9

MULTITERMINAL AND MULTI-INFEED DC SYSTEMS

9.1 INTRODUCTION

HVDC transmission systems designed and operated so far are point to point systems with two terminals (converter stations). A multiterminal DC (MTDC) system has more than two converter stations, some of them operating as rectifiers and others as inverters. The simplest way of building a MTDC system from an existing two terminal system is to introduce tappings. Parallel operation of converters and bipoles can also be viewed as multi terminal operation.

Unlike in AC systems, the task of extending two terminal systems to multiterminal systems is not trivial. The complexities of control and protection increase considerably, and the use of HVDC breakers is generally required in the MTDC systems.

In recent times, with growth in HVDC transmission, there could be more than one converter in proximity feeding same load area. The operational issues of such Multi-Infeed DC (MIDC) systems are similar to those of MTDC systems. Hence, MIDC systems are also discussed in this chapter. With recent advances in the emerging technology of VSC-HVDC transmission, the application of MTDC systems is becoming more attractive than before.

9.2 POTENTIAL APPLICATIONS OF MTDC SYSTEMS

Apart from tapping of power from existing two terminal systems, there are three specific areas of applications for MTDC systems. These are listed below:

1. Bulk power transmission from several remote generating stations to several load centres. Here, each generating plant (or unit) is connected directly to a rectifier station thereby dispensing with the AC collector system. Similarly, a converter station at each load centre eliminates the need to build additional AC (or DC) lines for flexible energy exchange.

An MTDC system has several advantages over the alternative of point to point systems. For example, consider a system of two generating stations and two loads as shown in Fig. 9.1. This is a radial system with two rectifiers and two inverters. For ensuring the same level of flexibility in energy exchange, three two terminal DC links will be required in addition to a link connecting the two receiving systems, which could be AC or DC (see Fig. 9.2). This would result in extra costs for the converter stations, lines and additional power losses in increased number of conversions.

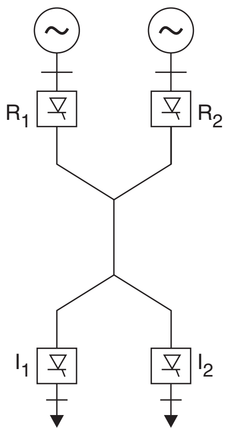

Fig. 9.1: MTDC system configuration for bulk power transmisstion

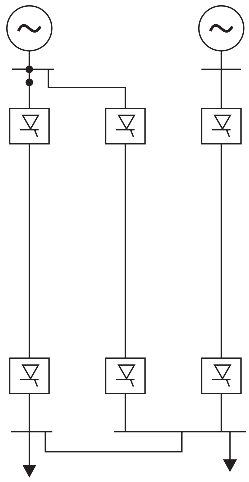

Fig. 9.2: Bulk power transmission using two terminal links

The elimination of AC collector system at the remote hydro generating stations can result in better efficiency in the operation of hydraulic turbines which are free to run at speeds independent of the system frequency.

2. Asynchronous interconnection between adjacent power systems. The advantages of asynchronous interconnection have already been described in Chapter 1. When more than two systems are involved, a MTDC system for interconnection is more flexible and economical than employing several two terminal DC links.
3. Reinforcing of an AC network which is heavily loaded. Consider an urban power system which is fed by a distant power station. It would be advantageous to arrange the power injection at more than one point so that the underlying AC network is not overloaded. This is easily achieved using a MTDC system with one rectifier station and several inverter stations (see Fig. 9.3).

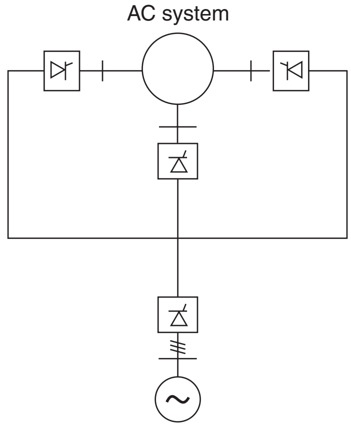

Fig. 9.3: Reinforcing of AC network using MTDC link

9.3 TYPES OF MTDC SYSTEMS

There are two possible types of MTDC systems

(*i*) Series

(*ii*) Parallel

The parallel MTDC systems can be further subdivided into the following categories:

(*a*) Radial

(*b*) Mesh

9.3.1 Series MTDC System

This is a natural extension of the two terminal system which is a series connected system. A three-terminal MTDC system is shown in Fig. 9.4. This shows a monopolar arrangement; however, a homopolar arrangement with two conductors is also possible. The system is grounded at only one point which may be conveniently chosen. If the line insulation is adequate, the grounding point can be shifted, based on changes in the operating conditions. Grounding capacitors may also be used to improve insulation coordination and system performance during transients.

