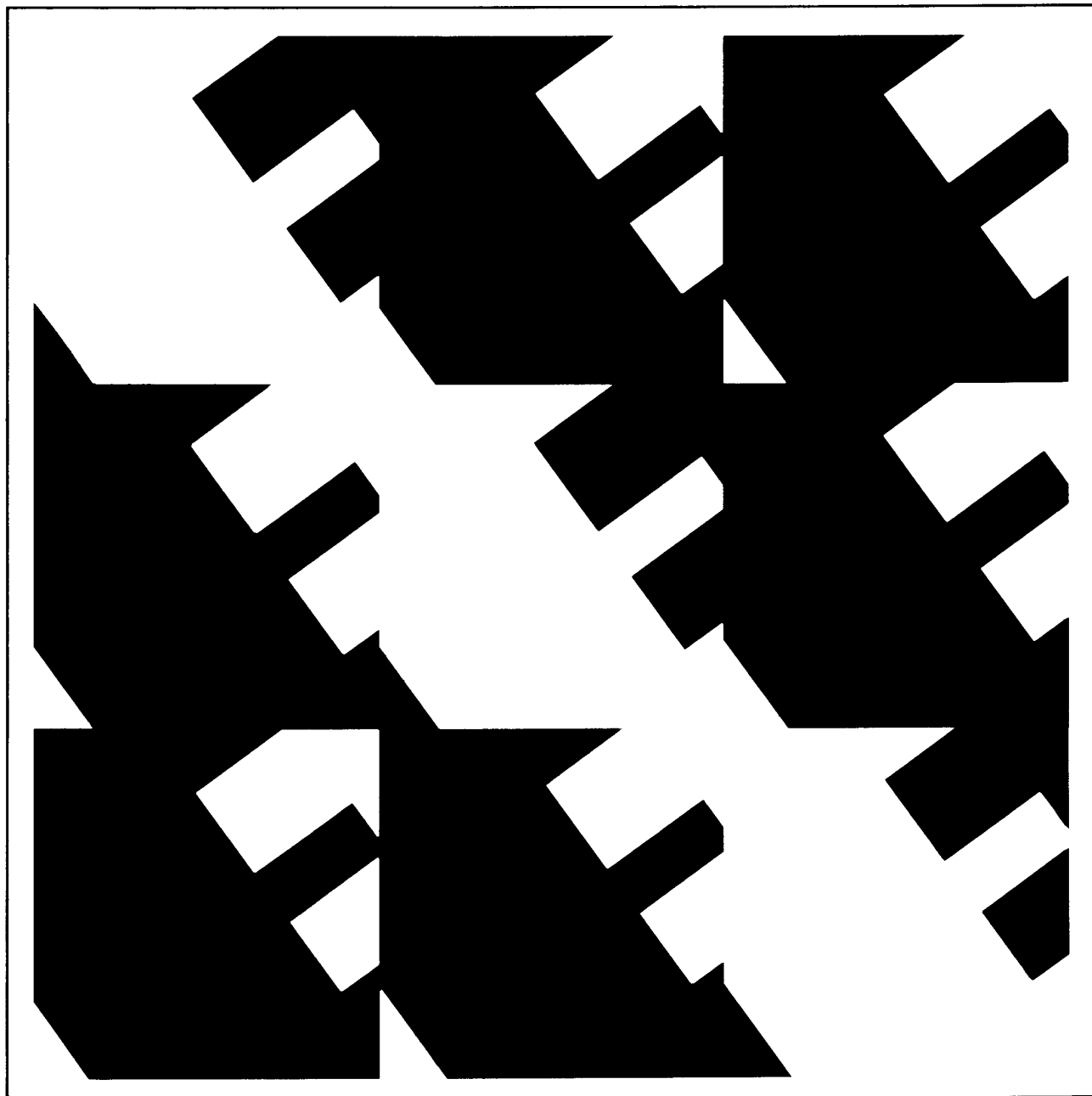


IEEE Guide for Specification of High-Voltage Direct-Current Systems Part I — Steady-State Performance

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**IEEE Guide for Specification of
High-Voltage Direct-Current Systems**

Part I

Steady-State Performance

Sponsor

**Substation Committee and Transmission and
Distribution Committee of the
IEEE Power Engineering Society**

Approved March 12, 1987

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(This Foreword is not a part of ANSI/IEEE Std 1030-1987, IEEE Guide for Specification of High-Voltage Direct-Current Systems, Part I — Steady-State Performance.)

