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ADVANCED CONCEPTS AND COMMISSIONING EXPERIENCES WITH THE SIDNEY CONVERTER STATION

by

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Summary

The 200 MW back-to-back Sidney Converter Station provides an energy interchange between the eastern and western United States-Canadian power grids. Although both systems are large, the relative weakness of both networks at Sidney, Nebraska required special equipment and advanced control features such as reactive power and voltage control, overvoltage control, a unique start-up sequence and power modulation with voltage control. The commissioning test results are presented, and major events that occurred during commissioning are discussed.

Keywords:

HVDC, System interconnection, weak a.c. networks, project data, control features, commissioning

Introduction

The 200-MW high-voltage direct current (HVDC) back-to-back Sidney Converter Station (SCS) is installed at Sidney, Nebraska, to provide an energy interchange between the eastern and western United States-Canadian power grids. Although the a.c. systems are large, electrically and geographically, the relative weakness of both a.c. networks at Sidney required the use of special equipment and control features to allow a successful interconnection.

Attempts to synchronously interconnect the eastern and western United States-Canadian a.c. networks were abandoned in the early 1970s. Large inadvertent power flows across the weak a.c. ties caused severe voltage excursions on either side. The completely disconnected mode of operation was continued until the installation of the 100 MW Hamil d.c. tie near Scottsbluff, Nebraska, in 1976 and the 200 MW Miles City d.c. tie in Miles City, Montana, in 1985. The 200-MW back-to-back converter station at Sidney permits a third asynchronous connection between the two a.c. systems.

Planning aspects and main data

Electrically, the strength of the a.c. systems at Sidney is expressed by the short-circuit ratio (SCR), which is defined as the a.c. system short-circuit power (without the converter station connected) divided by the transferred active power through the HVDC converter station. The SCS is designed to operate at full power with SCRs as low as 2.25. Fig. 1 shows the configuration of a.c. networks near the Sidney Converter Station. The low SCR, combined with the specified need to limit a.c. system temporary overvoltage (TOV) to 1.25 p.u. and a.c. system voltage regulation

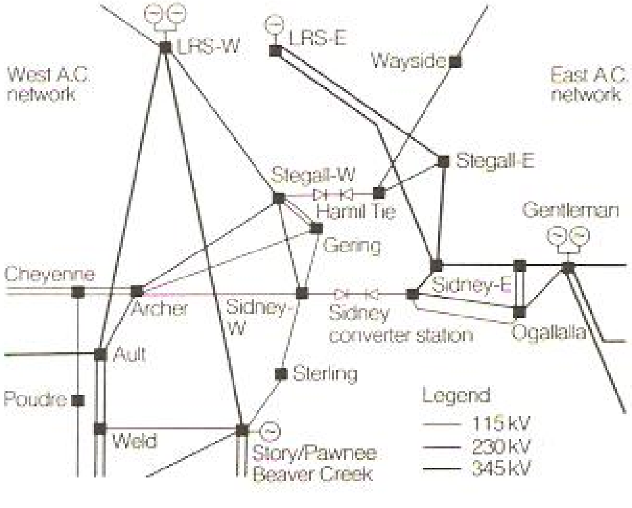

Fig. 1: Sidney Area A.C. System Configuration
LRS-E: Laramie River Station - East
LRS-W: Laramie River Station - West

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requirements, have resulted in reactive power compensation techniques utilizing extended firing angle control and switching of shunt reactive equipment. Control of a.c. system TOV is achieved by the application of special metal-oxide surge arresters and by the recovery characteristics of the converter station.

The SCS is a back-to-back 12-pulse monopole HVDC system designed to operate at 50 kV and 4140 A. The converter station is connected to the east and west a.c. system, at 230 kV, from an adjoining a.c. substation. The simplified single line diagram of the converter station is shown in Fig.2. The main a.c. and d.c. electrical characteristics are summarized in Table I /1/.

