ASPECTS OF CONVERSION OF THE NELSON RIVER BIPOLE 2 HVDC CONVERTERS FROM 12-PULSE TO 6-PULSE OPERATION

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ASPECTS OF CONVERSION OF THE NELSON RIVER BIPOLE 2 HYDC CONVERTERS FROM 12-PULSE TO 6-PULSE OPERATION

BY

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A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF ENGINEERING

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Abstract

In the early months of 1979, Manitoba Hydro was confronted with a serious problem involving the converter transformers for the bipole 2 operation of the Nelson River HVDC transmission system. The transformer problem left the negative pole of bipole 2, pole 3, without a converter transformer at each converter station.

Since the transformer outage was forseen to be a lengthy one, the system had a reduced transmission capability firstly due to the direct loss of the negative pole and secondly due to the necessity to operate the positive pole continuously in a monopolar mode which affects adversely the lifetime of the earth electrode. Studies were therefore undertaken by Manitoba Hydro to investigate the feasibility of making the equipment, designed for 12-pulse, perform in a 6-pulse mode. The results of the studies proved favourable and with the approval of the HVDC Working Group, who are the dc equipment suppliers, the negative pole of the bipole 2 was operated in a 6-pulse configuration successfully for a year.

The cost of the studies and modifications to the equipment were minimal and both Manitoba Hydro and the Working Group benefited greatly from this engineering exercise.

Symbols and Abbreviations

A	-	amperes
ac	-	alternating current
dc	-	direct current
FASOF	-	fast group blocking
Hz	-	hertz
HVDC	-	high voltage direct current
Idk	-	short circuit controller
Ids	-	direct current in smoothing reactor
kA	-	kiloampere
kV	-	kilovolt
ms	-	millisecond
MW	-	megawatts
NOSOF	-	normal group blocking
RSS	-	Root Sum Squared
TFM	-	thyristor fault monitoring
T31S	-	Wye converter transformer
Ud_E	-	earth electrode voltage (dc)
Ud_{gr}	-	group voltage (dc)
Ud_L	-	line voltage (dc)
VBE	-	valve base electronics
VG31	-	valve group pole 3 bipole 2
VG41	-	valve group pole 4 bipole 2

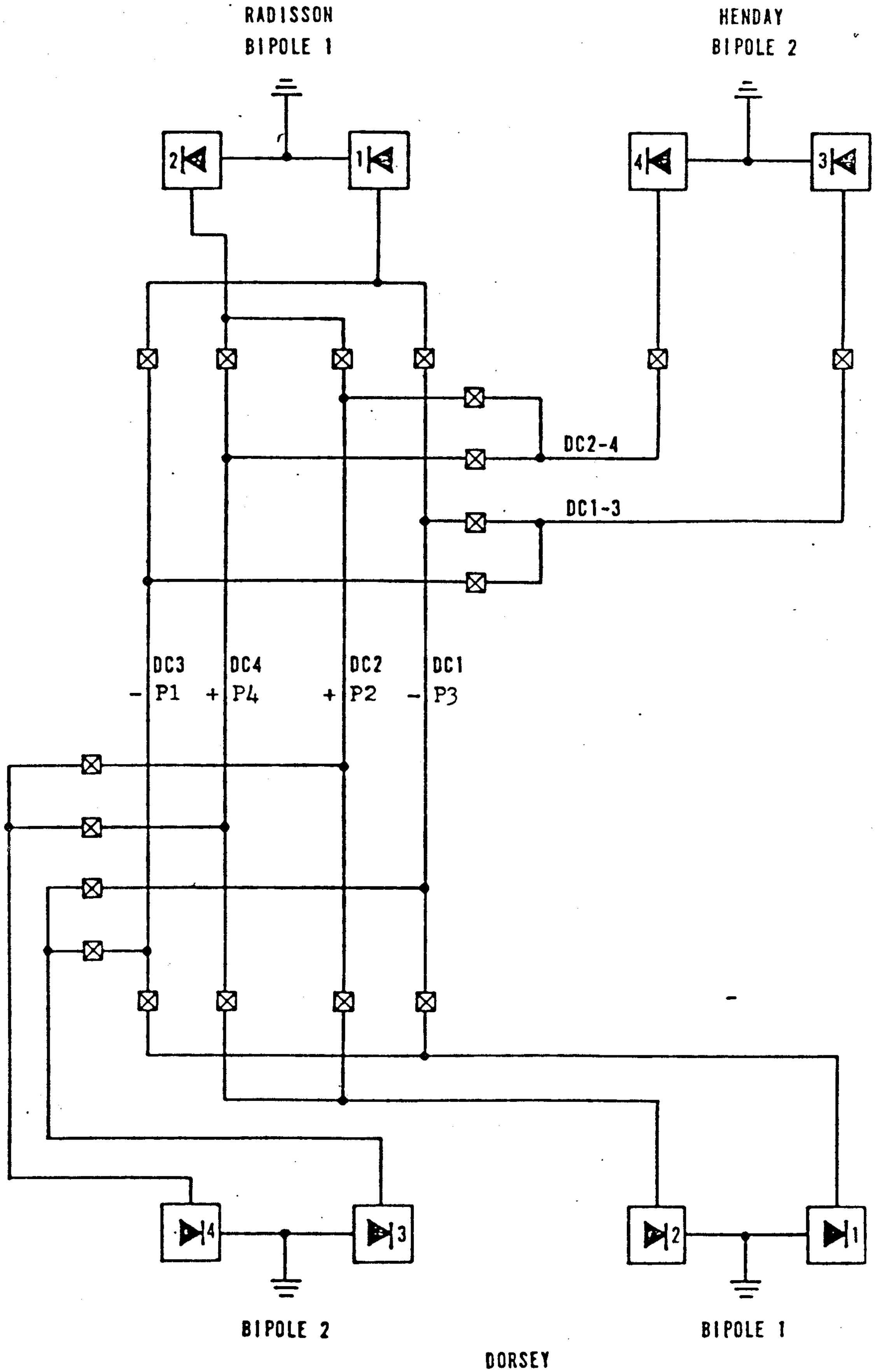
CHAPTER 1

Introduction

The Manitoba Hydro Nelson River High Voltage Direct Current Transmission System presently consists of two bipoles. Bipole 1 operates at ± 450 kV , 1800 A and bipole 2 stage 1 operates at ± 250 kV , 1800 A with a 2000 A cool weather rating. Each valve group in bipole 2 has two 6-pulse bridges connected in series and fed from wye-wye and wye-delta transformers. This combination eliminates, by phase cancellation, all 6-pulse characteristic harmonics on both the ac and dc electrical systems and results in only the characteristic harmonics of a 12-pulse converter. The single line diagram of the Manitoba Hydro HVDC System is shown in Figure 1.

Early in 1979 the converter transformers of bipole 2 experienced gassing problems. Converter transformers for bipole 2 are each a three phase unit as opposed to a bank of three single phase transformers, per valve group, on bipole 1. In April of the same year the wye transformer of the negative pole, pole 31 (VG31), at both Henday and Dorsey converter stations were sent back to the manufacturer. These transformers produced the highest gassing rate and were returned for further testing and internal examination by the manufacturer.

Due to the temporary loss of these transformers, 500 MW of dc transmission capability was lost to the system. This also entailed that the positive group, pole 4 (VG41), would have to run continuously and bipole 2 become a monopolar operation.



<u>HVDC SYSTEM - BIPOLES 1 AND 2</u>

FIGURE 1

It was discovered that the return of the wye transformers would be much later than previously anticipated. Operation of bipole 2 in a monopolar manner for an extended period of time would decrease the life expectancy of the earth electrode. This factor plus the recovery of 250 MW of dc transmission capability prompted investigations into the possibility of returning pole 3 into service in a 6-pulse operating mode.

Manitoba Hydro contacted the supplier of the converting equipment for their comments and approval for a 6-pulse operation of pole 3. The supplier is a consortium of Siemens, A.E.G. and B.B.C. who are known as the HVDC Working Group. It was the unique features of the control functions, protection detection and valve construction and structure that modifications to the original 12-pulse operation could easily be performed to arrive at a 6-pulse operation mode.

The major problem to the changes revolved around the 6-pulse generated harmonics which had not been provided for in the original filter design. The dc voltage harmonics would introduce telephone noise and interference in the southern end of Manitoba. The ac current harmonics in the northern system may cause ac system voltage distortions, Long Spruce generator heating and filter overloading at Radisson and Henday stations. Another concern was the possible resonance of the Henday electrode line at a 6th harmonic causing a possible overstressing of the neutral surge capacitors. This problem was later considered not serious and no changes were necessary.[1]

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[1] C.V. Thio, Report to H.V.D.C. Task Force Bipole 2 Six-Pulse Operation, (Report No. SPD 79-7, July 31, 1979) p. 1.

Therefore the two major considerations for 6-pulse operation revolved around the possible jeopardization of the Dorsey electrode site and the increased transmission capability of the dc system for reliability.

During the summer of 1979 the southern Manitoba area and Northern States experienced a dry weather condition. This condition resulted in high export sales to the United States and pole 4 of bipole 2 running continuously at a high load.

Running in this mode caused the Dorsey electrode to be the anode and to drive moisture away from the electrode by electro-osmosis at a theoretical rate of 0.5 to 15 M^3/hour/kA [2]. The dryness and monopolar operation could possibly result in the heating of the electrode and a thermal runaway condition. The thermal time constant of the Dorsey electrode for 1500 to 2000 amperes ranges from about 7 to 4 months. This can be derived from the graph in Appendix 1 produced by Teshmont Consultants Inc.

Measurements were taken at eight points at the electrode site for temperature and moisture content. A plan was also implemented to flood the electrode site during the fall before the winter freeze up. Appendix 2 is a table of the readings taken and a map of the measurement points at the Dorsey electrode site.

Six-pulse conversion was also favoured considering the transmission and generation capability of the Nelson River System.

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[2] C.V. Thio, Report to H.V.D.C. Task Force Bipole 2 Six-Pulse Operation, (Report No. SPD 79-7, July 31, 1979), p. 7.