This guide is based on a standard prepared by the International Electrotechnical Commission, (IEC), Document 22F, Performance of HVDC Systems, Part I, Steady-State Conditions. It was jointly sponsored by the DC Converter Stations Subcommittee of the IEEE Substation Committee and the Direct-Current Transmission Subcommittee of the IEEE Transmission and Distribution Committee.

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IEEE Guide for Specification of High-Voltage Direct-Current Systems

Part I Steady-State Performance

1. Scope and References

1.1 Scope. This guide provides general guidance on the steady-state performance requirements of high-voltage direct-current (HVDC) systems. It concerns the steady-state performance of two-terminal HVDC systems utilizing 12-pulse converter units consisting of three-phase bridge (double way) connections (see Fig 1). Excluded are multi-terminal HVDC transmission systems. Both converters are assumed to use thyristor valves as the main semiconductor valves and to have power flow capability in both directions. No consideration is given herein to diode valves.

This guide, which covers steady-state performance, is accompanied by companion documents for dynamic and transient performance. All three aspects should be considered when preparing two-terminal HVDC system specifications.

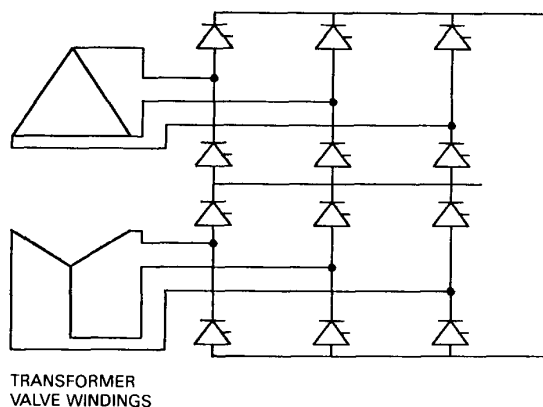
The user is cautioned to be aware of the difference between system performance specifications and equipment design specifications for individual components of a system. While equipment

specifications and testing requirements are not defined in this guide, attention is drawn to many of those that could directly affect performance specifications for the system. Also excluded from this guide are the matters of detailed seismic performance requirements. In addition, because there are many variations between different possible HVDC systems, this guide does not consider these in detail, consequently it should not be used directly as a specification for a specific project, but rather to provide the basis for an appropriate specification tailored to fit an actual system's requirements.

Frequently, performance specifications are prepared as a single package for both HVDC substations in a particular system. Alternatively, some parts of the HVDC system can be separately specified and purchased. In such cases due consideration should be given to coordination of such part with the overall HVDC system performance objectives and the interface of each with the system must be clearly defined. Data and parameters for such separate purchases must be obtained from one overall set of system studies. Typical of such parts, listed in the order of relative ease for separate treatment and interface definition are:

- (1) DC line, electrode line, and earth electrode
- (2) Telecommunication system
- (3) Converter building, foundations, and other civil work
- (4) Reactive power supply including ac shunt capacitor banks, shunt reactors, synchronous and static var compensators
- (5) AC filters
- (6) DC filters
- (7) Auxiliary systems
- (8) AC and dc switchgear
- (9) DC reactors
- (10) Converter transformers
- (11) Surge arresters
- (12) Valves and their ancillaries

**Fig 1
Twelve-Pulse Converter Unit**



(13) Control and protection systems
Items (12) and (13) are the most difficult to separate and separation of these two may be inadvisable.

