase shifting transformer in its Crossover Substation in Montana to improve power deliveries into the adjacent power system.

4. IMPROVED UTILIZATION OF EXISTING TRANSMISSION

Economic concerns and limitations on obtaining new right-of-ways for transmission lines have greatly increased the need for additional power transfer on the existing equipment. As a result, a number of new technologies for increasing the short-term capacity of lines and transformers are being developed. Because the facility rating may be higher for only a short period, the new technologies below will allow for increased transmission capability, however, it will be Non-Firm or interruptible capability. Non-Firm ATC may not be beneficial for incorporating new generation into Western's system, as typically the generator owner requests Firm or non-interruptible ATC.

Typically, the amount of clearance between energized conductors and other objects limits the capacity increase of most existing overhead transmission lines. As the load on a line increases, the temperature of the conductor increases causing the conductor to elongate. The increased elongation results in additional “sag” in the conductor, thereby reducing the clearance to other conductors and objects. The amount of sag for a given current loading is directly affected by the weather conditions including ambient temperature and wind speed.

Recent technology has focused on dynamically rating lines, or allowing the conductor current (Ampere) rating to vary as a result of changing system conditions or changing weather conditions. Dynamic Thermal Circuit Rating (DTCR), the Video Sagometer, and a differential Global Positioning System (GPS) sag monitor are all technologies where sag is measured in real time. These dynamic ratings offer benefits to the system. “Higher loading of equipment is usually possible using actual measured weather parameters. Traditional static ratings are overly conservative, since they are based on worst-case weather assumptions.[i]” As a result of the uncertainty of the sag during varying system loading and weather conditions, it is necessary to rate the line using a conservative approach. However, even with a very accurate method of determining the maximum real-time line rating, only additional Non-Firm ATC may be offered.

Dynamic Thermal Circuit Rating (DTCR) is software recently developed that uses real time weather data to determine such variables as temperature and wind that affect the sag of a conductor. “DTCR calculates dynamic thermal ratings (real-time ampacities) of power equipment based on actual load and weather conditions. The software will determine dynamic circuit ratings by evaluating all equipment ratings on a circuit and finding the most limiting ampacity for each rating scenario.[ii]”

Another new technology that may increase the ability to utilize dynamic line ratings is the Video Sagometer. This technology uses a small camera to monitor the sag of the conductor. The device is currently in a testing stage. However, the Sagometer could allow for accurate dynamic ratings in the future. “The system uses an imaging system to monitor the location of the conductor, or a target attached to it. The change in vertical position of the conductor in the image is directly related to the change in ground clearance/sag.[iii]"

Similar to dynamic ratings on transmission lines, the Electric Power Research Institute (EPRI), Inc. has developed a dynamic rating program for transformers. This program allows transformers to be operated above their nameplate rating in certain circumstances. Since transformers are one of the most expensive and critical components of an electrical system this dynamic rating allows an increase in power flow at no additional expense but at a risk of loss of life. The program, Power Transformer Loading and Operating Tool (PTLOAD), provides estimates for hot spots and aging parameters to dynamically rate transformers.

"Under some conditions, transformers may be safely operated at levels higher than nameplate ratings. EPRI's PTLOAD software provides a valuable tool for utility substation engineers to calculate maximum safe electrical loading of power transformers under a variety of conditions.[iv]" Western (UGPR) has installed temperature-sensing equipment at a critical transformer in its Denison Substation (Iowa) to remotely monitor equipment status during heavy transfer conditions to prevent loss of life due to high temperature operation. However, as with dynamically rating transmission lines, the ability to overload transformers for a short period of time will not actually increase the Firm ATC of the system but is a very useful operation tool to maximize loading conditions and address system contingencies.

The short term overloading of transformers and power lines can be a cost effective and efficient way to increase power transfer limits during system intact conditions and during system contingencies. However, this should not be viewed as a long-term solution to Firm ATC deficiencies and must not be accomplished at the expense of equipment damage or loss of life.

Recently, development has begun on a variety of new technologies for maintaining and extending the life of power equipment, which may reduce the costs to operate and maintain the power system. These types of new technologies won't likely increase the transmission capability, but may make it less expensive to expand the system to create additional Firm ATC. Some of these developments include EMAT, intelligent substations, performance of aging characteristic studies, and risked based maintenance.

