Section 451.6
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HVDC

Contents

1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, contractors and other interested parties with technical information for use in the design and construction of REA borrowers telephone systems. It is written to provide an understanding of high voltage direct current transmission (HVDC) systems. Potential problem areas will be discussed and techniques will be presented for application in areas where HVDC systems are proposed to determine any detrimental effects on the telephone system.

1.2 With the growing demand for electric power throughout the world HVDC transmission systems are becoming more popular. There are today specific applications where the dc transmission technique may offer a better alternative to ac transmission for bringing power to the ac network backbone system. The backbone system can be defined as that into which the generated power is delivered and from which the load is distributed. The three applications are:

1.21 Long-distance bulk power transmission lines from remote energy sources to the backbone system. This application is growing in importance for multiple reasons. Environmental impact of added generating stations near the user is producing increasing opposition from the public. Low cost energy sources are often located far away from these locations and transportation of the fuel in the quantity required would be prohibitive.

1.22 Interconnections between power systems or pools. HVDC transmission is especially suited for this application since the direction of power transmission can be reversed rapidly.

1.23 High power underground and/or submarine systems.

1.3 HVDC systems today are operating in the range of ± 400 kV with future systems planned for ± 600 kV. One pole operates at + 400 kV and the other pole at -400 kV with respect to ground or 800 kV pole to pole.

1.4 There are two potential harmful effects to telephone systems from a HVDC transmission system. First is the possibility of excess induced longitudinal noise voltages on nearby telephone facilities. A few problems have been reported near the systems that are operational but they have been rare. Second is the problem of corrosion during periods of monopolar operation with a full ground return between the earth electrodes. The potential noise problem will be discussed in this section. The problem of corrosion is beyond the scope of this section and will not be discussed.

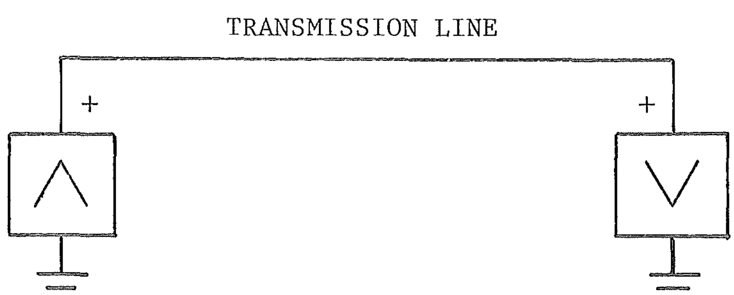
1.5 Costs of constructing a HVDC convertor station are higher than those for a conventional transformer station. These additional costs can be offset by savings in the transmission line itself. Only two conductors of smaller size in the dc line can replace six conductors of an ac line. The right of way for the dc line can be narrower than is required for an ac line.

2. THEORY OF HVDC OPERATION

2.1 It is beyond the scope of this presentation to show the detailed operation of all components used in HVDC transmission. The main device called a convertor will be treated as a unit with three ac connections and two dc connections. When the convertor has full dc voltage in the forward direction it is a rectifier and when it has full dc voltage in the reverse direction it is an invertor.

2.11 When two convertors are connected, one at each end of a transmission line power can be transmitted from one to the other.

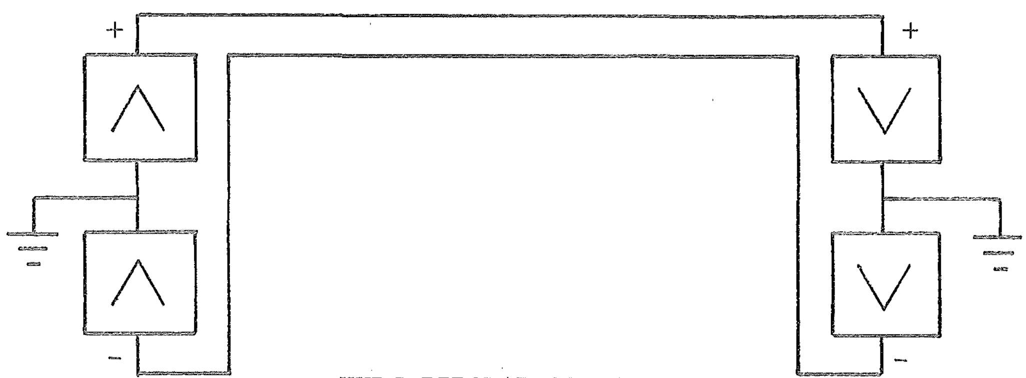
2.12 An HVDC system can operate efficiently with a single wire between the two convertors (monopolar operation) as shown in Figure 1. In this mode the system is operating with 100 percent earth return. While this method is utilized at some locations overseas it is not permitted in North America. With the high earth return current the chance of noise and corrosion problems multiply rapidly.