The total generating capability of the northern system is approximately 1200 MW from the Kettle generating station and 1000 MW from Long Spruce. The maximum dc transmission capability of bipole 1 1800 A at ± 450 kV is 1620 MW and bipole 2 2000 A at + 250 kV is 500 MW without pole 3. This results in a total generating output of 2200 MW with 2100 MW of transmission capability. Operation of pole 3 (negative) in 6-pulse would contribute 250 MW (125 kV, 2000 A) maximum and increase the total transmission capability to 2370 MW .

However, at the receiving end line loss must be considered. Operating at full power from the north with one line on each pole and assuming equal current sharing between the poles the total losses are 167 MW . If the system ran monopolar, pole 3's line could be used with pole 1's in parallel to reduce line losses. This results in 68 MW of losses for bipole 1 and 56 MW for bipole 2 at maximum output.

Therefore for a monopolar operation of bipole 2, the resultant receiving end power would be 2120 - 124 = 1996 MW and for 6-pulse operation would be 2200 - 167 - 2033 MW . This does not result in that much of an increase in receiving end power to the dc system for operating in a 6-pulse mode. Even if there was a loss of a group in bipole 1 it does not justify 6-pulse operation for increased capacity. This is mainly due to the fact that the generating capacity of the north is nearly equal to the bipole 1 and 2 monopolar dc transmission. If the generation was near to 2400 MW mark, 6-pulse operation combined with a firm load condition in the south may have made 6-pulse operation more desirable from the transmission and reliability aspect.

There was consideration for operating pole 3's dc line as a return for monopolar current. This would definitely save the electrode site. But with utilizing the dc line as a return path would leave the stations at a floating potential. Even if one station was tied to earth, the other station's potential rise during a fault condition may cause overstressing of the insulation.

Therefore the decision to study the possible operation and eventual fulfillment of 6-pulse operation of bipole 2 pole 3 was solely made on the Dorsey electrode. Some consideration was given to the increased reliability and transmission capability if a valve group was lost in bipole 1.

The scope of work involved with 12 to 6-pulse conversion entailed inputs from the HVDC Working Group and from many groups within Manitoba Hydro. These were the System Planning, Transmission and Stations and Production Divisions.

The writer of this report has gathered and consolidated the information from these various groups regarding the 6-pulse conversion and operation. The writer was involved in the ac and dc filter protection aspects and in the modifications to some of the protection and control circuits outlined in Chapter 3. The monitoring of the performance of 6-pulse during operation was done by the writer as part of his duties as Plant Engineer at the Dorsey HVDC Converter Station.

CHAPTER 2

Studies for 12 to 6 Pulse Conversion

2.1 General

Manitoba Hydro undertook numerous studies to evaluate the possibility of 6-pulse operation of bipole 2 convertors. The HVDC Working Group was contacted for necessary equipment modifications with Hydro's proposed design changes. The HVDC Working Group responded to Hydro's challenge to convert the 12-pulse group into 6-pulse with their own studies and design alterations. It was then Manitoba Hydro undertook to integrate the 6-pulse mode into its electrical network.

2.2 Problems Arising from 12 to 6 Pulse Conversion

The major areas of concern for operating in a 6-pulse configuration were additional ac and dc harmonics generated and the problems they would give rise to if left unfiltered. It was therefore necessary that studies be performed to investigate the problems of running pole 3 in 6-pulse and determine how it would affect the Manitoba Hydro system as well as other harmonic sensitive equipment belonging to other companies.

Associated with dc side voltage harmonics are the problems of telephone noise generated near the Stonewall area. The bipole 1 and 2 main dc lines and electrode lines run parallel to many telephone circuits. The electrode line, which contributes the most to the noise problem, runs to an electrode site which is situated twelve miles north of the Dorsey station.

Earlier studies had been conducted by Manitoba Hydro and it was concluded that there existed a unique resonance path where bipole 1 6th harmonic currents would flow along the bipole 2 electrode line and due to the neutral surge capacitors and electrode line reactance would generate a 360 Hz noise[3]. It was anticipated that this situation would conversely result in 6th harmonics from bipole 2 flowing down bipole 1's electrode line. The electrode line of bipole 1 is farther removed from surrounding telephone circuits than for bipole 2 and therefore would not contribute as much interference.

Presently there exists stray noise of the 3rd and 9th harmonics in the system. This may cause ac distribution transformers in the area to saturate. It was hoped that these noise sources would be minimized by 6-pulse operation but which may cause an increase in the 6th noise. Only during actual 6-pulse operation can these noise levels be verified to determine the total noise factor.

The other major concern that Manitoba Hydro was faced with was the Henday ac filtering and sending end harmonics. With the 6-pulse operation 5th and 7th ac current harmonics are produced yet the only filtering for these harmonics were situated at Radisson for bipole 1 operation. The situation was further complicated by the fact that the system is close to a 5th harmonic parallel resonance with the Henday high pass filters[4]. This would result in high bus distortions which may range up to 20%. Overstressing of the Long Spruce generators may also occur due to this problem.

The existing 12-pulse converting equipment would also have to undergo changes in order to accommodate a 6-pulse operation. This

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[3] C.V. Thio, Report to H.V.D.C. Task Force Bipole 2 Six-Pulse Operation, (Report No. SPD 79-7, July 31, 1979), p. 5.

[4] C.V. Thio, Report to H.V.D.C. Task Force Bipole 2 Six-Pulse Operation, (Report No. SPD 79-7, July 31, 1979), p. 2.

involved the areas of valve control, dc control, thyristor fault monitoring, valve base electronics, transformer control and protection as well as indoor and outdoor bus work connections. The HVDC Working Group and relavent departments within Manitoba Hydro were notified of the proposed 6-pulse operation and were asked to produce the necessary modifications to the equipment.

2.3 Conclusions from Studies

In order to resolve the problem of dc generated harmonics on the system, field measurements would be taken during the trial operation of 6-pulse. If the noise levels were unacceptable, then there was still the possibility of converting one of the existing dc side filters at Henday and at Dorsey into a 6th arm filter. This could be achieved by reconnecting various dc filter capacitor stacks to obtain the required capacitance for filtering. The HVDC Working Group was not in favour of this approach since it would involve extensive design changes to the capacitor unbalance protection circuits of the existing dc filter protection.

Since this approach was not favourable, it was proposed to string a line conductor on the pole beneath the electrode lines and thus possibly through induction decrease the noise effect on the telephone circuits[5].

The other associated problem of unfiltered 5th and 7th harmonics in the northern collector system was difficult because of a

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[5] C.V. Thio, Report to H.V.D.C. Task Force Bipole 2 Six-Pulse Operation, (Report No. SPD 79-7, July 31, 1979), p. 6.

5th harmonic resonance. This problem would be suppressed if both Henday high pass filters were connected to the system during 6-pulse operation and there were certain numbers of Kettle and Long Spruce generators connected as well. The high pass filters would sufficiently detune the resonance and could absorb the harmonics to suppress the bus distortion and cause no overstressing of the Long Spruce machines.

If this did not prove to be satisfactory in eliminating the harmonic problems, the possibility of converting one of the Henday high pass filters into a damped 6th arm could be persued. For this modification, a new air cored reactor would have to be furnished to meet the required filter loading.

Here again measurements would have to be taken in the trial period of 6-pulse operation. From the results a decision could be reached to resolve the ac generated harmonic current.

The HVDC Working Group and Manitoba Hydro design departments produced several modifications to enable the existing equipment to operate in a 6-pulse mode. These changes were not too elaborate and are dealt with in greater detail in Chapter 3.

2.4 Recommendation from 6-Pulse Studies

After all the studies were undertaken by Manitoba Hydro and the HVDC Working Group, the results were encouraging enough to attempt 6-pulse operation. A cost study was prepared and the engineering and material was well within reason.

Therefore Manitoba Hydro gave approval for the implementation of VG31 in 6-pulse operation.

CHAPTER 3

Modifications to Equipment

3.1 General

Once the decision to modify bipole 2 pole 3 into a 6-pulse group was made, several changes where needed to the measuring, protection and control systems. Since the wye converter transformer was not present, alterations to the bus work and command to and replies from the transformer had to be compensated for.

3.2 Design Changes

The following is a list of the changes that were made to the existing equipment to operate in a 6-pulse mode. These changes were produced by Manitoba Hydro and the HVDC Working Group.

3.2.1 Voltage Measuring Circuit

In bipole 2 the dc voltage is measured in four locations per pole. The measured voltages are utilized for various protection control and indicating equipment throughout the system. Figure 2 illustrates the location of the measuring equipment.

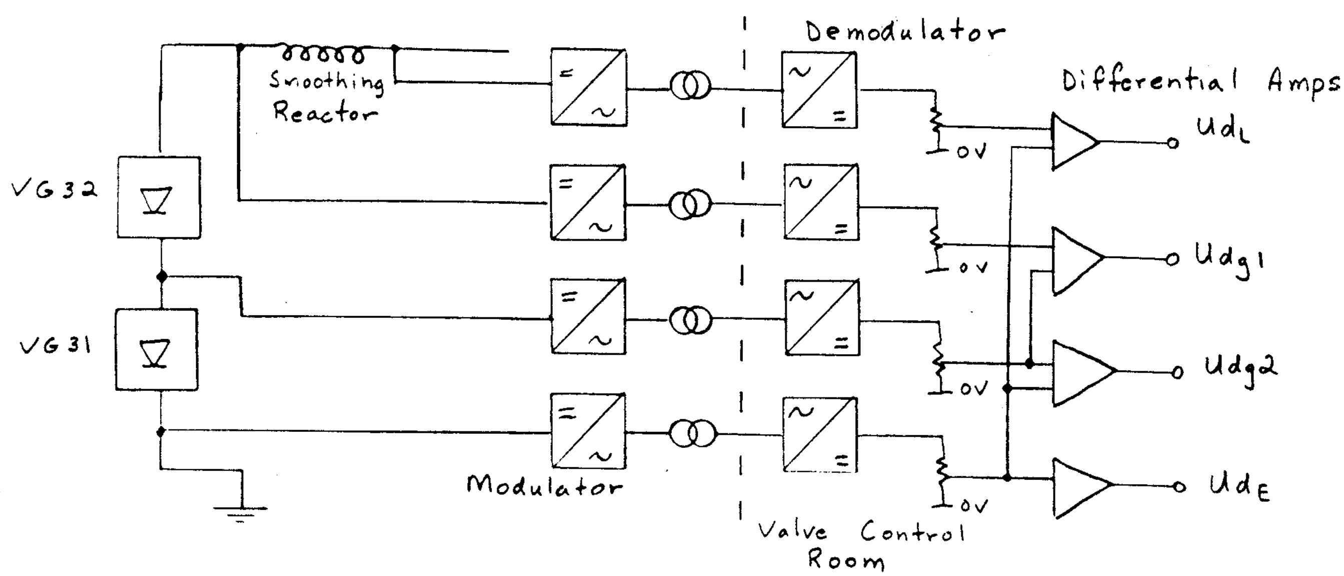

Figure 2

The earth sides of the voltage dividers are connected to one cable which is grounded in the station to one point only. The voltage dividers are made up of RC networks and are constructed in sections. The number of sections depends on the level of voltage to be measured. The measured signal is fed to the adjusting unit located in the base of the divider. The low voltage signal is sent to a modulator where it is frequency modulated. The modulated signal is transmitted via an STC cable to an isolating transformer located in the valve control room.