EMAT is a nondestructive test for ACSR conductors. The EMAT project, being developed by EPRI, tests the wear on ACSR conductors. EMAT has the potential of predicting when lines may fail. This will allow for a more reliable power system. This project is still in the developmental stage.

Another cost savings maintenance technology being developed by Power System Engineering Research Center (PSERC) is the Intelligent Substation. "It is the goal of this project to integrate technological advances from artificial intelligence, fault diagnostics, and data processing to enable substation equipment to self-monitor, self-diagnose and self-communicate results of their self-assessment to the substation maintenance authorities. This technology would reduce maintenance cost and also increase reliability by only performing maintenance when indicated rather than follow periodic maintenance.

Due to the increased demand on the power system, research and development has occurred regarding high temperature operations that equipment can withstand, as well as how to increase the life expectancy of equipment. PSERC has recently researched such topics as the Evaluation of Critical Components of Non-ceramic Insulators (NCI) In-Service: Role of Seals and Interfaces, Conditions Monitoring and Maintenance Strategies For In-service Non-ceramic Insulators, UG cables, and Transformers. These studies use a variety of techniques to find the weak spots in components, to not only build better components in the future, but also predict hardware failure and decrease outages.

It is important to note that all of these technologies may help to optimize the real-time operation of the power system, however, they may not defer major system expansion requirements. In the long run, these measures alone will not increase the Firm ATC. During the high temperatures of summer with high power transfer levels, the capacity of the system will continue to be limited by the thermal ratings of the conductors, transformers, and other substation equipment.

5. POTENTIAL NEW EQUIPMENT TO IMPROVE TRANSMISSION CAPABILITY

Although upgrades to existing equipment may require a smaller capital investment than installing new equipment, upgrades to existing equipment still has its limitations based on the age of the equipment and the technology being considered. Therefore, research emphasis has been put into developing improved new equipment to increase the transfer capability of the power system. This new equipment can be separated into three categories: transmission lines, substation equipment, and generation station equipment

Transmission:

Research for improvements to transmission lines has primarily focused on a new conductor called Aluminum Conductor Composite Reinforced (ACCR). This conductor can operate at three times the ampacity of Aluminum Conductor Steel Reinforced (ACSR) conductor and has a much higher heat rating, but doesn't weigh as much. Western is participating in a pilot project with 3M to field test this new conductor on its Jamestown – Fargo 230 kV line in North Dakota.

“ACCR conductor is probably going to be marketed as a replacement for ACSR conductors in areas were electrical loading has to be increased. ACCR can be installed without changing out structures because of the higher current carrying capacity.[v]” This new conductor would allow the use of existing towers and right-of-way decreasing installation costs. This conductor will likely not be commercially available until late 2003 depending on field test results. As part of the project, 3M is preparing a cost-benefit analysis for Western.

Western has participated in several projects using Flexible Alternating Current Transmission System (FACTS) devices to improve power system control and transfer capability. These devices improve system operation because they allow for more accurate control of the flow of power, and better control of voltage and system stability. A project by EPRI entitled Transmission Networks with Multiple FACTS Controllers: Control Conceptualization was aimed at creating the software that would control multiple FACTS controllers. “The relief of transmission congestion in bulk power transmission systems is a highly sought critical capability in electric power system operation. The utilization of properly designed flexible AC transmission system (FACTS) control logic for this purpose, combined with the design of controls for transient response improvement, and security enhancement as well as steady state system control is proposed.[vi]”

Several of the FACTS technologies are based on voltage source converters (VSC). These devices can be connected as series devices, shunt devices, or a combination of both. Typically, these VSC devices are being used for power quality reasons. FACTS devices are usually more expensive than traditional SVC devices.

EPRI has recently finished research on a Convertible Static Compensator (CSC). This is a specific type of FACTS controller. "The CSC provides flexible dynamic voltage control (to avoid voltage instability), as well as simultaneous real and reactive power flow control on multiple transmission corridors (without risk of transient or dynamic instability).[vii]" This technology would give the ability to transfer power flow from an overloaded line to another more lightly loaded line.