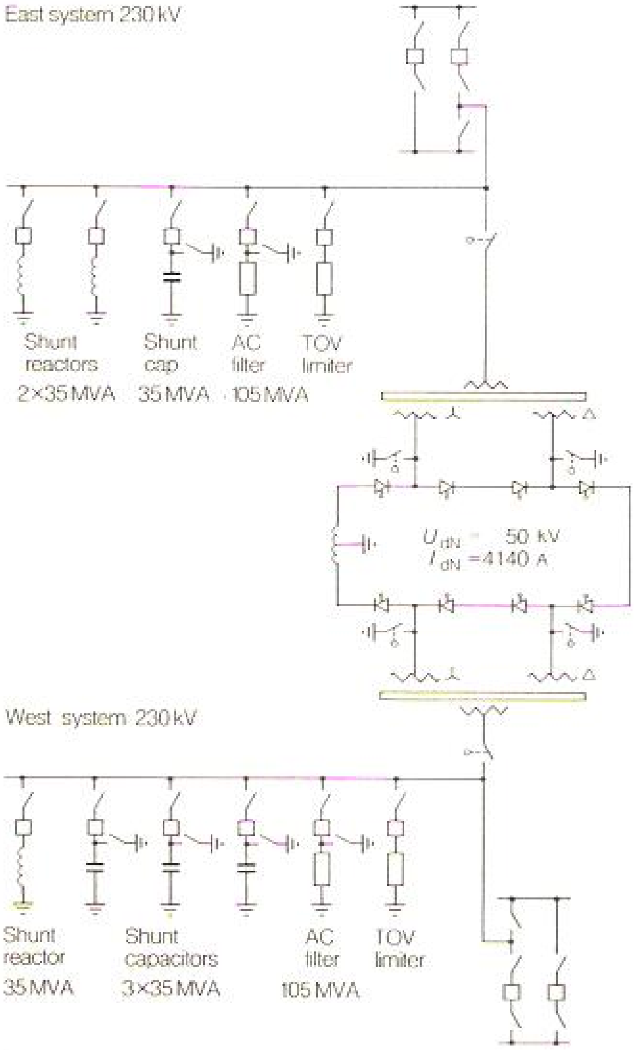

Fig. 2: Sidney Converter Station Simplified one-line diagram

Special features of the SCS

Reactive power and voltage control

To control the east and west converter station a.c. bus voltages, the concept of operation with extended firing angle control has been applied /2/. Fig. 3 shows the P_d/Q_d diagram of the converter with the steady-state operation range used to fullfil the specified requirements.

A.C. System Parameters

	East	West
Bus voltage (A.C., line-to-line)		
Nominal (kV)	230	230
Controlled range (p.u.)	0.95-1.05	
Short circuit capacity		
Minimum (MVA)	700	450
Maximum (MVA)	2200	1075
Frequency (asynchronous-Hertz)	60	60
Reactive requirements (maximum)		
Capacitance (MVAR)	69	136
Inductive (MVAR)	225	158

D.C. Parameters

	East	West
Rated power (MW)	200	
Voltage (kVDC)	50	
Current (amperes)		
Minimum	414	
Maximum	4140	
Valve Arrangement	12 pulse	
Smoothing reactor (millihenries)	30	
AC Filters (MVAR)	105	105
Shunt capacitors (MVAR)	35	3 x 35
Shunt Reactors (MVAR)	2 x 35	35

Table I: Electrical Characteristics of Sidney Converter Station

The a.c. voltage in one network can be regulated by changing the reactive power of the converter by setting of the control angle and through this, the d.c. voltage and d.c. current of the back-to-back scheme. This means, however, that the reactive power changes correspondingly in the other a.c. network, too.

Full voltage control would take place only when both sytems have the same reactive power requirements. If this is not the case, i.e. one system has a positive and the other has a negative voltage deviation, the situation cannot be improved by changing the control angle only. The reactive power can be changed asymmetrically, however, by the transformer tap changer.

The reactive power, and hence the bus voltages of the two a.c. systems can be regulated independently by a combination of rapid control of the thyristor valves firing angle, with slow asymmetrical control by means of the transformer tap changer.