The valve control room supplies the adjusting unit single-phase 60 Hz 200 V ac supply. Signals received at the valve control room are demodulated and processed by the appropriate amplifiers for different functions. The measuring system is shown in Figure 3.

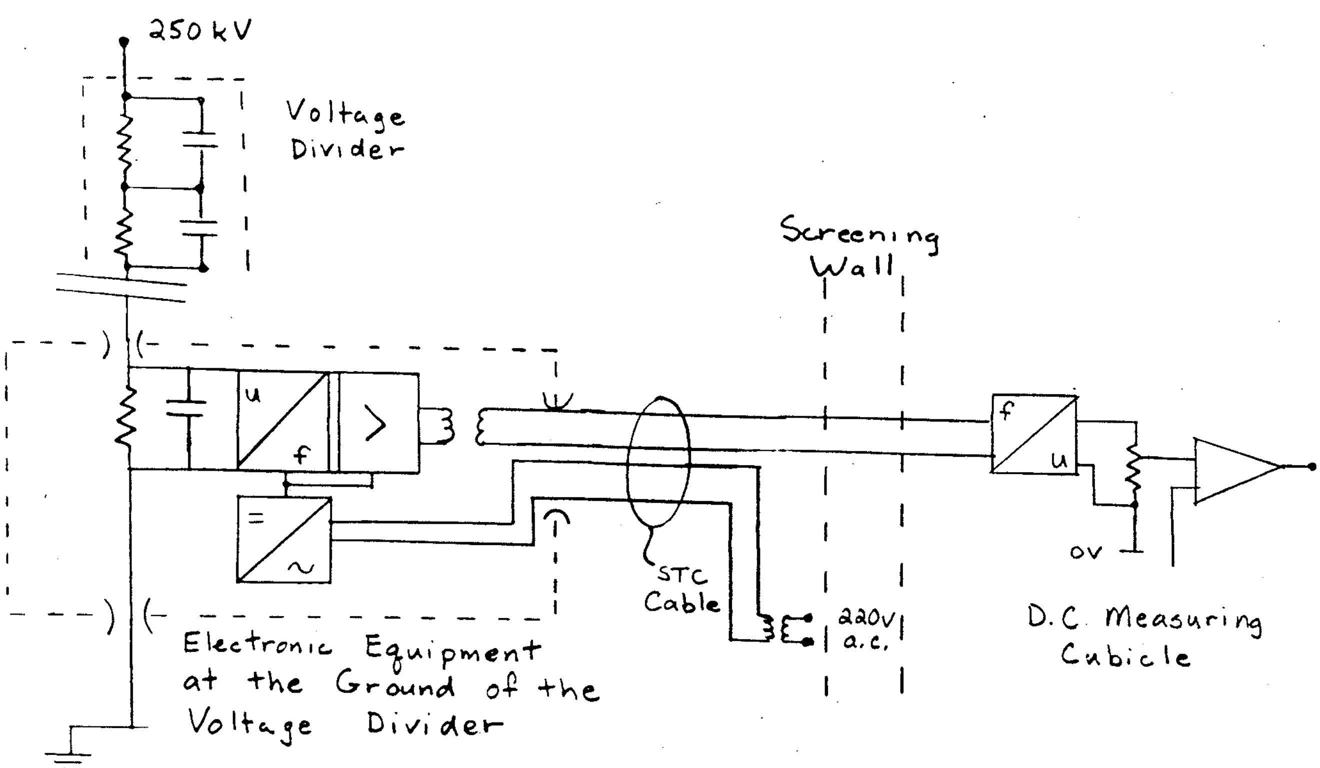

Figure 3

The voltage signals that are measured are Ud_L , the pole voltage, Ud_{gr} , the group voltage, and Ud_E , the earth electrode voltage. During 6-pulse operation the voltage signal Ud_L will be half the rated value (125 kV dc) . In order to avoid complicated changes to threshold values in protection circuits that utilize the line or group voltage as an input, the voltage signals were calibrated to double their values in the measuring cubicle.

This meant that the calibration of the demodulators were to be changed from a ratio of 1/2 : 1 : 80 to a value of 1 : 1 : 40 for the pole voltage and from 1/2 : 1 : 40 to 1 : 1 : 20 for the group voltage[6]. The modification was achieved by exchanging circuit boards in the demodulator. The output of the demodulator boards is sent to differential amplifiers where the signals Ud_L , and Ud_{gr} and Ud_E are calculated and then fed to the different functions.

3.2.2 Valve Controls

In the pole control cubicle a true measurement of the 6-pulse group voltage is required to determine the proper current order. Since the voltage measurement was altered, the gain of two amplifiers must be changed from -1 to -1/2 . This was achieved by soldering 20K resistors in parallel to the feedback resistor R7 of the amplifier on card A326 of swing frame A102 and another 20K in parallel with R27 on card A319 on swing frame A102. This is shown in Figure 4 below[7].

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[6] G. Bruske, Valve Control Modes for 6-Pulse Operation, (letter dated 79-09-18), p. 1.

[7] G. Bruske, Valve Control Modes for 6-Pulse Operation, (letter dated 79-09-18), p. 1.

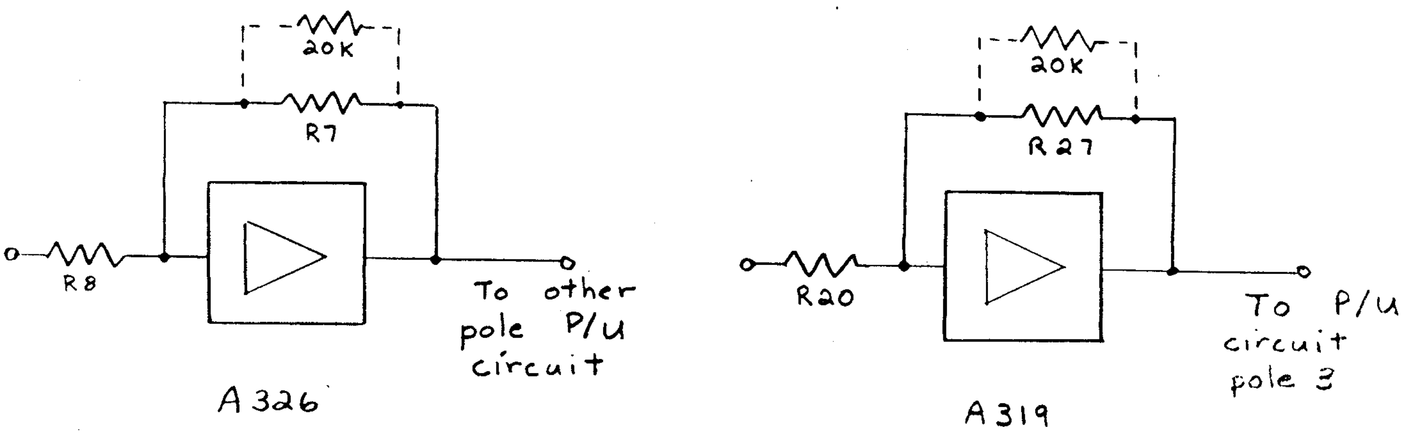

Figure 4

This modification ensured that the correct voltage was used so that Po/U , the power order divided by the bipole voltage, would produce the correct current order for each pole.

In order to start the bipole 2 fault recorder, the threshold detector for dv/dt had to be changed by replacing R1 (39k//82k) on card A305 swing frame A101 with a 20k ohm resistor.

The bipole 2 fault recorder starts only with a set rate of change of voltage as opposed to the bipole 1 Hathway system. The Hathway starts on the rate of change of voltage as well as by contacts from various block, deblock and protection circuits.

In the valve group control cubicle, a modification was necessary during 6-pulse operation to avoid selecting the extinction angle of the faulty bridge.

The extinction angle, (γ) gamma, of each valve is measured by monitoring the end of current signal either from the valve base electronics or from the a.c. current transformers on the converter transformers. The current end signal sets a bi-stable circuit which is reset by the appearance of positive voltage across the valve. The duration of the pulse is integrated and the output voltage is proportional to the extinction angle. Through a sample and hold circuit, the smallest extinction angle is selected to represent the bridge extinction angle. The extinction angles from both bridges, wye and delta, are fed to control circuits in the group and in the pole.

In 6-pulse operation of pole 3 the gamma output from the wye bridge will be zero. To inhibit this faulty signal from being selected, it was interrupted by taking out the diode V15 of PCB A102/A344 in the group control cubicle[8]. This is illustrated in Figure 5 below. Only gamma signals from the healthy bridge would now be evaluated.