Of the newer technologies, the new ACCR conductor would be of value for reconductoring thermally limited line segments that limit transmission capability, if the new conductor were cost-effective. CSC and FACTS applications would have to be reviewed on a case-by-case basis. They could be applied wherever they are economically justified and would provide the necessary system performance improvements. Existing Static Var Compensators provide many of the same benefits as the CSC and FACTS applications, but at a much lower cost.

Substation Equipment:

There have been a variety of new technologies developed to improve substation design and modifications. Emphasis has been directed towards monitoring and controlling substations. Projects such as Power Systems Monitoring Using Wireless Subs look at the possibility of cost savings by transmitting internal substation data using spread spectrum radio waves. "This project will demonstrate feasibility and benefits of wireless technology when used for substation and system-wide applications." In addition, a new concept of mobile agents for distributed computer network applications will be demonstrated using the monitoring applications. Both approaches are to provide cost savings when implementing the communication systems for monitoring applications.[viii]" The project uses multiple data collection points, called mobile agents to transmit data to a typical personal computer whose data can then be transmitted to a central station. This wireless concept will ideally decrease the initial cost of substation wiring.

Another new technology being incorporated into substations is Enhanced State Estimation via Advanced Substation Monitoring. This project focuses on methods to accurately transmit communicated data to the control center's state estimator by pre-packing important data before transmitting. The system controller can then readily determine the current state of the power network.

Generation:

Recently, there has been increased interest in distributed generation and interconnection requirements of these resources to the power grid. This distributed generation has led to a project entitled New System Control Methodologies. The intent of this project is to create a standard control system that is consistent with present day operating requirements and reliability criteria. "Generators remain the fundamental control resource for achieving system-wide goals of frequency regulation, stable electro-magnetic dynamic responses and to a lesser degree, voltage control. One key question relates development of practically measurable indicators of generator contributions to these system wide control objectives, which can be in conflict with the primary profit making activity of producing energy.[ix]" As a result, Western may be very limited in its ability to mandate the use of this type of new technology by new generation proposed for interconnection to the Federal system.

6. POTENTIAL NEW PRACTICES TO IMPROVE TRANSMISSION CAPABILITY

Western has actively supported a new initiative by EPRI, which is documented in a book entitled Guidebook to Increase Power Flow in Transmission and Substation Circuits. This guidebook will include topics relevant to new technologies in increasing power flow in an existing system. The goal of the book as stated by EPRI is to "increase power flow resulting from the implementation of best practices on transmission and substation circuit components.[x]"

Fault locating is a critical aspect of power system reliability and delivery. When a fault occurs, the sooner it is located, the sooner the transmission line can be restored to service. PSERC is currently working on a project for TVA, with Western funding, and is planning to release the results to all members in report entitled Fault Location Using Sparse Data and Wireless Communications for Collection of PQ Data in the TVA System. The project goal is to "develop new algorithmic and concepts for on-line monitoring of the power system conditions where better accuracy and faster response are possible.[xi]" Another goal of the project is to "make the use of the data recorded by both Diver's and PQ meters readily accessible to the users in a more efficient way.[xii]" With the current changes taking place in the power industry, there is a need for a more stable power system with the increasing complexity of planning in a dynamically changing environment. PSERC has begun a project called Robust Control of large-scale Power Systems. "This project seeks to apply modern robust control methods to analyze and design controllers for large-scale power systems, developing algorithms that remain tractable in these high dimensional applications.[xiii]"

The power system is experiencing growth in all aspects including distributed ownership. Due to this development, state estimators will have to interact with multiple utilities. This creates a degree of uncertainty. Also, utilities will have potentially interacting control devices such as FACTS that will have to be modeled. These issues have led PSERC to develop a project entitled Power System, State Estimation and Optimal Measurement Placement for Distributed Multi-Utility Operation. This project will look at economically upgrading the measurement systems of the power system. It will also look at incorporating power flow control devices and incorporation of their characteristics into existing state estimators. Finally, this project will look at "robust estimation methods which can be implemented in a distributed manner in order to minimize data exchange between utilities, yet maintaining coordination between open state estimates, using the newest mobile agents in communication technology.[xiv]" This project should reduce uncertainty in diffusing utility assumptions allowing a stronger interconnected system.

