OBSERVATIONS ON LOW SHORT CIRCUIT CAPACITY STATIONS - MILES CITY AND SIDNEY

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ABSTRACT

This paper presents some observations regarding two back-to-back direct-current (d.c.) stations being installed for the Western Area Power Administration at Miles City, Montana, and Sidney, Nebraska. The stations are required to operate under low short circuit capacity conditions. The paper could assist those investigating the addition of a back-to-back d.c. station.

INTRODUCTION

The Western Area Power Administration (Western) transmits and markets of Federal power to more than 500 wholesale customers in 15 Central and Western States over 16,000 miles of transmission lines. However, due to separation of the East and West interconntected systems, this large transmission network is divided into two asynchronous and electrically separated systems. To facilitate power transfers to Western's customers on both sides of the ties, Western is installing two 200-MW back-to-back d.c. stations: one at Miles City, Montana (inservice February 1985), the other at Sidney, Nebraska (inservice January 1987).

At Miles City, the d.c. station is connected to weak alternating-current (a.c.) systems on both sides. At Sidney, however, the East and the West side transmission networks are much stronger under system intact conditions, and possess satisfactory short circuit capacities. Loss of the key 230-kV line on the West, however, reduces the West terminal short-circuit capacity to a marginal level. A second 230-kV line is planned and will raise the West-side short-circuit capacity and provide needed capacity during an outage. During the vendor selection for both d.c. stations, the impacts of the a.c. system weakness was of major concern. Additionally, a good deal of effort was spent by Western developing an approach to power dimensioning at Miles City. It was correctly anticipated that from an economic standpoint the extremely low Miles City short circuit ratio(SC ratio) would not allow full 200-MW transfer from West to East.

Before discussing the particulars of the d.c. converter stations, a brief explanation of the East-West ties is probably in order.

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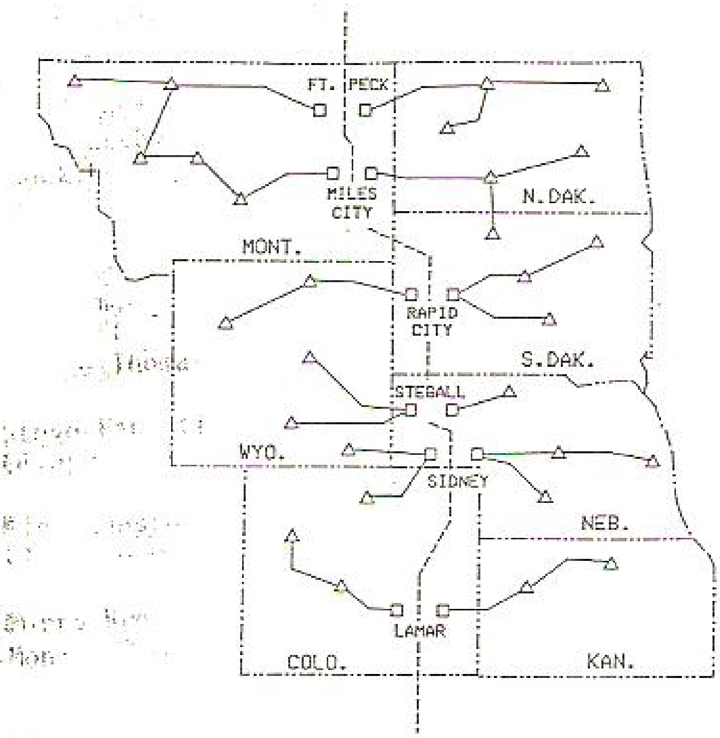

Figure 1 East-West Boundary

EAST-WEST TIES

The United States a.c. network is operated open between the Western States and the Midwestern and Eastern States. The separation points are illustrated in Figure 1 and are essentially along the "boundary" between the States of Montana, Wyoming, and Colorado and the Dakotas, Nebraska, and Kansas. However, the boundary is not quite this straightforward as portions of eastern Montana are on the East side and part of western Nebraska is normally connected to the West side.

Western delivers power from Federal hydrogeneration on both sides of the East-West ties. The East-West separation was a serious impediment to using the Federal resources in the most economical manner.