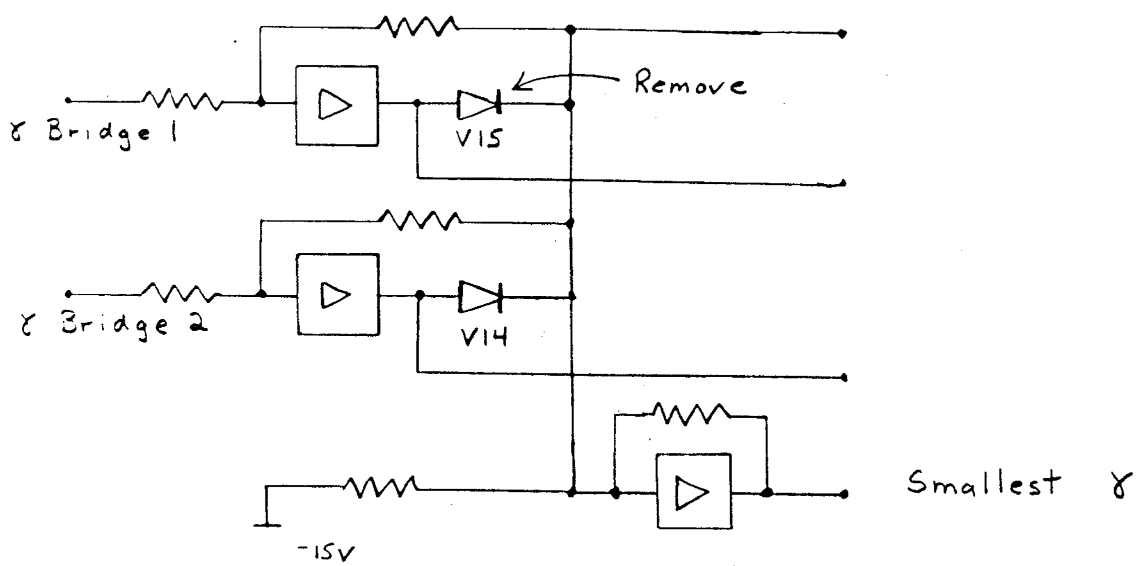

Figure 5

[8] G. Bruske, Valve Control Modes for 6-Pulse Operation, (letter dated 79-09-18), p. 2.

3.2.3 Bypass Switch Monitoring

The deblocking sequence of a group in bipole 2 relies on the bypass switch being able to successfully open and establish a voltage across the breaker contacts.

Once the valve group is ordered to deblock, start pulses are released to the valves with the bypass switch closed and carrying dc current. This dc current can either be from the other group in the same pole or spill current from the other pole. Figure 6 shows the valve group pole configuration.

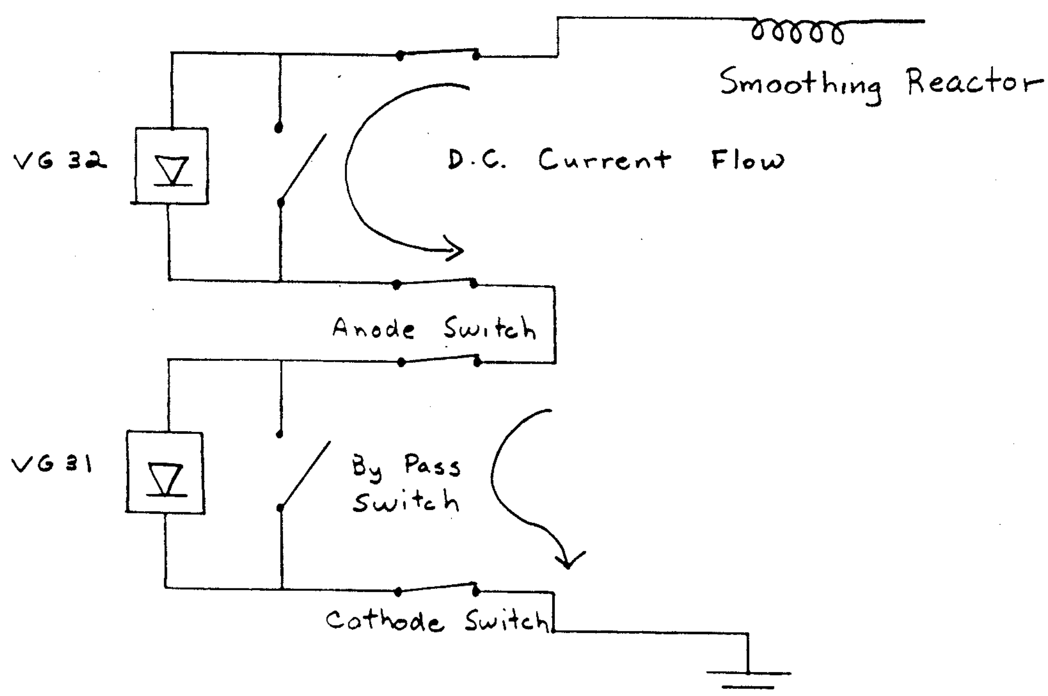

Figure 6

The valve group produces enough current equal and opposite to the dc current that is flowing through the bypass switch. This is achieved by the short circuit controller (I_{dk}) which is located in the valve group control cubicle. The reference value to the controller is the measured current in the bypass switch. The error between this signal and the rectified ac current is used to control the output firing angle. The indication that the error is zero allows the bypass switch to open.

The bypass switch monitoring circuit performs the following check. The group voltage, which is the voltage across the switch, is compared to a preset threshold value. If the bypass switch has not sufficiently exceeded the setting within a certain adjustable period of time, the bypass switch has failed to extinguish. The switch is ordered to reclose and a normal shut down command (NOSOF) is given to the group switching controls.

The 90° voltage that is measured across the bypass switch goes through a 720 Hz filter before being compared to the threshold level. Since in the 6-pulse operation, this 90° group voltage will have a frequency of 360 Hz, a new filter had to be built and tuned for the measured voltage[9].

A new printed circuit board card was designed and installed in swingframe A103 position A361 to allow proper monitoring of the bypass switch voltage.

Once the bypass switch has successfully opened, the group voltage controller is then activated to achieve the rated group voltage by a ramp function.

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[9] G. Bruske, Valve Control Modes for 6-Pulse Operation, (letter dated 79-09-18), p. 2.

3.2.4 By-Pass Monitor

The bypass monitor circuit is designed to detect a bypass in a bridge being formed on the valves for longer than 150 ms and to protect against failure of the bypass switch to close. This circuit is located in the group control cubicles.

The circuit receives the ac currents from two separate current transformers sources which are fed into the bridge control cubicles. The two sets of three phase currents are rectified. The rectified values are compared to the dc current in the smoothing reactor.

The output of the above detectors is processed in the group control cubicle on card A334 swing frame A103. With the wye bridge not in operation, this circuit would be triggered and block the group by the FASOF circuit. To inhibit this protection, card A345 on swing frame A103 of the bridge control cubicle was removed. It was replaced by a blank card that would maintain a low signal, zero volts on pins A02 and C02 in this position[10].

In this manner the protection circuit in the group control cubicle would see no signal from the bridge and not initiate a shut-down of the group.

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[10] G. Bruske, Valve Control Modes for 6-Pulse Operation, (letter dated 79-09-18), p. 1.

3.2.5 Valve Base Electronics - Thyristor Fault Monitoring (VBE-TFM)

The valve base electronics serves as an interface between control, protection and logic circuits of the thyristor valve and outside equipment. The VBE receives start/stop pulses from valve control, gathers information for the thyristor fault monitoring equipment, and protects the valve by monitoring the thyristor electronic circuits.

During 6-pulse operation, one half of the valve tower would be by-passed. This would mean that no ac voltage would appear across the top two bridge arms of each tower during the start up sequence of the valve group. The thyristor electronic circuits would report back to the VBE via a fiber optic system of this failure. To prevent the TFM from interogating these wye bridge arms, their code words were removed[11]. In this way the TFM by-passes those bridge arms. As well, all the light emmitter cards for the affected bridge arms were removed. This meant that start pulses were not sent to the thyristor modules in the star bridge. A picture of the cubicle in the VBE with the light emmitters pulled is shown in Appendix 3.

The task of the thyristor fault monitoring is to monitor the valve for faulty thyristor pairs and faulty electronic units. It accomplishes this by checking the information in the VBE. Since the code words were removed from the wye bridge arms, the TFM could not interogate that area of the VBE. This would result in an alarm which

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[11] D. Buck, Modification of TFM/VBE for 6-Pulse Operation, (letter dated 79-09-18), p. 1 .

did not block the group but prevented the group from deblocking[12].

In order to avoid this problem a card was built which would ignore the signals from the wye bridge arms but still properly analyse signals from the operating delta group. The circuit in Appendix 4 illustrates the card that was built to perform the above selection.

3.2.6 DC Controls

The dc controls commands the tap changers and receives the tap position from the two converter transformers. Commands and replies had to be modified to accommodate for the absence of one of the transformers of the 12-pulse group.

The following is a summary of the various minor changes that were performed in order to exclude the wye transformer and half of the valve tower in the dc control scheme.

- the "fault start 1 timer" had to be increased to its maximum limit of 40 seconds. This was done due to the increased pre-check time of the TFM when interogating the valve tower during the start 1 program.

- in the tap changer control cubicle, several changes were made in order to accommodate for the loss of the wye transformer.

1) commands to raise and lower the wye transformer were disconnected.

2) pins for voltage supervision were removed.

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[12] D. Buck, Modification of TFM/VBE for 6-Pulse Operation, (letter dated 79-09-18), p. 1.

3) "the tap changer is running" pins were taken out and the internal sides jumpered to the external sides of the delta bridge terminals in order to satisfy the tap changer logic.

4) the "motor protective switch" pins were pulled. Jumpers were also installed to indicate the proper signal back to the tap changer logic circuit.

5) on the tap changer indication all pins were removed and jumpers installed in such a manner as to indicate to the logic circuits that both transformers were on the same tap position.

3.2.7 Transformer T31S Protection

Associated with the transformer were protection circuits found in the converter building and the relay building that had to be disconnected. The supplies for auxilaries also had to be removed. The following items were related to these circuits.