PSERC is also developing a project entitled Integrated Security Analysis. "This project is investigating the integration of existing tools for static, dynamic, voltage, and steady-state security framework. It will include the examination of efficient mechanisms for determining security results and conveying these results most effectively to assist system operators.[xv]" The ultimate goal is to allow system operators the ability to predict system capabilities faster and with a higher degree of accuracy.

Reliability of the power system is a major issue within utilities. PSERC has created a project with the goal of probabilistic risk assessment of both system reliability and component reliability. The project is called Compensative Power System Reliability Assessment. "This project will result in a comprehensive reliability assessment mythology that provides quantitative relations among design products and reliability levels.[xvi]" The project will provide two major benefits. The first is better cost benefit analysis and the second is better risk assessment.

PSERC is also researching other computer-aided solutions to common problems to allow operators to more easily see aspects of the power system. A project targeted at faster more easily accessible data is Coordination of Line Transfer Capability Ratings. This project is focused on "developing tools for computing multi-dimensional transfer limits, which incorporate several transmission path flows into the formulation under suitable constraints.[xvii]" This project should lead to tools that will improve reliability, identify critical network components and quickly compute line capability.

Another project targeting a better understanding of power systems is PSERC's visualization of Power Systems and Components. The data that is available within a power system is immense. The goal of this project is to develop computer software that will create easily viewable 2 dimensional and 3 dimensional images of power system quantities for better operational control.

With the increased integration of diverse parties connected to the power system, concern for potential cascading disturbances on the power system has increased. PSERC recently researched where vulnerable relays exist, identifying the most cost effective solution to avoid cascading effects. "This research project focused on studying key elements relevant to transmission line protection, generator protection and system stability. The goal was to illustrate the basic methodology for planning system upgrades and to show the feasibility of studying rare events of power systems precisely using a modern powerful parallel computing facility.[xviii]"

A number of power system limitations are based on stability constraints where the acceptable performance is determined in the transient timeframe. However, many of the critical models for this stability analysis approximate behavior based on assumed typical values. PSERC has set out to more accurately identify some of these assumptions. "The objective of this project is to explore and develop more efficient techniques to quantify how the results of transient stability time-step simulation studies vary as functions of importance.[xix]"

The above technologies and concepts may provide some operational improvements and in certain instances may be used to increase operating limits. However, they are not presently commercially viable and have not been demonstrated to increase the transmission capability. Western may consider some of these technologies in the future if they prove to be a viable method to improve system capability.

7. APPLICABILITY OF NEW TECHNOLOGIES

Western is committed to finding the most economical means to upgrade and operate the transmission system reliably. Western will continue to evaluate new technology and better practices in its design, construction, maintenance, and operating philosophies. New technologies may be considered for new transmission facilities if they are technically viable, are found to be cost effective, and can provide a benefit to the transfer capability of the system.

The technologies that have been presented in this report represent possible solutions to a variety of issues facing the power industry. However, most of these technologies are not yet commercially viable and may be only temporary solutions to problems. Others require investments not directly related to current problems, but that may lead to future cost savings. Very few of the new technologies for which Western has provided research development monies can be used in projects identified in the "Montana-Dakotas Regional Transmission Study". The application of some of the technologies that might be considered is discussed below.

All aspects of dynamic line rating are a possibility for increasing the real-time loading of Western's transmission system to accommodate increased Non-Firm transmission utilization. As noted earlier, application of dynamic line ratings does not generally allow for increased Firm ATC, and system additions are generally required to provide increased Firm transmission capability.

ACCR (Aluminum Conductor Composite Reinforced) conductor is a very promising technology for the construction of new lines as well as the reconductoring of certain existing lines. ACCR conductor could provide a significant upgrade in thermal line ratings. Reconductoring with ACCR conductor alone cannot, by itself, solve many of the problems of increasing generation in the Dakotas as the loss of the reconductored line may still lead to problems. As ACCR conductor is added to new transmission lines and existing lines are reconductored, these improvements could lead to increased transfer capability in the Dakotas, where the system is limited by thermal rating constraints. Currently, ACCR conductor is not commercially available. Once the field-testing phase is complete and the new conductors are available, use of ACCR conductor will be evaluated on a case-by-case basis and will be utilized when it is economically feasible.