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2. Outline of Steady-State HVDC System Performance Specification

A complete steady-state performance specification for an HVDC system should consider the following items:

Section	No
3.	Types of HVDC systems
4.	Environment
5.	Rated power, voltage, and current
6.	Overload and equipment capability
7.	Minimum power transfer and no-load standby state
8.	AC system
9.	Reactive power
10.	DC line, electrode line and ground electrode
11.	Reliability
12.	Control and metering
13.	Telecommunication
14.	Auxiliary power supplies
15.	Audible noise
16.	Harmonic interference — ac
17.	Harmonic interference — dc
18.	Power line carrier interference
19.	Radio interference
20.	Losses
21.	Provision for expansion to the HVDC system.

The items listed above are covered in this guide. Equipment items are often separately specified and purchased. The dc line, electrode line and ground electrode (see Section 10) are included only because of their relationships with the HVDC substations.

For the purpose of this guide, a converter station is assumed to consist of one or more converter units installed in a single location together with buildings, reactors, filters, reactive power supply, control, monitoring, protective, measuring and auxiliary equipment. While there is no discussion of the ac switching substations in this guide, ac filters and var banks may be connected to an ac bus separate from the HVDC substation as discussed in Section 16.

3. Types of HVDC Systems

3.1 General. This part of the specification should include the following basic data:

- (1) General information on the location of HVDC substations and the purpose of the project
- (2) Type of system needed, including a simple one-line diagram
- (3) The number of 12-pulse converter units
- (4) Pertinent information derived from the discussion in this section

Generally, in studies of projects of the types discussed in this guide, economic considerations should take into account the capital costs, the cost of losses, and the other expected annual expenses.

3.2 HVDC Back-to-Back Ties (Fig 2). In this arrangement there is no dc transmission line and both converters are located at one site. The valves for both converters are located in one valve hall, or even in one integrated structure. Similarly, many other items for the two converters, such as the control system, cooling equipment, and auxiliary system, may be located in one area or even integrated in layout into configurations common to the two converters. Circuit configurations may vary. Examples are given in Fig 2 (a), (b), (c), and (d). The performance and economics of these configurations differ and should be evaluated. DC filters are not needed.