In 1967 a sustained effort was made to operate the system closed. Due to the a.c. system weakness, synchronous operation across the East-West boundary was abandoned in the early 1970's. A transfer trip scheme had been installed which detected impending power surges using the specially developed 97RC (rate-of-change) relay and automatically tripped the ties to minimize impact of the power surges. However, this scheme could not prevent numerous and severe voltage excursions at the neighboring loads adjacent to the boundary.

Installation of the 110-MW Stegall, Nebraska, .c. back-to-back tie in 1976 by the Tri-State Generation and Transmission Association demonstrated the feasibility of asynchronous interconnection to restore integrated operations. However, this installation did not allow Western to transfer firm power as Western has no firm contractual rights through the Stegall d.c. tie. The transfer of firm resources across the east/west boundry by Western was limited to switching units back and forth at its Fort Peck and Yellowtail Powerplants in Montana. Weakness of the a.c. system west of Fort Peck and east of Yellowtail greatly restricted Western's ability to swap units.

DC SITE SELECTION

Western began study of seven potential sites for a back-to-back d.c. station in 1979. Miles City was chosen as the prime location due to a number of factors including:

1. Relative close proximity to both East-side and West-side Federal hydrogeneration.
2. Western has 230-kV lines on both sides connecting to Miles City and paths from the Federal hydrogeneration to Miles City.
3. There were joint benefits from the station. Basin Electric Power Cooperative needs a path from its East-side generation to its West-side loads in central Montana.

These advantages outweighed the recognized low short circuit capacity at Miles City. In early 1982, the decision was made to proceed with the purchase of a 200-MW tie to be installed at Miles City, Montana.

Sidney, Nebraska, was also a promising candidate. Among the advantages of this site:

1. Western has isolated loads adjacent to Sidney on the East side that could be served through a d.c. link from its West-side resources.
2. Relatively strong a.c. networks on both sides of the tie.
3. Western owns transmission lines on both sides connected to Sidney.

The decision was made in late 1983 to also construct a 200-MW d.c. station at Sidney, Nebraska.

DEFINITION OF SHORT CIRCUIT RATIO

The a.c. system appears as a frequency dependent impedance when viewed from the terminal of a d.c. system. The ratio of the fault Mega Volt-Amps (MVA), at fundamental frequency, to the capacity of the d.c. station can be termed the Short Circuit Ratio (SC atio). Any contribution to the fault MVA from the .c. station due to the associated a.c. filters or shunt capacitors/reactors should also be considered when calculating the SC ratio. The shunt reactive equipment will have an impact on the fault MVA as the equivalent impedance will be either raised (filters, capacitors) or lowered (shunt reactors) by the presence of the shunt equipment. Synchronous machine subtransient reactances are used in the calculations of the a.c. system impedance.

LOW SHORT CIRCUIT RATIO CONCERNS

There is a certain level of short circuit capacity that is required for the proper operation of a d.c. station. A minimum SC ratio level of 2.5 has often been used as a lower limit for acceptable d.c. operation. Based on Miles City simulator study results, the validity of this ratio as a lower value can be questioned, and it should only be used as a general rule-of-thumb. Western's experience has been that only through detailed discussions with the prospective suppliers can the purchaser obtain the most acceptable minimum value(s) of SC ratio.

The concerns that are often cited for low SC ratio stations are as follows.

DYNAMIC OVERVOLTAGE

There are two principal sources of dynamic overvoltage (DOV). A d.c. station simultaneously consumes reactive power and generates harmonic currents at the rectifier and the inverter terminals. The a.c. filters which shunt off the harmonic currents generated by the d.c. station are capacitive at fundamental frequency. The filters may be used to supply all or part of the station reactive requirement. Power factor correction equipment in the form of shunt capacitors may also be installed and constitute another source of dynamic overvoltage in case of d.c. blocking, inadvertant station shut down, or delayed restart after an a.c. system disturbance. The lower the short circuit capacity or SC ratio, the higher the DOV which may be experienced under these conditions.

Possible adverse effects of very high DOV levels (above, say, the 1.30pu range) include:

A. Damage to local customer equipment.

B. Economic penalty due to higher required terminal insulation levels on the d.c. station and associated equipment.

C. Inability to restart the d.c. valve thyristors into very high DOV levels. Special schemes may be necessary to protect the thyristors in case of restart delay.