HVDC MONOPOLAR OPERATION

FIGURE 1

2.13 In North American installation a second wire is added between the two convertors (bipolar operation) as shown in Figure 2. Even though the transmission is controlled separately when the current is equal there will be no current flowing through the earth. All current will flow in the metallic path of the two transmission lines.

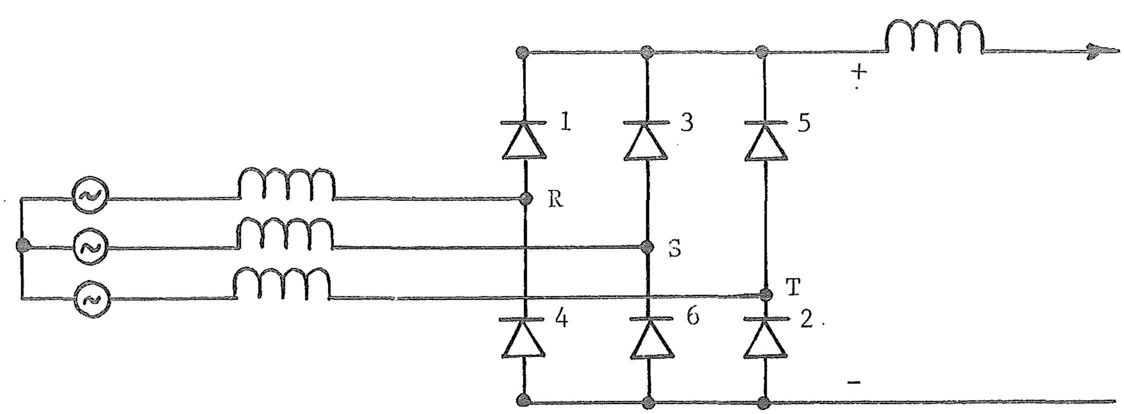


HVDC BIPOLAR OPERATION

FIGURE 2

2.14 During periods of operation when one convertor is shut down at each station as for maintenance the second transmission line can be used for the return path thus minimizing earth return current. Only in the case of transmission line failure should it be necessary to utilize monopolar operation until repairs are completed.

2.2 A single two-way six pulse convertor bridge as shown in Figure 3, is a basic building block for a HVDC transmission system. It consists of six thyristors or mercury-arc valves. They fire (start to conduct voltage in the forward direction) when the voltage in the forward direction is positive and a control pulse is sent to the valve. There are thus six pulses for each Hertz of the 3-phase ac input or output.