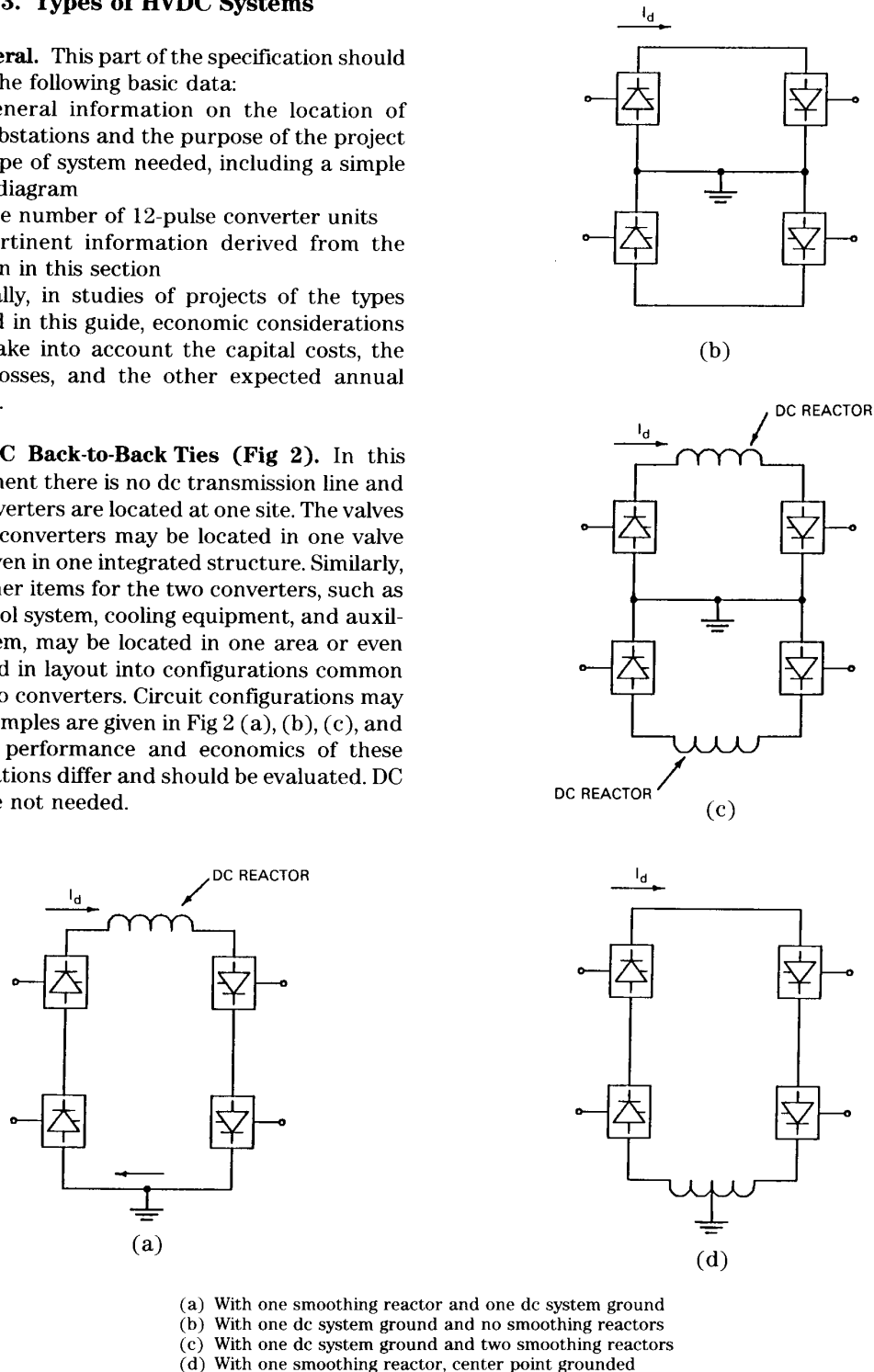


Fig 2
Examples of Back-to-Back HVDC Systems

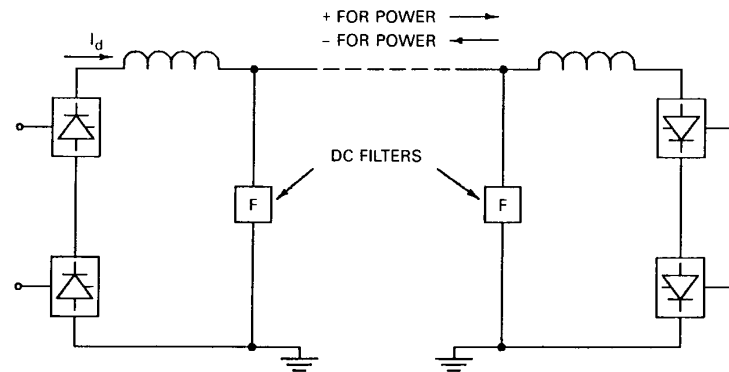


Fig 3
Monopolar Ground Return System

The voltage and current ratings for a given power rating should be optimized to achieve the lowest converter cost, including the evaluated cost of losses. As a rule then, with no line losses to consider, the voltage rating will be low and the current rating high in comparison with schemes that include overhead lines and cables. Ordinarily the user does not need to specify the direct voltage and current ratings, unless there are specific reasons to do so: for example, for compatibility with an already existing station or to provide for a future expansion. Economics dictate that each converter usually will be a 12-pulse converter unit. Where operating criteria require that loss of one converter unit will not cause loss of full power capability, large HVDC substations could be comprised of two or more back-to-back ties. For this, some of the equipment can be located in the same area or even physically integrated between the back-to-back ties for economic reasons.