D. Insulation levels on existing a.c. station equipment may be inadequate.

VOLTAGE CHANGE ON SWITCHING

Low SC ratio is indicative of a.c. system weakness. To avoid customer complaints because of erratic and bothersome voltage fluctuations consideration should be given to the maximum allowable shunt reactive bank size for which more than occassionally switching will be allowed.

Western is not aware of any firmly established industrywide standards on acceptable momentary voltage changes. Limits in use appear to be based on individual utility practice and experience.

CURRENT CONTROLLER STABILITY

Another concern that has been cited but is perhaps not as widely known as the preceding is that of possible inverter current controller instability under low SC ratio conditions.[1] [2] The inverter current controller, when in constant extinction angle control, exhibits a negative resistance characteristic whose slope increases as the strength of the a.c. system decreases. Thus the negative resistance characteristic increases with lower SC ratio level. The SC ratio threshold level that will lead to inverter controller instability is independent of the thyristor firing scheme and has not been lowered, even with use of an equidistant firing control scheme. A 1979 paper on this subject stated a minimum SC ratio of 2 was acceptable in many cases for controller stability.[3]

The opinion has been expressed to the authors that concern for controller stability is not significant if the a.c. voltage distortion is limited to low levels by filtering. This could warrent further investigation.

RECOVERY RATE

The recovery rate of the d.c. station after a disturbance that resulted in either commutation failure(s) or a quite low level of d.c. current is dependent on the magnitude and phase angle of the short circuit impedance of the inverter side a.c. system. Should the attempted speed of recovery be too fast, new commutation failures will result. The specific recovery speed should be carefully studied. Use of a d.c. simulator to demonstrate recovery performance of the d.c. controls is strongly recommended, particularly where the SC ratio levels re low.

DC SYSTEM PERFORMANCE

The basic data for the Miles City and Sidney d.c. stations are presented in Tables I and II.

The measures taken to address the low SC ratio situation at each station are briefly presented next.

DIMENSIONING THE STATION (Power Transfer-System Intact)

Tables I and II include tabulations of short circuit ratios for the Miles City and Sidney converter stations under system intact and worst-case contingency conditions. The initial Miles City system intact short circuit ratio is 2.75 (550 MVA) on the East and 2.0 (400 MVA) on the West. The 2.0 SCR led Western to specify a reduced power transfer from West to East, the most demanding direction from an a.c. voltage support (MVAR) standpoint. The shunt reactive required at Miles City to support the a.c. voltage for a 200-MW West-to-East transfer level, resulted in DOV levels above 1.55pu under d.c. load rejection conditions. Also, stable recovery for post-fault conditions was considered to be a potential problem at the 200-MW transfer level. It was decided that the economic penalty of operating at the rated 200-MW level would be prohibitive, so a more realistic 150-MW transfer level was specified as an acceptable maximum value.

At Sidney, there is sufficient short circuit capacity to support a full 200-MW transfer in either direction.

POWER TRANSFER CONTINGENCY CONDITIONS

The tables show that the SC ratio levels will fall considerably if worst-case contingency conditions occur. A significant reduction in power transfer capability at Sidney will be required when the key line on the West, the Stegall-Sidney 230-kV line, is out of service. This is one reason Western is considering the construction of an additional 230-kV line into Sidney on the west.

Should the economics warrant, Western will also consider building additional West-side transmission, at Miles City.

CURRENT CONTROLLER STABILITY

The negative resistance inverter characteristic consideration has not been a problem at either Miles City or Sidney. Traces were presented for both stations by their respective suppliers demonstrating stable controller performance under the worst-case SC ratio conditions. The Miles City supplier has also presented a d.c. simulator demonstration of stable controller performance under a variety of conditions, including minimum SC ratio levels. The Sidney supplier will perform similar d.c. simulator studies shortly.

DYNAMIC OVERVOLTAGE

The key issue in the Miles City selection and a major issue in the Sidney station selection was the strategy proposed by each prospective supplier to control DOV to the specified levels.

Most DOV strategies presented to Western relied on fast restart of the d.c. station to consume reactive power and quickly reduce or prevent expected DOV levels. However, Western considered it prudent to also consider the situation where the d.c. fails to restart (or restart is significantly delayed).