The Convertible Static Compensator, as well as other FACTS devices, could be very applicable to a variety of areas in current Western (UGPR) studies to control power flow in a variety of areas. However, FACTS and CSC's must be evaluated on an individual basis as current technologies like SVC's provide many of the same benefits at a much lower cost. These types of devices must be specifically designed for each application, and therefore may be applicable depending upon the system requirements to accommodate new generation or increased transfer capability. Therefore, specific cost comparisons is difficult to make. In past applications, FACTS installations can cost up to 60% more than traditional methods.

Utilization of existing technologies such as new lines, upgraded lines, phase shifting transformer, SVCs, and series capacitors will still be employed to enhance system capacity where they are found to be economical. The following proposed system enhancements are outlined in the "Montana-Dakotas Regional Transmission Study":

a) Uprate of existing Western 230 kV lines to 345 kV by modifying the existing structures. This type of modification is very cost effective when compared to building a new line.
b) Addition of SVC's to provide increased transfer capability, and to provide dynamic reactive support for simple induction wind turbines.
c) Addition of phase shifting transformers to confine the impacts of the power transfers associated with large new generation in the Dakotas.
d) Additions of series compensation (series capacitors) to a large number of Western's and other 3rd party existing transmission lines to increase the transfer capability of the power system.

Some of the following technologies may be beneficial in the future, but they do not enhance the amount of transfer capability in the system to aid the connection of lignite and wind energy to Western's Upper Great Plains Region transmission system.

- EMAT technology
- Risk based maintenance
- Intelligent Substations
- New Control Methodologies
- Technologies and concepts listed including Section 6 " Potential New Practices to Improve Transmission Capability"

As new technologies in bulk power delivery become available, Western will continue to look at each new project for cost-effective applications. When possible, new technologies will be used to create a more reliable system with increased transfer capability, and to provide for more cost-effective power delivery.

[i] *Dynamic Rating Concepts for Overhead Lines:* EPRI, Palo Alto, CA: 2000 1000444 Pg 5-2.

[ii] *Dynamic Rating Concepts for Overhead Lines:* EPRI, Pg 5-2.

[iii] *Dynamic Rating Concepts for Overhead Lines:* EPRI, Pg 2-2.

[iv] *EPRI New Research for 2002;* EPRI, Palo Alto, CA 2002 051929.

[v] Morris, Brian (2002). *Composite Conductor.* April 19, 2002.

[vi] *Transmission Networks with Multiple FACTS Controllers: Control Conceptualization: Control Strategy and Design for FACTS*, EPRI, Palo Alto, CA; 2001. 1001973.

[vii] *EPRI New Research for 2002,* EPRI Palo Alto, CA: 2001 1002106.

[viii] *"Power System Monitoring Using Wireless Substation and System Wide Communications,"* in Research Projects of the Power Systems Engineering Research Center, pg. 67.

[ix] "*New System Control Methodologies",* in Research Projects of the Power Systems Engineering Research Center, pg. 114.

[x] *EPRI New Research for 2002,* EPRI Palo Alto, CA: 2001 051833.

[xi] *"Fault Location Using Sparse Data and Wireless Communications for Collection of PQ Data in the TVA System,"* in Research Projects of the Power Systems Engineering Research Center, pg. 70.

[xii] *"Fault Location Using Sparse Data and Wireless Communications for Collection of PQ Data in the TVA System,"* in Research Projects of the Power Systems Engineering Research Center, pg. 70.

[xiii] *"Robust Control of Large Power Systems,"* Research Projects of the Power Systems Engineering Research Center, pg. 117.

[xiv] *"Power System, State Estimates and Optional Measurement Placement for Distributed Multi-Utility Operation,"* in Research Projects in the Power Systems Research Center, pg. 120

[xv] *"Integrated Security Analysis,"* in Research Projects in the Power Systems Research Center, pg. 126.

[xvi] *"Compensative Power System Reliability Assessment,"* in Research Projects in the Power Systems Research Center, pg. 129.

[xvii] *"Coordination of Line Transfer Capability Ratings,"* in Research Projects in the Power Systems Research Center, pg. 133.

[xviii] James Thorp and Hangye Wong, Computer Simulation of Cascading Disturbances in Electrical Power Systems (Cornell University, 2001), pg. 24.

[xix] *"Techniques for the Evaluation of Parametric Variation in Time Step Simulations,"* in Research Projects in the Power Systems Research Center, pg. 157.