3.3 Monopolar Ground Return HVDC System (Fig 3). Cost considerations often lead to adoption of a monopolar ground return system, particularly for cable transmission, which often is expensive. The monopolar ground return configuration might also be the first stage in development of a bipolar scheme. Monopolar arrangements may include one or more 12-pulse units in series or parallel at the ends of the HVDC transmission (Figs 4 and 5). More than one 12-pulse unit might be used:

- (1) To ensure partial transmission capacity during converter unit outages
- (2) To complete the project in stages
- (3) Because of physical limitations of transformer transport

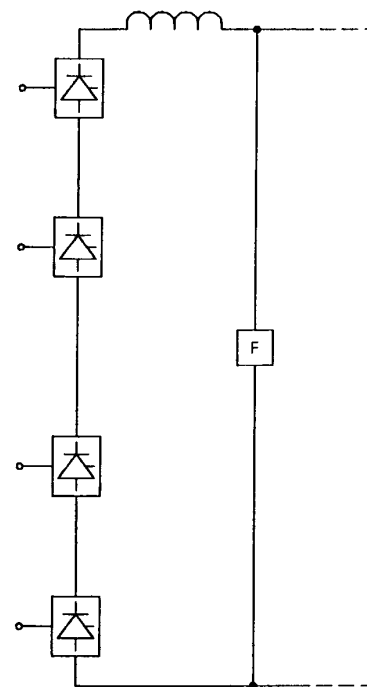


Fig 4
Two Twelve-Pulse Units in Series

This arrangement requires one or more dc reactors at each end of the HVDC overhead line or cable; these are usually located on the high-voltage side. However, the dc reactors may be located on the ground side when the resulting performance is acceptable. When the line is overhead, dc filters

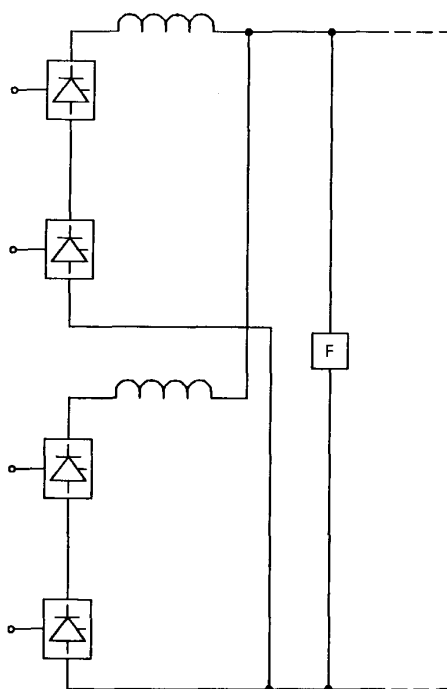


Fig 5
Two Twelve-Pulse Units in Parallel

are likely to be needed at each end (see Section 17). It also requires an electrode line and a continuously operable ground electrode at the two ends of the transmission. This involves consideration of issues such as possible interference with other underground or underwater metallic structures, and magnetic field effects.

3.4 Monopolar Metallic Return HVDC System (Fig 6).

This configuration will generally be used:
(1) As the first stage in construction of a bipolar system and if long-term flow of ground current is not desirable during the interim period, or
(2) If the transmission line length is short enough to make it uneconomical and undesirable to build electrode lines and ground electrodes, or
(3) If the earth resistivity is high enough to impose an unacceptable economic penalty

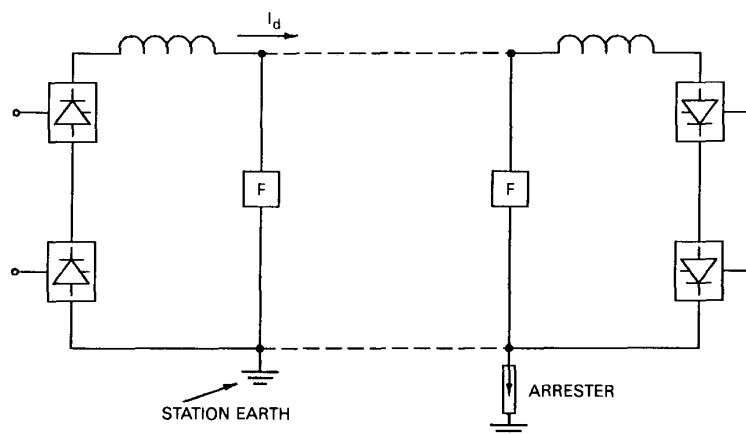
It utilizes one high-voltage and one low-voltage conductor. The neutral is tied at one of the two HVDC substations to its station ground or alternatively to the associated ground electrode. The other HVDC substation neutral is tied to its station ground either through a capacitor or an arrester, or both.