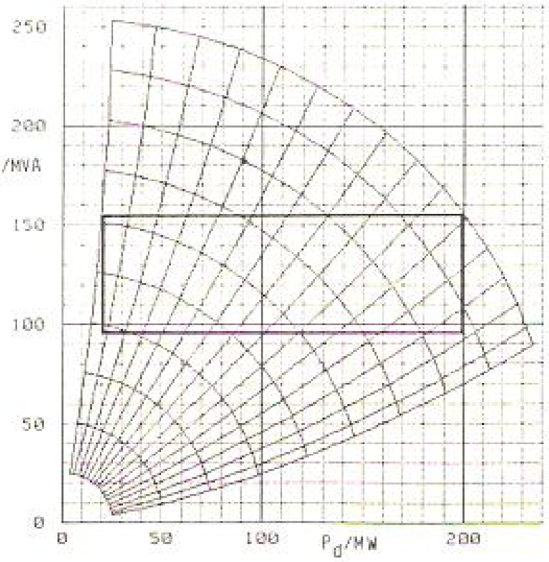

Fig. 3: P_d/Q_d diagram of the converters Operating area in P-U mode

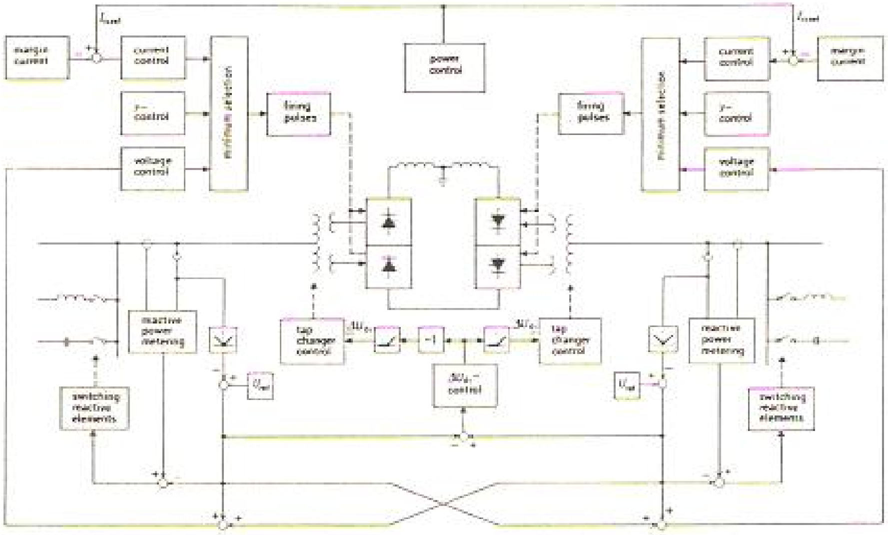

Fig. 4: Block diagram of the converter control

Naturally, the design limits of the converter must be taken into account. If the reactive power requirement lies outside the steady-state limits, the reactive power elements (reactors or capacitors) are switched in or out. The rating of switched reactive power elements is less than the range of the converter's reactive power that is controlled by firing angle to reduce the number of switching operations and to prevent hunting. The principle of the control used is shown in Fig. 4 /3/.

The action of voltage control is shown in Fig. 5. The oscillogram was taken during commissioning to demonstrate power steps from 150 MW to 190 MW and back to 150 MW. It can be seen that the voltage control scheme regulates the a.c. voltages within ± 1 %.

Start-up sequence

During the start-up sequence of the SCS large a.c. filters (105 MVAr) are connected to the a.c. networks. This could lead to a voltage increase of about 10 % at switching. To avoid such a large voltage change, a unique concept for the start-up sequence has been used. Fig. 6 shows the oscillogram of the start-up sequence taken during commissioning. After switching in the converter transformers on both sides, bypass operation on the west side is initiated (t_1). The east converter is feeding approximately 0.15 p.u. d.c. current through the bypass path with a control angle at approximately 90°. At time t_2, a.c. filters are switched in on the east side and simultaneously the d.c. current is increased to 0.5 p.u. to compensate for the reactive power of the filter /2/. It can be seen on the trace of the voltage U_E that the a.c. voltage hardly changes. At time t_3, the west a.c. filters are switched in, the bypass is released on the west side and power transmission started. Voltage changes