- in the transformer T31S protection cubicle, fuses were pulled to disconnect the 125 V dc supply for the main and back up trips. The main trip protection supply fail alarm and back up alarm were also disconnected at the terminal blocks.

- the transformer T31S connection protection C.T. circuits were removed on the terminal blocks. The ground over-current was disconnected in this panel.

- the 120/208 V supply to the transformer kiosk lighting and heater was turned off. The 600 V for the fans and pumps to the transformer kiosk were also disconnected. The alrams for T31S under voltage was blocked and for the deluge system were removed.

3.2.8 Valve Hall

In order to effectively cater for the missing wye transformer in the valve hall, the bridge arms associated with the transformer were short circuited.

An 2000 MCM cable was installed to connect the 250 kV bus with the 125 kV bus.

Appendix 5 shows photographs of the actual bus connection.

On the outside of the valve hall, all conductors from the ac wall bushings were disconnected.

3.2.9 Henday Modifications

The modifications at Dorsey were done at the Henday station with one more added. For the proper operation of 6-pulse in the north, both Henday high pass filters were required to be put into service. If there was a loss of a filter bank at Henday, 6-pulse operation would be blocked by wiring the necessary logic to the NOSOF circuit of VG31.

3.3 Results of Modifications

The modifications to the valve group were done in a very short period of time. They were effective and did not alter the basic design concepts and features of the 12-pulse group in terms of control and protection functions.

CHAPTER 4

Bipole 2 Six Pulse Commissioning Tests

4.1 General

Once the modifications to the equipment at the Dorsey and Henday Stations were complete, 6-pulse operation was attempted in the beginning of October 1979. Engineering staff from Manitoba Hydro monitored many functions related to the 6-pulse mode. Most of the concern was in the northern collector system due to the additional 5th and 7th ac harmonics which would now be introduced.

4.2 Outline of Activities

Before the 6-pulse valve group could be put into operation, a series of tests were conducted on the bypass switch monitoring circuit. These tests were carried out by opening the bypass switch at Henday under current. The group current controller (Idk) was disabled and the signal Idk = Ids was simulated. The current was produced at Dorsey for the test and could be adjusted.

The criterion for successful operation of the bypass switch circuit was that the threshold detector would not pick up during the arcing of the switch, but would pick up once the group voltage was established.

Three tests were done at Henday on the bypass switch with the threshold setting of the detector set from 1 volt to 7 volts. This meant that the detector doesn't trip until after the arc extinguishes. This new setting was adopted for both ends of the system. Appendix 6 shows the oscillograph of the Henday group deblocking and 6-pulse volts generated by the group. The reclose of the bypass switch was generated by a timer as a precaution during these tests.

Once the bypass switch testing was complete the 6-pulse group was prepared to deblock. Harmonic current measurements were made at the following listed locations in the north:

1) on both H.P. filter banks at Henday;
2) on the 230 kV side of T31 transformer;
3) on the Long Spruce generator; and
4) on the Henday ac bus.

Several tests at different dc loadings were made during the next few days of the testing program. This involved operating the northern system in different configurations with respect to ac filters at Henday and Radisson as well as running various combinations of generators at Kettle and Long Spruce.

Manitoba Hydro and Manitoba Telephone System were also taking readings in the Stonewall area to see the effect of the unfiltered voltage harmonics on the line.

Minimal readings and measurements were taken at Dorsey since bipole 1 provided adequate filtering of the 5th and 7th ac current harmonics.

4.3 Test Results

Measurements taken during 6-pulse testing at different power orders produced results that were favourable for 6-pulse operation.

The current readings on the two H.P. filters at Henday and the 5th harmonic filters at Radisson resulted in the operation of 6-pulse only with both Henday filters connected to the system. With one filter at Henday the maximum current on VG31 was approximately 700 A without overloading the filters. Table #1[13] below shows the RSS currents (Root Sum Squared) for the filters at Henday at different current orders. The rated RSS current for the Henday H.P. filter is 670 A .

			FB1	FB2
One H.P. Filter				
VG31	Id = 300 A			
		A	524	
		B	532	
		C	524	
	Id = 600 A			
		A	N/A	
		B	600	
		C	560	
	Id = 700 A			
		A	640	
		B	644	
		C	592	
Two H.P. Filter				
VG31	Id = 670 A			
		A	506	504
		B	508	506
		C	508	507
	Id = 1200 A			
		A		510
		B		512
		C		512
	Id = 1800 A			
		A	518	520
		B	522	520
		C	524	520
	Id = 2000 A			
		A	520	516
		B	521	520
		C	521	520

Table 1

Henday Hi-Pass Filter Currents (RSS) Measured

With only one H.P. filter bank at Henday connected, the bus distortion at Henday was large ranging from 7% to 17%.

The large bus distortion and the large harmonic currents during 6-pulse operation were attributed to a 5th parallel resonance condition which had to be catered for during 6-pulse operation. Figure 7 shows the Henday bus voltage profile.

During the testing, the Long Spruce generators were monitored for heat rise by employing heat sensitive tape. The tape indicated that there was no generator heating problems.

Noise measurements in the Stonewall/Warren area showed that there was a reduction in noise levels with 6-pulse operation. There was no apparent interference with CNCP telecommunications equipment. So it was concluded that there was no need for additional dc filters to reduce MTS telephone noise[14]. This result was expected by Manitoba Hydro in their planning reports.

4.4 Conclusions

The operation of VG31, pole 3 of bipole 2, in a 6-pulse mode up to full load was feasable and did not create any serious problems. But it was stipulated that during 6-pulse operation, both high pass filters at Henday must be connected since the 5th harmonic resonance would create an overload of one Henday filter and possibly the Radisson

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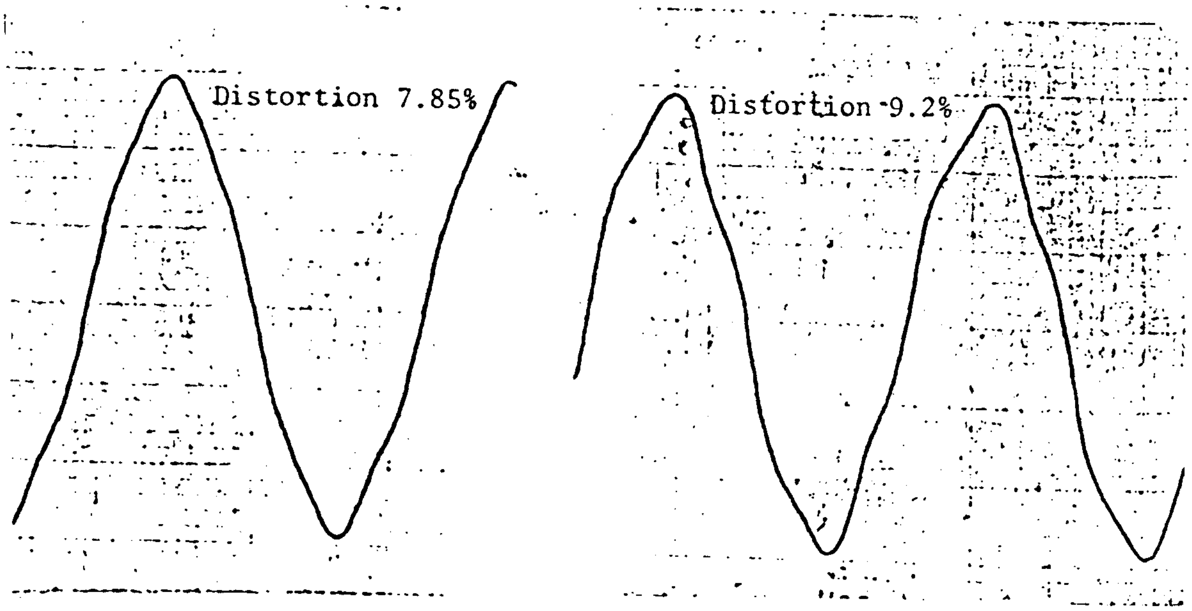
[13] R.B. Wagg, Bipole Two Six Pulse Operation, Henday Commissioning Results, (letter dated 79-10-19), p. 10.

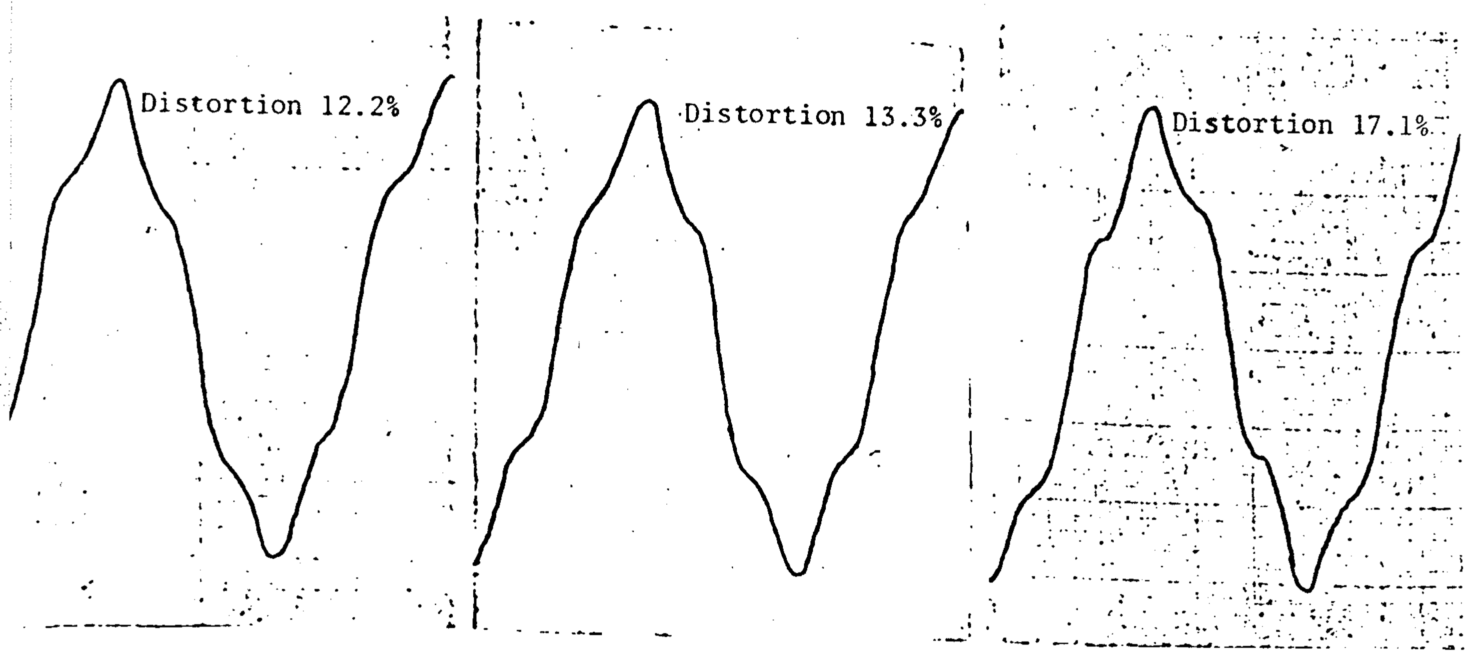
[14] C.V. Thio, Bipole Two Six-Pulse Operation, (letter of 79-10-22), p. 1.