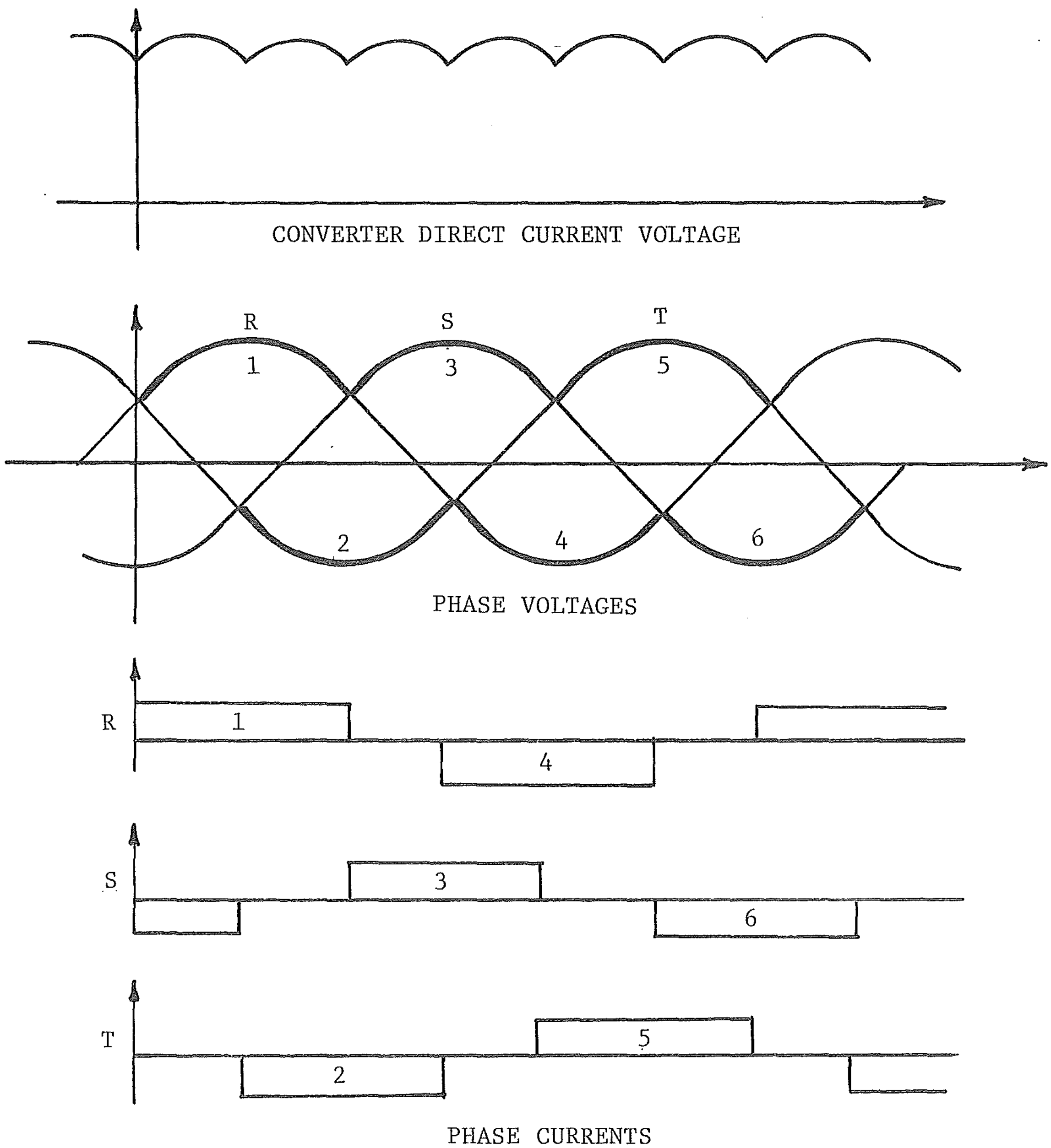


TWO-WAY 6--PULSE CONVERTOR BRIDGE

FIGURE 3

2.21 A study of the convertor operation will provide an understanding of how the ac is rectified to dc. When valves are not controlled the switching (commutation) of current will take place automatically. This occurs so that the ac phase with the highest potential will be connected to the positive terminal and the phase with the lowest to the negative dc terminal. The firing sequence is shown in Figure 3.

2.22 Commutation of the current from one valve to the next (i.e., 1 to 3) takes place when the cross over points of the voltage curves is reached as shown in Figure 4. The heavy lines on the voltage curves indicate the valve is firing. Flow of phase current in the ac side of the convertor is also shown in Figure 4 together with a curve of the direct current voltage.



TWO-WAY 6-PULSE CONVERTOR OPERATION (UNCONTROLLED VALVES)

FIGURE 4

2.23 When used as an invertor the valves are fired in the same sequence by pulse signal. A current is produced on the ac side similar to the phase currents shown in Figure 4 resulting in the conversion to ac.