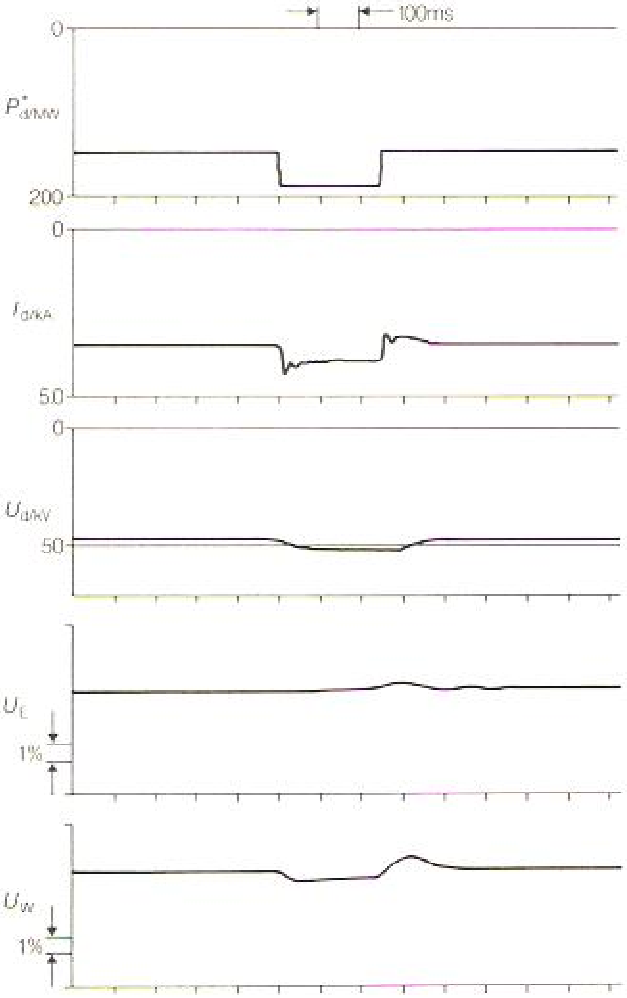

Fig. 5: Power step from 150 MW to 190 MW and back to 150 MW
power direction west to east

P^*_d power set value
I_d d.c. current
U_d d.c. voltage
U_E a.c. voltage on the east side bus
U_W a.c. voltage on the west side bus

of less than 4 % occur transiently during the start-up sequence, after which the voltage control scheme regulates the a.c. bus voltage to the initial value (t_4).

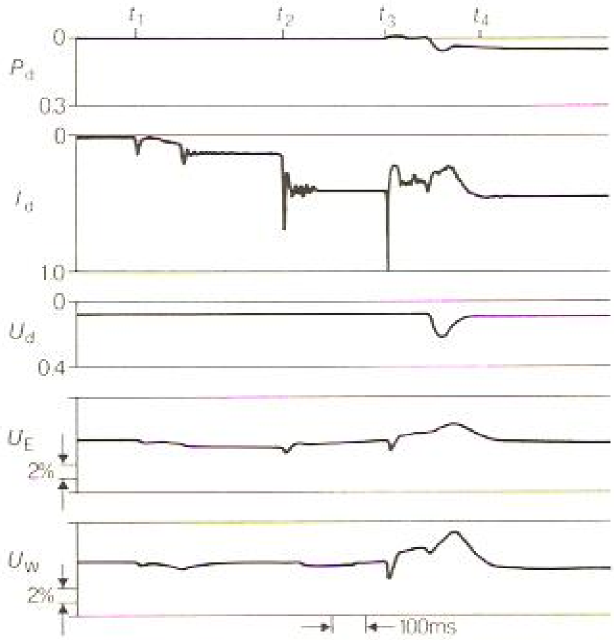

Fig. 6: Start-up Sequence

P_d	transmitted power
I_d	d.c. current
U_d	d.c. voltage
U_E	a.c. voltage on the east side bus
U_W	a.c. voltage on the west side bus

Control of temporary overvoltage

Faults in the a.c. systems close to the SCS bus and subsequent disconnection of the faulty line can lead to extremely weak network conditions. At blocking of the d.c. link under these conditions, TOV's of over 2 p.u. may be expected which would last until the d.c. link restarts or, if it remains blocked, until the a.c. filters and shunt capacitor banks are disconnected.