VG31

Id = 300 A

Id = 400 A



Id = 500 A

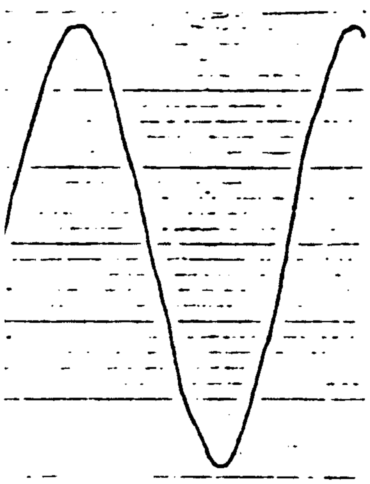
Id = 600 A

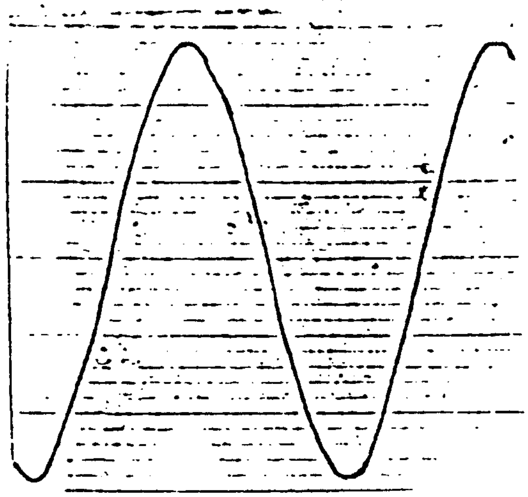
Id = 700 A

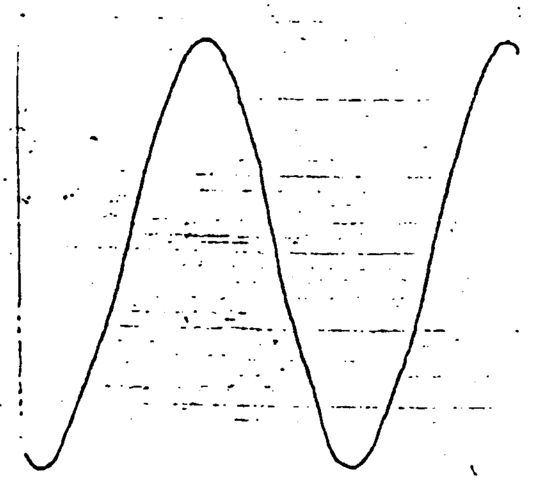
Henday Bus Voltage

One High Pass Filter

Figure 7a





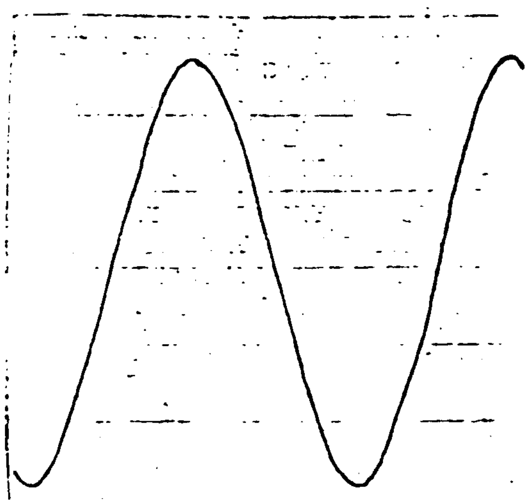


VG31

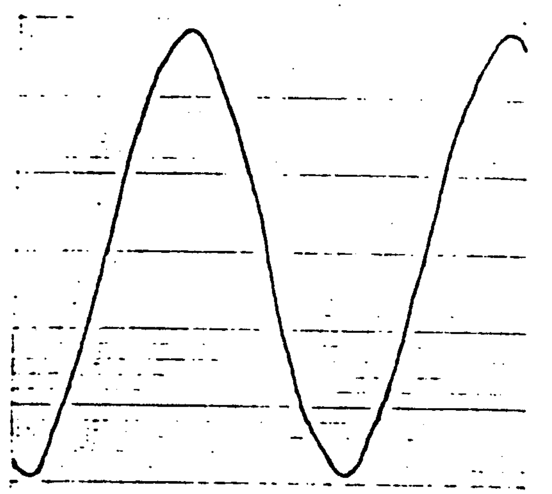
Id = 600 A

Id = 800 A

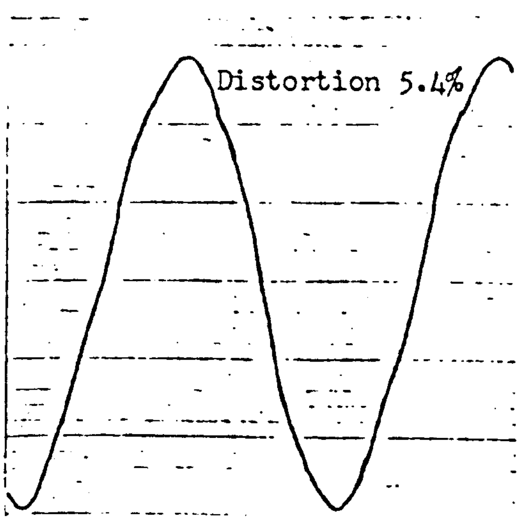
Id = 1000 A



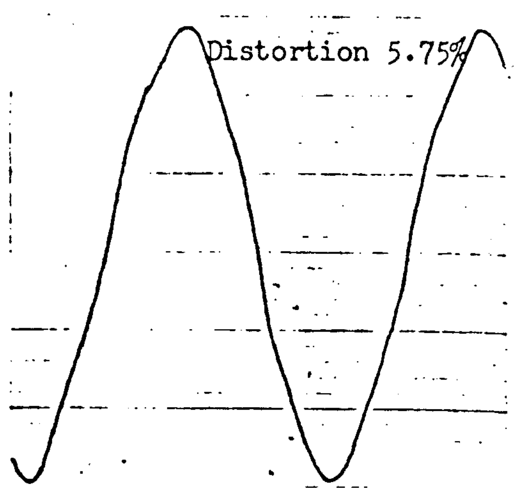
Id = 1200 A



Id = 1500 A



Id = 1800 A



Id = 2000 A

Henday Bus Voltage

Two High Pass Filters

Figure 7b

5th harmonic filter[15].

The decrease in telephone noise during 6-pulse operation compared to running bipole 2 in monopolar operation was an added bonus.

Therefore it was concluded that no further modifications were required to the filtering circuits and control circuits for adequate 6-pulse operation.

[15] E. Wistow, 6-Pulse Testing - Test Results (letter of 79-10-12), p. 2.

CHAPTER 5

Operation of 6-Pulse

5.1 General

Commissioning of the 6-pulse operation was conducted during the first week of October 1979. After that, the group was handed over to the System Operations Division of Manitoba Hydro to be put into commercial use. The 6-pulse operation of VG31 lasted for almost one year until the wye converter transformers arrived to each site from the manufacturer.

5.2 Performance

Throughout the period when operating in a 6-pulse mode the control and protection circuits operated without any trouble nor false indication. The group was subjected to ac system disturbances and dc line oscillations during the course of operation. The 6-pulse group behaved normally in these system disturbances.

The 6-pulse group experienced commutation failures and slight ac over-currents with the proper protection and control circuits operating properly.

The ac and dc filters were not subjected to any overloadings due to the operating restrictions imposed on the group.

The operation of 6-pulse did not interfere or cause any communication problems in the north nor the south during its operation.

CHAPTER 6

Conclusions and Recommendations

The operation of the 6-pulse system of bipole 2 tied in very closely to the studies performed by Manitoba Hydro prior to the decision to proceed with 6-pulse operation. This provided planners more confidence in their modelling and system behaviour studies.

The 6-pulse decision definitely increased the lifetime of the electrode site. During the winter period 6-pulse operation was almost continuous and at high loads as well. It allowed Manitoba Hydro to increase export sales and add more realiability into the system. With bipole 2 running bipolar instead of monopolar, the telephone noise in the south was reduced which was a definite plus to public in the Stonewall area and improved public relations.

The changeover from a 12-pulse system to a 6-pulse mode was engineered by Manitoba Hydro with the help of the HVDC Working Group. This operation enhanced Manitoba Hydro's engineering expertise as well as demonstrating the flexibility of the supplier's equipment. A 6-pulse operation of this kind was the first attempt ever made and to succeed thus bringing a new dimension to HVDC technology.

The outcome of this 6-pulse operation could hopefully encourage manufacturers' of HVDC equipment to incorporate additional flexibility in their future HVDC design projects. For the loss of one component should not completely cripple the group.

Manitoba Hydro at one time after 6-pulse operation had contemplated making the changeover from 12 to 6-pulse faster and without the complications of removing and adding wire and pins. This idea was turned down since the engineering time would be more than the actual time to complete the changeover.