DC reactors are needed at both ends of the high-voltage conductor. However, the dc reactor may be located on the ground side when the resulting performance is acceptable. DC filters almost certainly will be needed if the dc line is overhead.

If this configuration is the first stage of a bipolar system, its neutral conductor could be insulated from the high voltage at this stage of development.

3.5 Bipolar HVDC System (Figs 7 and 8). This is the most commonly used arrangement when a dc transmission line connects two HVDC substations. Insofar as lightning performance of the line is concerned, it is effectively equivalent to a double circuit ac transmission. It reduces harmonic interference from the dc line as compared

Fig 6
Monopolar Metallic Return System



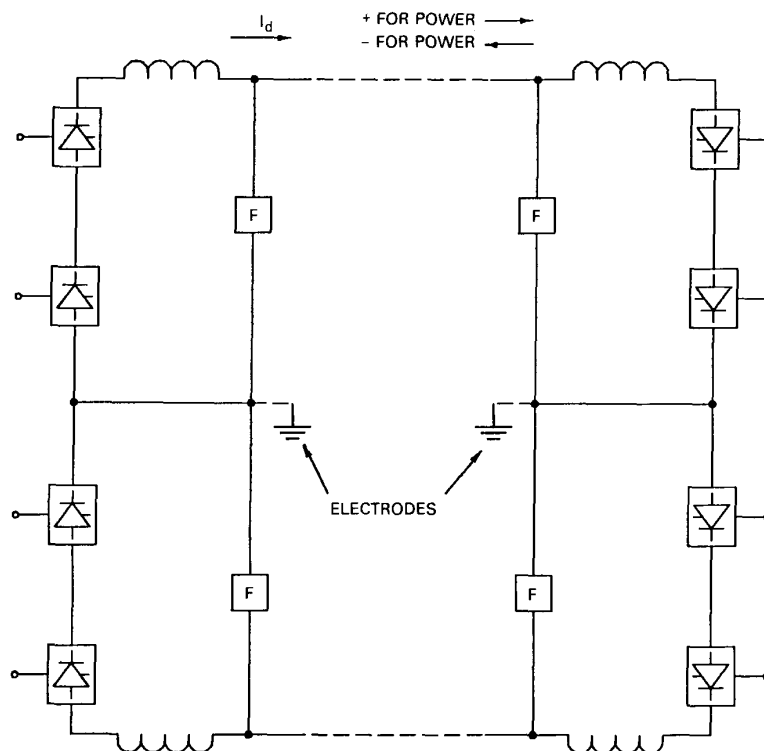


Fig 7
Bipolar System

with monopolar operation and it holds ground current flow to a small value. When combined, two monopolar ground return schemes give a bipolar system.

For power flow in one direction, one pole has positive polarity to ground and the other pole has negative polarity to ground. For power flow in the other direction the two poles reverse their polarities. When both poles are in operation, the imbalance current flow in the ground path can be held to a very low value.

This configuration offers the opportunity for a number of emergency operating modes. Consequently the requirements in 3.5.1 to 3.5.6 should be considered in the specifications.

3.5.1 During an outage of one HVDC transmission line pole, converter equipment of the other pole should be capable of continuous operation with ground return.

3.5.2 If long-term flow of ground current is undesirable and if the defective line pole still retains some less-than-normal voltage insulating capability, the bipolar system should be capable of operation in the monopolar metallic return mode (Fig 8). To switch into this emergency operating mode, the conductor of the off-pole is first connected in parallel with the ground path and then the ground path is interrupted to transfer the current to the metallic path (through the conductor of the off-pole). Load transfer without interruption requires a metallic return transfer breaker (MRTB) at one terminal of the dc transmission. When a short interruption of power flow is permitted, an MRTB is not necessary. The neutral equipment at the MRTB end of the HVDC transmission system must be insulated from ground for a somewhat higher voltage than at the other end of the system.