So as not to endanger customers connected to the a.c. system, it was required to limit TOV to 1.25 p.u. within two cycles. To achieve this requirement, a temporary overvoltage limiter consisting of parallel connected metal oxide (MO) arresters is used. As the equipment has to limit overvoltage to a very low value, the MO arresters would be overloaded from energy standpoint if they were connected continuously to the system voltage. The TOV limiter is therefore only switched in on demand by a circuit breaker /4/.

The switching of the TOV limiter is initiated when critical faults are detected. Taking into account the opening time required for the breaker to clear the fault, and the closing time of the TOV limiter breaker, the overvoltage reduction takes effect not later than 2 cycles after occurrence of the temporary overvoltage.

If the d.c. power transmission recovers, the temporary overvoltage is quickly reduced and the TOV limiter can be disconnected. The maximum stress for the MO arresters of the TOV limiter occurs, however, if the d.c. does not recover. In this case the TOV limiter has to limit the overvoltage until the reactive power equipment can be switched off. The calculated maximum energy of the limiter is 28 MJ/phase. Fig. 7 shows a TNA simulation of the maximum energy design case for the TOV limiter.

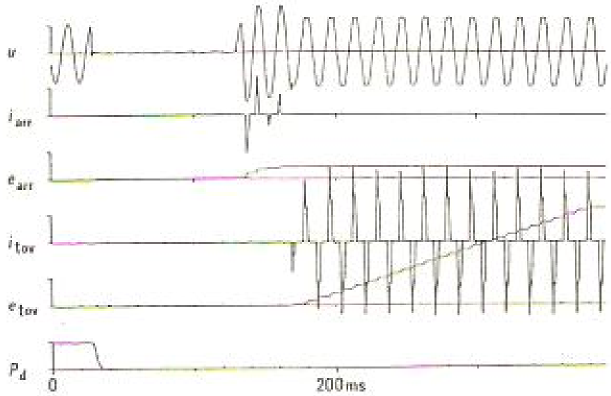

Fig. 7: Operation of overvoltage limiter following fault in the a.c. system and disconnection of the a.c. line. HVDC remains blocked.

U	busbar voltage
i_{arr}	current through transformer arrester
e_{arr}	energy stress of transformer arrester
i_{tov}	current through overvoltage limiter
e_{tov}	energy stress of overvoltage limiter
P_d	HVDC transmission power

An additional measure to limit TOV that is implemented in the SCS control scheme is the use of bypass operation in the event of a fault close to the converter bus. If the d.c. link would block during the fault, the undisturbed bus of the link would bear the full load rejection which could lead to high overvoltages. To avoid this stress, a bypass is initiated on the faulted side, the undisturbed side firing angle is automatically adjusted to approximately 90°, and the d.c. current is reduced to keep the reactive power of the undisturbed side nearly constant, thus preventing the overvoltage /5/.

Power modulation

The a.c. networks to which the SCS is connected are not only weak but, the eastern network exhibits instabilities under certain network fault conditions. Studies indicated that increased power infeed to the eastern network via SCS could produce transient instability for a number of faults in the network. Therefore, it was necessary for the SCS control to incorporate HVDC power modulation so as to dampen instability swings when power is transmitted from west to east. This is done by the Remedial Action Scheme (RAS) which was added to the HVDC control. The power modulation of SCS is initiated on detection of east side power generator shaft speed deviations at the Laramie River Station (LRS) in Wyoming. A signal is transmitted to the SCS via microwave, and, according to the determined transfer function, the active power of the d.c. link is modulated. In some cases which depend on the network configuration, the modulation is not used, but the d.c. power is reduced to the minimum value by ramping. Also, for loss of key lines on the west side, the SCS is ramped down for SCS power transfers in either direction. One of these cases is illustrated in Fig. 8. The oscillogram was taken during commissioning at 100 % power transfer from the eastern to the western a.c. network. Due to the disconnection of an a.c. line on the inverter side, the power ramp is applied in the d.c. scheme reducing transmitted power to 10 %. That means a 90 % load reduction is initiated. First, transients can be seen in the oscillograms when the a.c. line is disconnected and the network configuration is changed. Then the transmitted power is reduced according to a ramp. D.C. voltage and d.c. current are changed in such a way that the reactive power of the station is adjusted to keep the the a.c. bus voltage almost constant.