In conclusion, the 12 to 6-pulse changeover was completed with a minimal amount of modifications and system complications. It enabled Manitoba Hydro to run the system with increased capacity, realiability and enhanced HVDC technology by the increased flexibility of converter operation.

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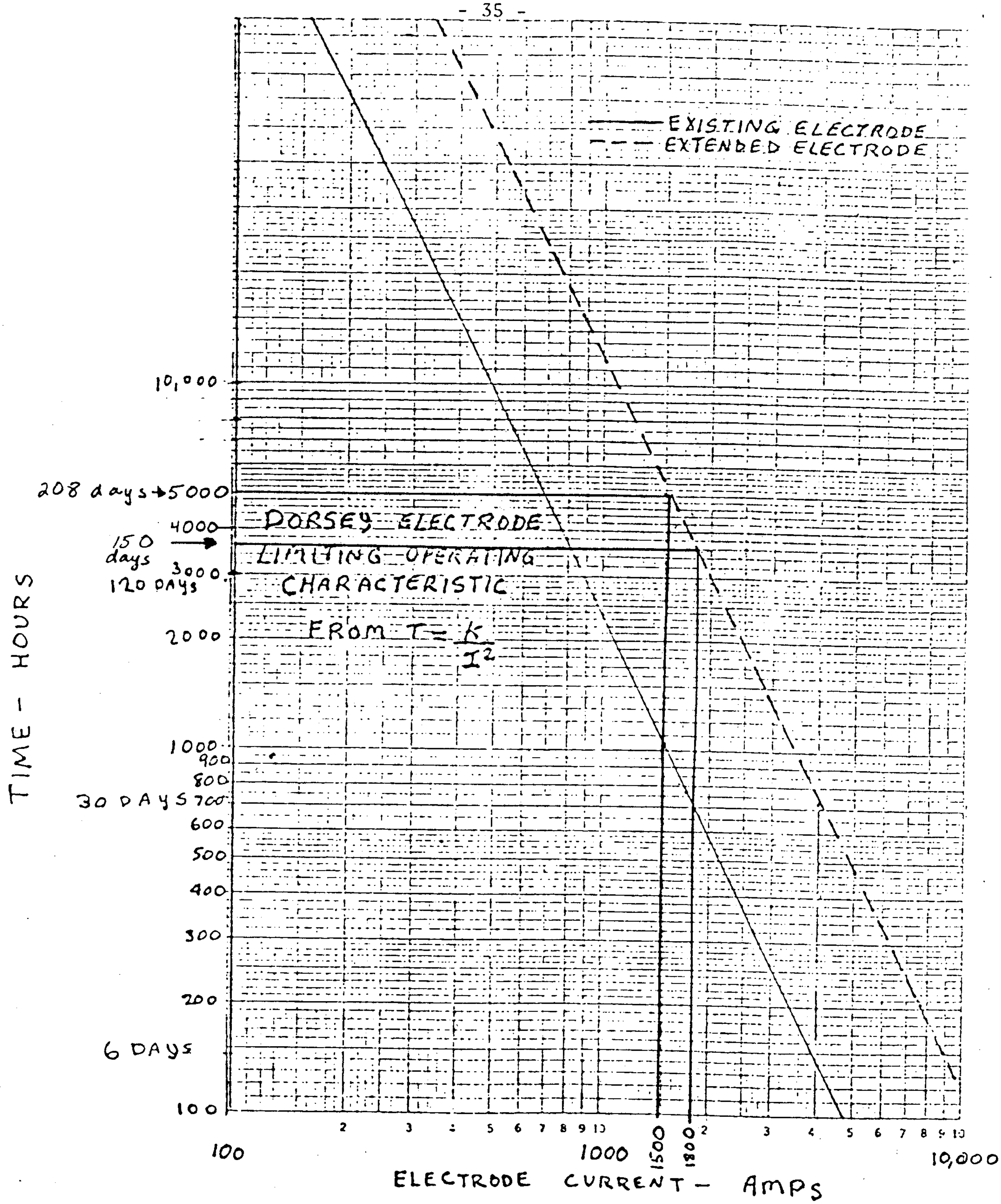
APPENDICES

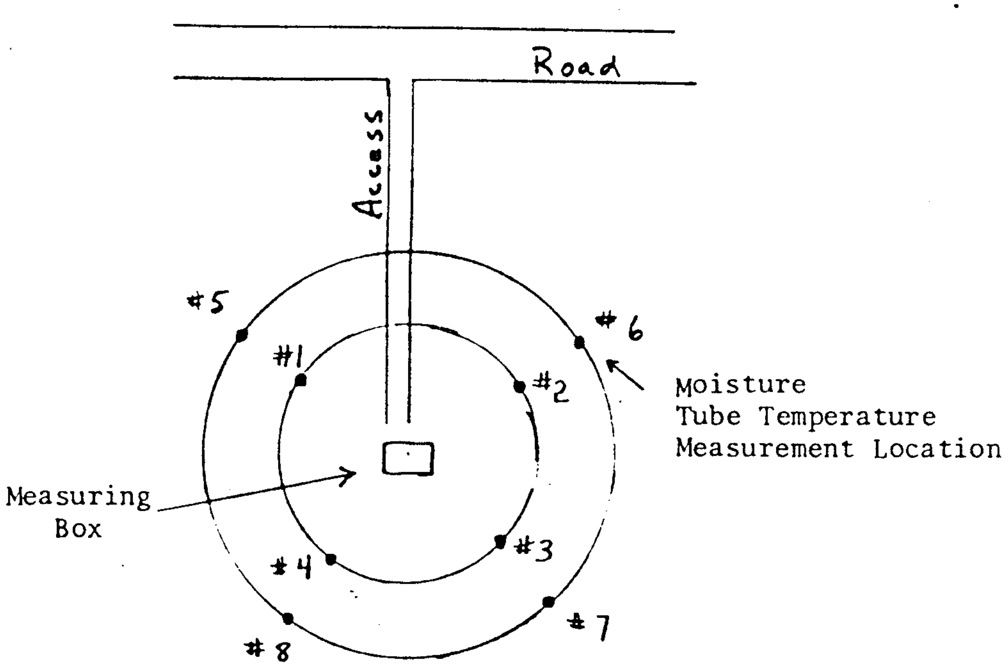


DORSEY ELECTRODE OPERATING TIME CONSTANTS

APPENDIX 1

ELECTRODE SITE MEASUREMENTS

TIME	AMBIENT TEMP.	MOISTURE TUBE TEMP. MEASUREMENTS #1	#2	#3	#4	#5	#6	#7	#8	SKYWIRE TO GR. V	(ELECTR) BP2 AMPS
15:00	20	–	10	–	–	–	8.9	–	–	Not Avail	–
13:30	14	9.0	9.5	11	9.5	10.5	10.0	10.5	8.5	540	1560
13:30	15	9.0	9.0	8.5	8.5	10.5	9.5	10.5	10.5	225	1175
14:00	10.5	9.5	9.0	8.5	9.0	9.0	9.0	10.0	9.5	–1.0	0
14:00	–9	8.0	8.0	7.0	8.0	7.0	8.0	8.0	8.0	5.6	25
13:35	–1.5	7.5	6.0	6.5	7.0	7.5	8.0	8.0	7.5	0.4	0
09:30	–7	6	6	6	6	6	6.5	7	6	8.0	30
10:00	14	8	N/A	8.0	7.5	9.0	8.5	7.5	7.5	360	1440
09:15	25	7	12	6	7	8	9	8	9	–330	1080
10:10	24	8	N/A	7	9	7	9	8	8	5½	4A (in)
09:15	20	9	12	8	8	10	9.5	8.5	11	–480	1560
13:15	23.5	8.5	18	8	7.5	10	10	9	7.5	–328	1080
10:00	6	9	9	9	9	10.5	10	9	8	8.0	