2.3 Although it is possible to operate with only a single 6-pulse convertor group at each end of the transmission line it is preferred to have at least two. By connecting one convertor group Y/Y and the other Δ/Y two 6-pulse convertors will function as a single 12-pulse convertor. In this mode of operation the 6th harmonic in the voltage on the dc side and the 5th and 7th harmonics on the ac side will disappear.

2.4 A convertor bridge is a generator of harmonics. On the ac side it can be considered as a generator of current harmonics and on the dc side voltage harmonics. With a 6-pulse convertor harmonics of the order n=k 6±1 (K=1, 2, 3, etc.) will appear in the ac phase currents. On the dc side of the convertor voltage harmonics of the order n=K 6 (k=1, 2, 3, etc.) will be found. Thus with a 6-pulse convertor the current harmonics 5, 7, 11, 13, 17, 19, 23, 25, etc., are fed to the ac network and the voltage harmonics 6, 12, 18, 24,etc. are fed to the dc network.

2.41 The 12-pulse convertor generates current harmonics of the order n=K 12±1 (K=1, 2, 3, etc.) and voltage harmonics in the order of n=K 12, 11, 13, 23, 25, etc. are fed to the ac network and the voltage harmonics 12, 24, etc. are fed to the dc network.

2.42 Filters can be installed on both the ac and dc side of the convertor group to reduce the interference with communications circuits.

3. INDUCTIVE COORDINATION

3.1 The best indicator a power company has of the efficiency of power system operation is the telephone system. Telephone circuits act as long probe wires and study of the induced longitudinal voltage can provide valuable clues to power line conditions that need improvement. This valuable tool to noise investigations is discussed in detail in TE&CM Section 452. Its application to HVDC's systems is for the determination of the contribution of the system of overall telephone system noise.

3.2 When it is learned that a HVDC transmission system will be constructed the first action is to determine where exposures will occur along the proposed route of both ac and dc lines. All cables should next be checked to insure shields are continuous, ground electrodes are connected where required and there is no damage along the cable route to the cable shield.

3.21 Several locations should be selected, each near the end of a cable exposed to the proposed transmission line, for measurements. The measurements may be made on a working pair although it would appear more desirable to select an idle pair which will not be placed in service during the period of testing.

3.22 Three series of measurements should be made. First, are the pre-energization measurements which can be completed any time prior to start of tests to preclude something happening to the telephone circuits that might result in erroneous conclusions.

3.23 Second, are the test and start-up measurements. This is an important series of measurements. More personnel will be required since measurements at all locations on both the ac and dc side must be completed within the testing period scheduled for each convertor station. Among the operational mode tests which may be performed by the power company are:

A. AC Line Exposure
   1. Without ac filters connected
      a. Bipolar
      b. Monopolar with metallic return
      c. Monopolar with earth return

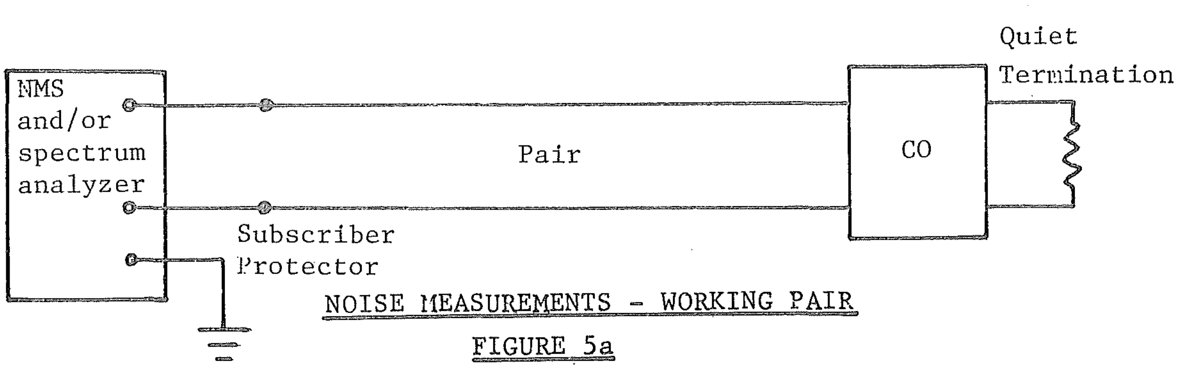
   2. With ac filters connected
      a. Bipolar
      b. Monopolar with metallic return
      c. Monopolar with earth return

B. DC Line Exposure
   1. With dc filters connected
      a. Bipolar
      b. Monopolar with metallic return
      c. Monopolar with earth return

3.24 Third are the post-energization measurements. The series of measurements completed during the test and start-up period should identify any unexpected noise which could then be resolved. The post-energization measurements will provide a continuing check on induced harmonic noise levels.