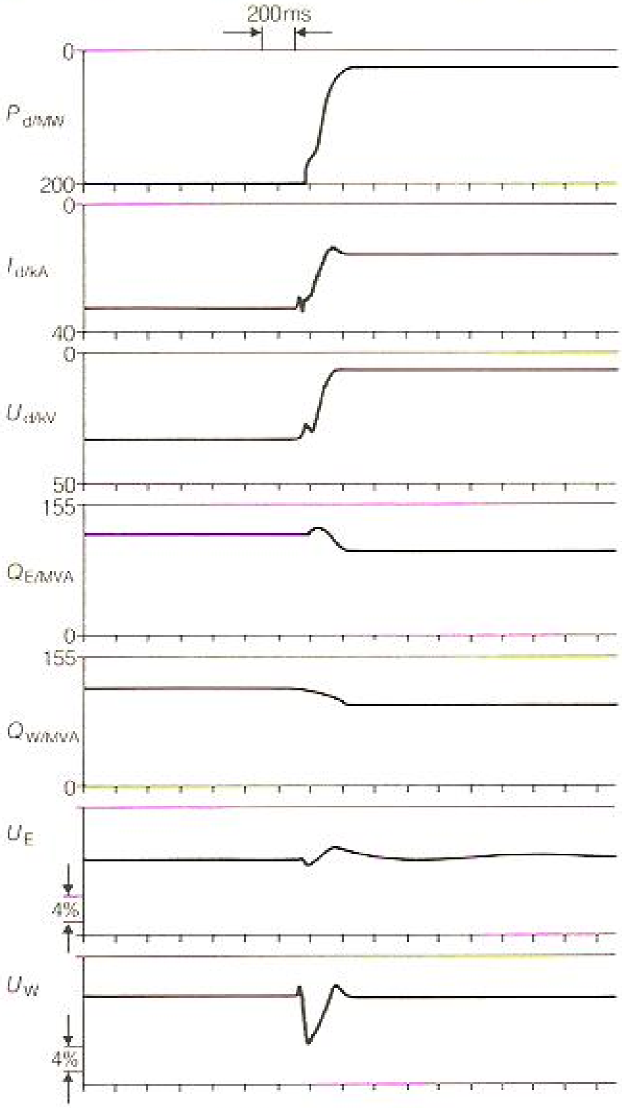

Fig. 8: Line switching in the western a.c. network with subsequent power ramping from 100 % to 10 % rated power

power transmission east to west

P_d	transmitted power
I_d	d.c. current
U_d	d.c. voltage
Q_E	converter reactive power - east side
Q_W	converter reactive power - west side
U_E	a.c. voltage - east side bus
U_W	a.c. voltage - west side bus

Ramping is also used as back-up for the case where the microwave signal between LRS and SCS is lost while the modulation process is being activated.

The functioning of the hardware for RAS scheme was first tested on a TNA simulator. Additionally, the transfer function and proper parameter setting of the RAS scheme were also analyzed in an extensive computer study which made use of Netomac program /6/. The d.c. link was simulated using the detailed representation of the SCS, RAS control, a.c. networks, and generators, including the generator excitation systems, governors and power stabilizers.

Fig. 9 gives an example of the results of this study. A three phase fault at Sidney on the 345 kV Sidney-Keystone line in the eastern network and subsequent disconnection of the line have been assumed. Rotor swings of the Laramie generator can be seen on the oscillogram. Power modulation of the SCS, initiated by the RAS scheme dampens the rotor swings successfully. Without RAS scheme in operation swings would amplify and lead to instability.