The specifications require the following performance:

DOV LIMIT

Time	Miles City	Sidney
0-1.999 cycles	No limit	No limit
By 2 cycles	1.40pu West 1.30pu East	1.25pu Both sides
By 250 msec	1.20pu	1.15pu
By 600 msec	±5 percent of pre-disturbance voltage or 1.05pu, whichever is greater	Same as Miles City

The Miles City DOV control strategy is as follows:

1. Limit DOV to specified levels through use of specially designed zinc oxide devices. The devices must be carefully designed to handle the high dynamic overvoltage energy duty.

2. Restart d.c. station to reduce DOV to specified levels by two cycles.

3. Trip station if d.c. system fails to restart.

The Sidney DOV control strategy is as follows:

1. Use metal oxide (ZnO) devices to limit DOV to 1.25pu.

2. Restart d.c. station to reduce DOV to specified levels by two cycles.

3. Switch out d.c. station shunt capacitors and filters if d.c. station fails to restart.

Other possible methods of limiting the DOV include:

1. Build new transmission lines to strengthen a.c. network (increases SC ratio).

2. Install synchronous condensors at station (also increases SC ratio).

3. Fast capacitor/reactor switching through SVS type controls or other means.

A method recently presented is to use the d.c. station VAR absorption capability to limit post-fault DOV to acceptable levels. [4] During the fault the firing angle is automatically increased to provide for much greater VAR absorption by the d.c. station immediately at the time of fault clearing.

RECOVERY RATE

Recognizing the low SC ratio levels at Miles City and also under some conditions at Sidney, a relatively slow recovery rate of 500 msec after a.c. faults was specified for both stations. By 500 msec, the power should return to 90 percent of the predisturbance level or to a stable-but-reduced level if low SC ratio conditions so require.

At Miles City, the recovery time is about 200 msec, except for the most severe disturbances. The recovery time is increased to 400-450 msec for loss of key 230-kV lines on either side. In addition, loss of the East side Miles City-Dawson County 230-kV line requires the recovery power not exceed 170-MW for East-to-West transfers.

The Sidney station will have considerably faster response times than specified except that a reduced recovery power will be necessary after loss of the Sidney-Stegall 230-kV line.

VOLTAGE CHANGE ON SWITCHING

Due to possible impact on any nearby consumers, this is also a key issue, particularly at Miles City where the d.c. station is only some two miles from the town.

The specifications are as follows:

LIMITS ON VOLTAGE CHANGE

Time	Miles City	Sidney
-1.99 cycles	8 percent	8 percent
By 2 cycles	2 percent	8 percent
By 3 cycles	2 percent	3 percent

The voltage change criteria will limit the size of reactive bank that can be switched. This may be an economic burden for low SC ratio stations due to a need for more smaller reactors and capacitor banks plus increased duty on their switches.

At Miles City, the maximum allowable size determined from the studies is 15 MVAR. On-site tests on the East side have shown the instantaneous actual change in voltage to be 2.2 percent, which is within the specification. Sidney, with a considerably higher SC ratio level and less restrictive requirements, can switch 35 MVAR capacitor banks or reactors.

PROCUREMENT PROCEDURES

Western has two procurement procedures to purchase such costly equipment as d.c. stations.

FORMAL TWO-STEP

This procedure was used for the Miles City purchase. The steps can be briefly summarized:

1. Evaluate each technical proposal for compliance with the specifications. No bid price is received at this point.

2. Allow bidders, usually after one round of technical discussions, one chance to revise their submittals.

3. Exclude any proposal that generally fails to meet specifications. Key criterion is that the bidder would have to change so many areas or make such a significant change to meet the specification that the revised proposal would essentially constitute a new technical proposal.

4. Price bids are then received from the acceptable technical proposers, after revisions are accepted so that all technical specifications are met.

5. Bidder is selected based on low price.

This process normally requires less time than the other approaches; however its primary disadvantage is a very limited opportunity for discussions between proposers and Western. Since no technical weighting is given in the selection process, the technical approach does not receive any selection credit other than to be rated acceptable or unacceptable. This is not to say this selection method did not work well at Miles City. Western did recognize the shortcomings of the approach and used a negotiated procurement procedure for its Sidney d.c. station.

NEGOTIATED PROCUREMENT

The negotiated procurement approach allows the bidders to modify proposals as they become more aware of Western's prime concerns through intensive technical/price discussions. Briefly, the steps include:

1. Review technical proposal and establish initial technical ratings.

2. Meet with bidders for thorough discussions. Review technical areas. Review price proposal for reasonableness and balance.