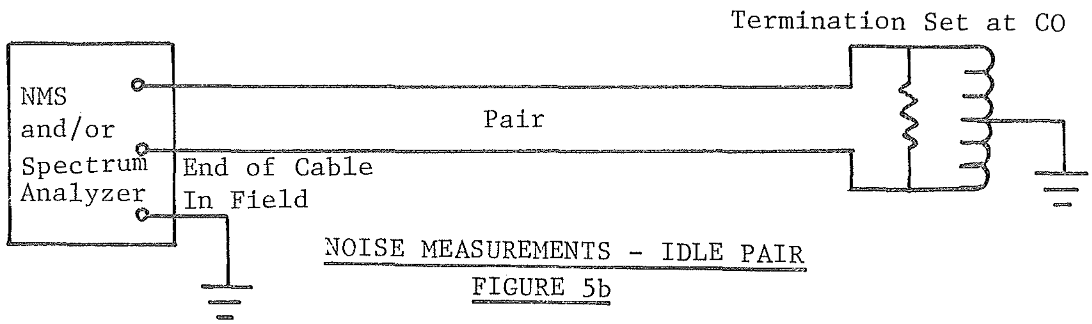
4. MEASUREMENTS

4.1 Noise-to-Ground (Ng): This is a key measurement since it provides the level of induced longitudinal noise voltage from the power line. Test connections are shown in Figure 5a when measurements are made on a working line and in Figure 5b when measurements are made on an idle pair. On subscriber loops measurements should be made at the subscriber end.



NOISE MEASUREMENTS - WORKING PAIR

FIGURE 5a



NOISE MEASUREMENTS - IDLE PAIR
FIGURE 5b

4.11 Ng measurement, working pair

4.111 Dial quiet termination.

4.112 Switch in hold coil of test set.

4.113 Set NMS function switch to the Ng poistion.

4.114 Read and record Ng with "3kHz Flat" and "C-msg." weightings.

4.115 Read and record Ng harmonic levels with the spectrum analyzer set for "3kHz Flat" weighting to the 50th harmonic.

4.12 Ng measurement, idle pair.

4.121 Set NMS function switch to the Ng position.

4.122 Read and record Ng with "3kHz Flat" and "C-msg." weightings.

4.123 Read and record Ng harmonic levels with the spectrum analyzer set for "3kHz Flat" weighting to the 50th harmonic.

4.2 Noise Metallic (Nm): This measurement is meaningful in calculating the circuit balance. No circuit with less than good balance as defined in TE&CM 451 should be selected for these measurements. The test connections are shown in Figures 5a and 5b for measurements on a working line and idle pair respectively.

4.21 Nm measurements, working pair.

4.211 Dial quiet termination.

4.212 Switch in hold coil of test set.

4.213 Set NMS function switch to the Nm (600Ω) position.

4.214 Read and record Nm with "3kHz Flat" and "C-msg." weightings.

4.215 Read and record Nm harmonic levels with the spectrum analyzer set for "3kHz Flat" weighting to the 50th harmonic.

4.22 Nm measurement - idle pair

4.221 Set NMS function switch to the Nm (600Ω) position.

4.222 Read and record Nm with "3kHz Flat" and "C-msg." weightings.

4.223 Read and record Nm harmonic levels with the spectrum analyzer set for "3kHz Flat" weighting to the 50th harmonic.

4.3 Calculate and record circuit balance: Ng + 40-Nm = Balance in dB.

4.4 The power company may want to make probe wire measurements along the power line (on both the ac and dc side of convertor) during the test and start-up, and post energization periods. The telephone company should take part in these measurements when in their service area.

4.5 All recorded data from telephone measurements should be made available to the power company.