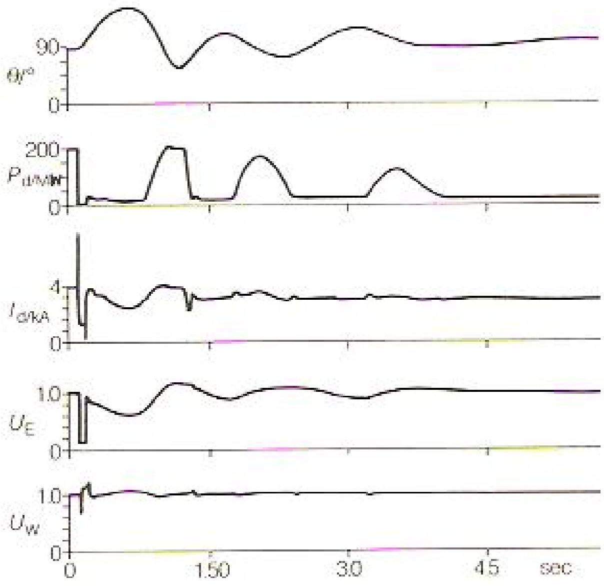

Fig. 9: Power modulation of SCS scheme following the 3 phase fault in the eastern a.c. network

θ	rotor angle of Laramie generator
P_d	power transmitted by SCS
I_d	d.c. current of SCS
U_E	a.c. voltage - east side bus
U_W	a.c. voltage - west side bus

Without the use of special control features, the large variation in active power during modulation would lead to excessive reactive power changes and voltage swings in the weak a.c. west network. Therefore, during active power modulation, the west side reactive power is controlled simultaneously to keep the a.c. voltage nearly constant in the unfaulty west system, as can be seen on the trace of the west a.c. voltage.

Major events during commissioning

On February 18, 1987, during commissioning of the start-up sequence, the converter on the east side was at first operated at α = 90° to feed 0.1 p.u. d.c. current through the bypass on the west side; then the current was increased to 0.3 p.u. and the east side a.c. filters were switched in at the same time (see Fig. 6). Incomplete 12 pulse operation occurred, transiently producing noncharacteristic 5th and 7th harmonics. Line protection relays located on the eastern a.c. network and sensitive to harmonics, operated and disconnected first the 345 kV line between the Sidney and the Laramie River Station and later, the line between Sidney and Stegall (Fig. 1). The converter station was isolated and shut down. Because of the changed network configuration and the voltage swings occurring the last connection to the Laramie River Station was also disconnected and the power station was forced to be shut down /7/. So as not to endanger the Laramie generator which has a low capacity to withstand harmonics and negative sequence currents, the commissioning of SCS was interrupted for approximately 4 months to allow extensive studies to be made on the network and to clarify whether the specified harmonic distortion at the SCS had any unfavorable effects on the Laramie generator. The studies showed that a relatively high 5th harmonic current is present in the a.c. network even without the SCS being in operation, and that low attenuation of 5th and 7th harmonics between the SCS bus and the 200 km remote Laramie bus is indicative of possible resonance near the 5th and 7th harmonics. However, the generator is not endangered if the distortion at the SCS bus remains within present limits as is the case during start-up and subsequent operation. The d.c. control was adjusted and additional monitoring of harmonics was installed at LRS and Sidney prior to commissioning. In the event that the 5th or 7th harmonic were to exceed specific limits, the SCS would shut down by internal monitoring or by a special negative-sequence relay being installed on the a.c. networks.

On November 9, 1987 trial operation started and was successfully completed on November 19, 1987.

During the 10 day trial operation, the SCS was operated continuously every day except for two one hour periods each day, when the station was blocked and deenergized as an operating exercise and for training purposes. The power schedule through the SCS provided for operation up to 200 MW in both an east to west and west to east direction. Generally, the operation was controlled via dispatchers in Loveland, Colorado, except for some on-site operational training.

Conclusions

The back-to-back Sidney Converter Station incorporates a number of solutions unique in the HVDC technology. The commissioning tests showed that performance fullfils the requirements. On November 19, 1987 trial operation was successfully concluded and acceptance of the facilities is scheduled for December 8, 1987.

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