3. Establish new technical ratings of the revised proposals.

4. Present technical rating and price proposal to selection official.

5. Selection Official makes choice on basis of combined technical rating and price proposal. Technical ratings may carry more weight than price.

The advantage of this approach is increased flexibility to Western. The prime disadvantage is the greatly increased staff workload and overall processing time. On the other hand, the complexities of purchasing a satisfactory d.c. station with one or more low SC ratio terminals would strongly favor a negotiated procurement approach. Due to increased flexibility, Western will likely use this procurement process in future d.c. project procurement.

References

[1] "Alternative Techniques and Optimization of Voltage and Reactive Power Control at HVDC Converter Stations", J.P. Bowles, IEEE Conference, Winnipeg, Canada, July 9-11, 1980.

[2] "H.V.D.C. infeed to weak a.c. systems with reactive compensation", J.D. Ainsworth, CIGRE SC 14, Scandinavia, 1979.

[3] "SOME CONSIDERATIONS ON THE SHORT CIRCUIT REQUIREMENTS FOR AN HVDC TERMINAL", L. Carlsson and H. Martensson, CIGRE SC 14, August 1979 Meeting.

[4] "AC SYSTEM REPRESENTATION RELEVANT TO AC FILTERING AND OVERVOLTAGES FOR HVDC APPLICATIONS", J. Kaeuferle, K. Sadek, and H. Koelsch, CIGRE SC 14-08, August 1984 meeting.

[5] "Miles City DC Tie-Purpose and Need", T. Weaver, L. Greiner, and R. Johnson, IEEE Conference on Transmission and Distribution, May 1984.

TABLE I

Miles City Station Data Sheet

System Data		
Commissioning Date:		February 1985
DC Power Rating (Initial AC System)		200 MW east to west, 150 MW west to east
Ultimate AC System		200 MW east to west, 200 MW west to east
DC Voltage Rating (kV)		82
DC Current (kA):		
Maximum		3.095
Nominal		2.476
Minimum		0.248
Voltage Dependent Current Limit		Yes
6-Pulse Bridge Rating (kV)		41
Terminal Data		
Minimum Firing Voltage		0.15 PU
Minimum Extinction Angle (Degrees)		14.5
Minimum Firing Angle (Degrees)		8 short-time, 12 nominal
Inverter Control Mode		CEA
Margin Current (A)		248
Fault Recovery (Worst Case)		
Restart Delay After AC Fault Clearing (Cycles)		2
Recovery Current		0.30
Recovery Rate After 3-Phase AC System Fault		2 PU/SEC
AC System	**East Side**	**West Side**
Minimum Short Circuit Ratio (PU) Initial System No Contingencies	2.75	2.0
Initial System Worst Contingency	2.1	1.5
Final System No Contingencies	-	4.8
Final System Worst Contingency	-	2.0
Commutation Transformers		
Number Per Pole		1 (dual secondary)
Rating (MVA each)		233
Rated kVac		230
Reactive Compensation (MVAR)		
Filters		75/75
Capacitors		113/143
Reactors		60/60

TABLE II

Sidney Station Data Sheet

C System Data

Commissioning Date:	January 1987
DC Power Rating:	±200 MW
DC Voltage Rating (kV):	63
DC Current (kA): Maximum	6.0
Nominal	4.140
Minimum	.414
Voltage Dependent Current Limit:	Yes
6-Pulse Bridge Rating (kV):	31.5

Terminal Data

Minimum Firing Voltage:	
Minimum Extinction Angle (Degrees):	18 degrees
Minimum Firing Angle (Degrees):	5 short-time 13 nominal
Inverter Control Mode:	CEA
Margin Current (A):	

Fault Recovery (Worst Case)

Restart Delay after AC Fault Clearing (Cycles):	7 msec
Recovery Current:	1.242 kA
Recovery Rate after 3-phase AC System Fault:	Under study

AC System SCR	East-Side	West-Side
Minimum Short Circuit Ratio:		
Initial System No Contingencies	8.6	5.2
Initial System Worst Contingency	2.95	2.2
Final System No Contingencies	-	8.6
Final System Worst Contingency	-	5.6

Commutation Transformers

Number per pole:	3 single-phase (dual secondary)
Rated (kV) (ac):	230

Reactive Compensation (MVAR)	East/West
Filters	105/105
Capacitors	35/105
Reactors	75/35