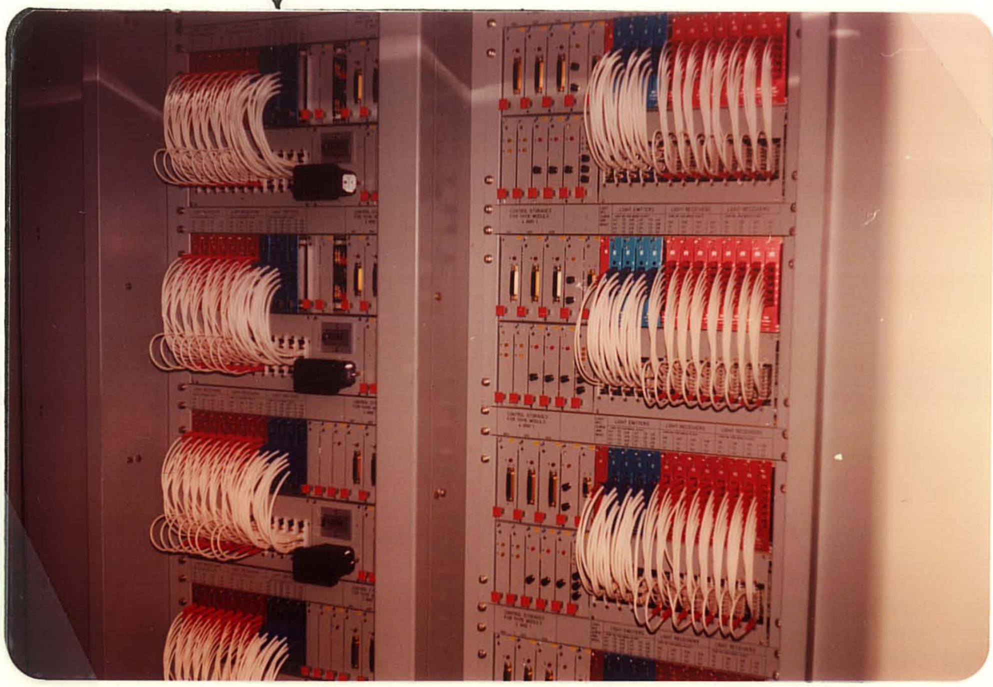


Dorsey Electrode Site

DORSEY ELECTRODE SITE MEASUREMENTS

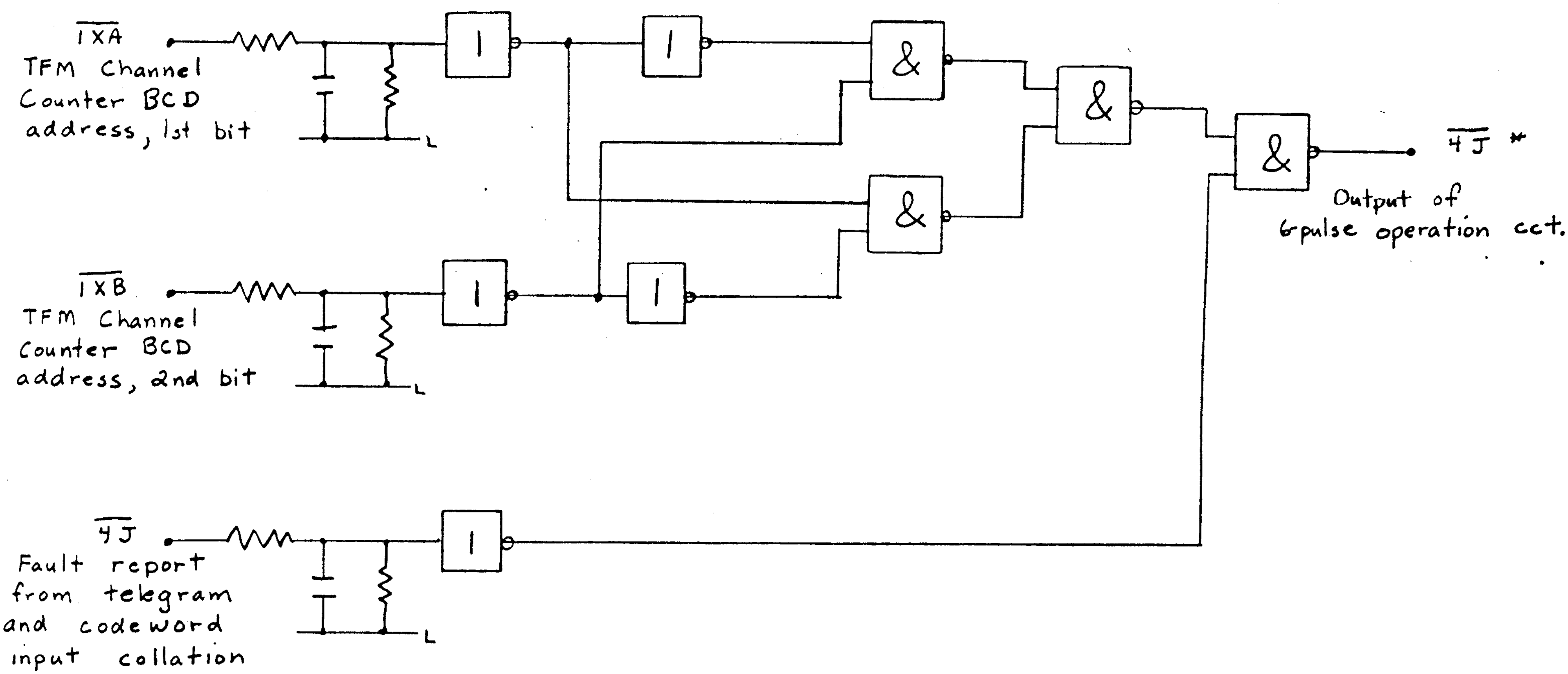
APPENDIX 2

Pulled Light Emmitter Cards



VALVE BASE ELECTRONICS

APPENDIX 3

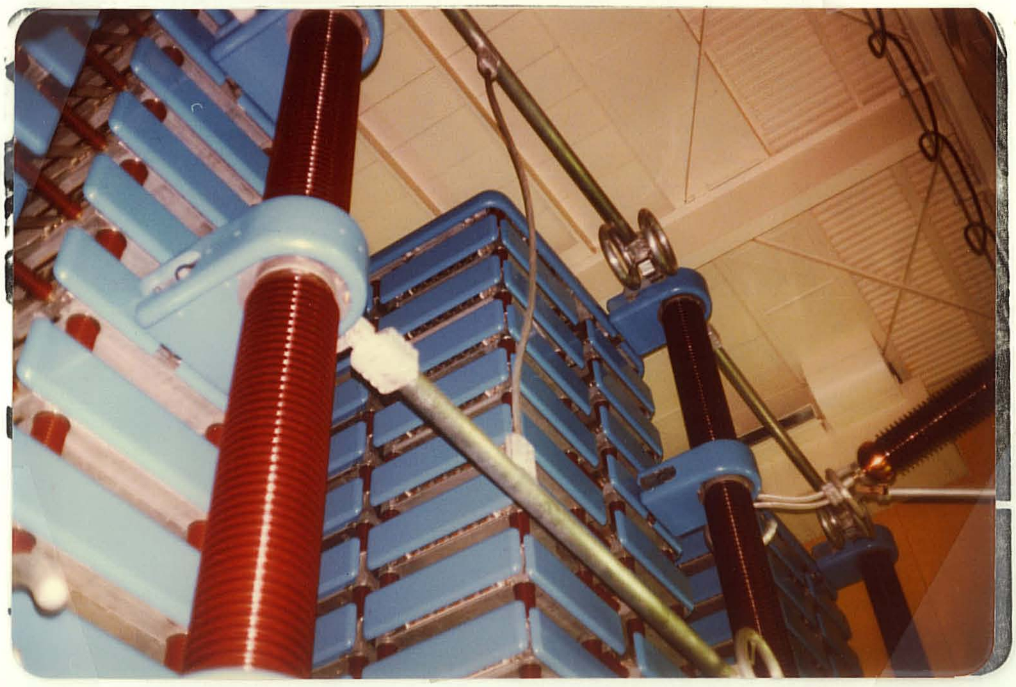


Blocking of TFM Fault Signals by 6-Pulse Operation

BLOCKING OF TFM FAULT SIGNALS

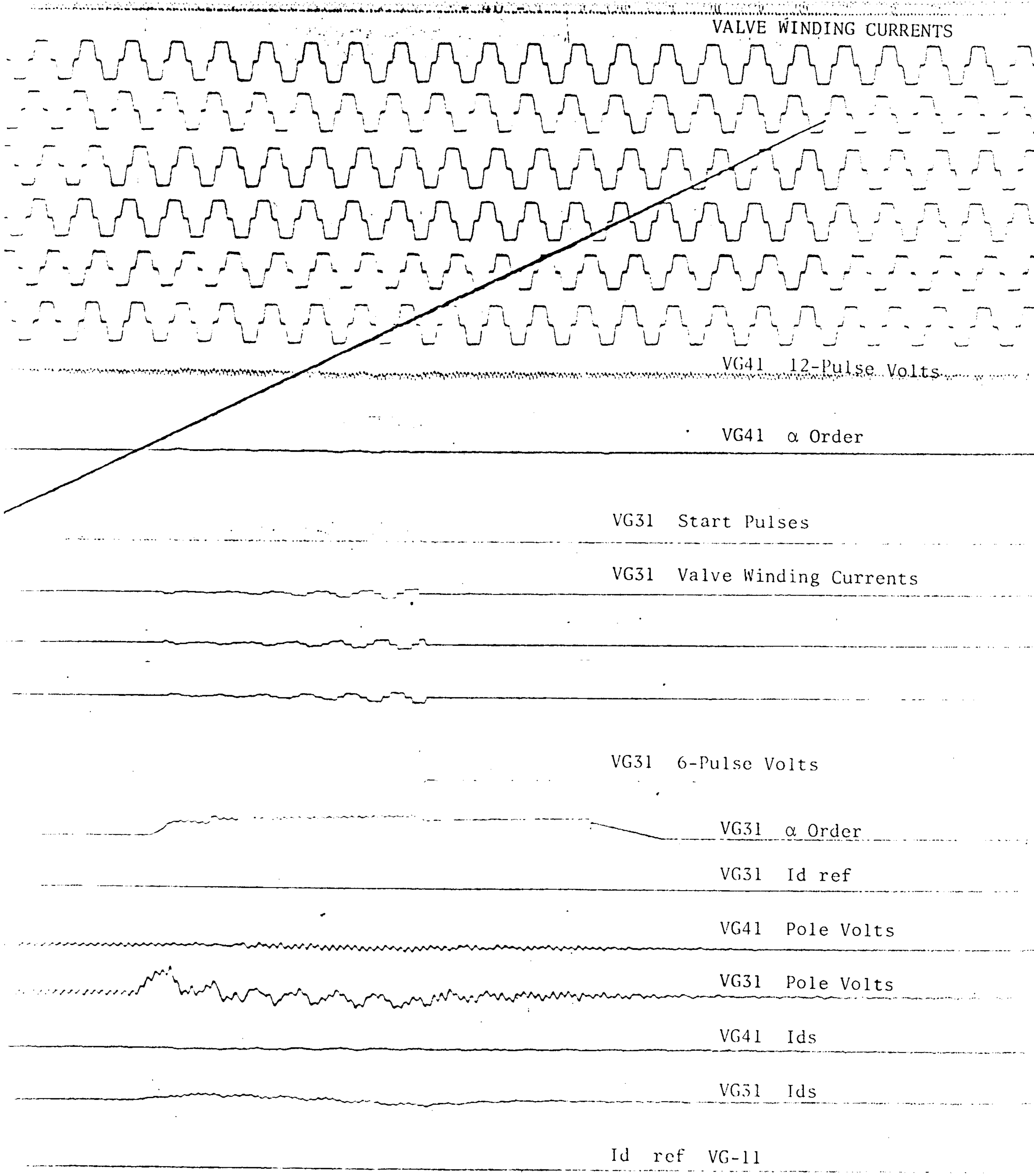
APPENDIX 4

16.5.79 T. Hummerston



VALVE HALL BUS CONNECTION

APPENDIX 5



OSCILLOGRAPH OF 6-PULSE DEBLOCK-BLOCK

APPENDIX 6