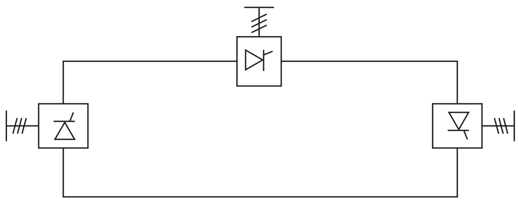

Fig. 9.4: A series connected MTDC system

In a series connected system, the current is set by one converter station and is common for all the stations. The remaining stations operate at constant angle (extinction or delay) or voltage control. In order to minimize the reactive power requirements and the losses in valve damper circuits, the normal operating values of firing angles may be adjusted using tap changer control. At all times, the sum of the voltages across the rectifier stations must be larger than the sum of the voltages across the inverter station. In case of a drop in the voltage at the current controlling rectifier station, the inverter with the larger current reference takes over the current control.

The switching in or out of a bridge is accomplished by deblocking/block and bypass in a manner similar to that in a two terminal system. The clearing of a fault in the DC line is also similar. The power reversal at a station is also done as in a two terminal system, by reversing the DC voltage by converter control.

The power control in a two terminal system is accomplished by adjusting the current while trying to maintain a constant voltage in the system. This is done to minimize the losses. However, in a MTDC series system, central control would be required to adjust the current in response to changing loading conditions. The local control of power would imply adjusting voltage at the converter station using angle and tap controls. Using only one bridge or a 12 pulse unit for the voltage control and operating the remaining bridges at minimum (or maximum) delay angle can reduce the reactive power requirements.

9.3.2 Parallel MTDC System

Here, the operating philosophy of constant voltage AC systems is extended to DC systems. The currents in all the converter stations except one are adjusted according to the power requirement. One of the terminals operates as a voltage setting terminal at constant angle or voltage. An example of 3 terminal radial system is shown in Fig. 9.5. This shows a monopolar system but bipolar arrangement would be normally used.

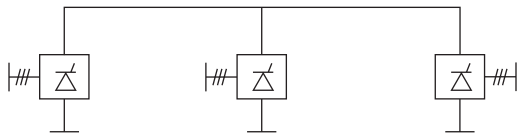

Fig. 9.5: A parallel connected radial MTDC system

A radial system is one in which the disconnection of one segment of transmission would result in interruption of power from one or more converter stations. In a mesh system, the removal of one link would not result in a disruption, provided the remaining links are capable of carrying the required power (with increased losses). Evidently, a mesh system can be more reliable than a radial system. An example of a 4 terminal mesh system is shown in Fig. 9.6.

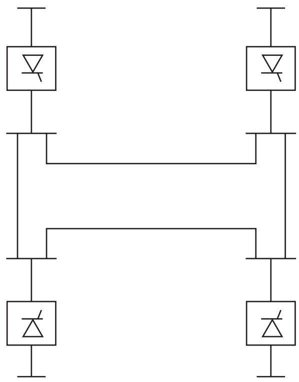

Fig. 9.6: A parallel connected mesh type MTDC system

The power reversal in a parallel MTDC system would involve mechanical switching as the voltage cannot be reversed. Also, loss of a bridge in one converter station would require either the disconnection of a bridge in all the stations or disconnection of the affected station.

9.3.3 Comparison of Series and Parallel MTDC Systems

The advantages and disadvantages of series and parallel MTDC systems are given below:

1. High speed reversal of power is possible in series systems without mechanical switching. This is not possible in parallel systems.
2. The valve voltage rating in a series system is related to the power rating, while the current rating in a parallel connected system is related to power. This would imply that for small power ratings of the tap, series connection may be cheaper even though valves have to be insulated for full voltage to ground. The parallel connection has the advantage of staged development in the converter stations by adding parallel converters as the power requirements increase.

3. There are increased losses in the line and valves in series systems, in comparison to parallel systems. The system operation in series systems can be optimized by operating the largest inverter at rated voltage.
4. Insulation coordination is a problem in series systems as the voltage along the line varies.
5. The permanent fault in a line section would lead to complete shutdown in a series connected system, while it would lead to only the shutdown of a converter station connected to the line section in a radial MTDC system. With provisions for fast identification and clearing of faults in mesh connected system, there is no disruption of power transfer.
6. The reduction in AC voltages and commutation failures in an inverter can lead to overloading of converters as current is transferred from other terminals in a parallel system. The problem is severe if the rating of the inverter is relatively small. Increased values of smoothing reactor and voltage dependent current limits can reduce the severity. However, the valve ratings would increase, resulting in increased unit costs. A recent study shows that the cost of a 500 MW DC equipment (at ± 500 kV) would be 74% of the cost of a 1000 MW DC equipment [11]. It is concluded that a practical limit to unequal inverter ratings may be 75% : 25%.
7. The control and protection philosophy in a series MTDC system is a natural extension of that in a two terminal system. However, extension to parallel systems is not straightforward. Increased communication requirements and problems in recovery from commutation failures are associated with parallel systems. HVDC breakers of appropriate rating may be required for clearing faults in the DC line or converter stations.

From the relative merits and demerits of series and parallel MTDC systems described above, it may be concluded that series connection is appropriate for taps of rating less than 20% of the major inverter terminal. Parallel connection is more versatile and is expected to be widely used as in AC systems. The first application of a MTDC system is the Sardinia-Corsica-Italy link where an existing link between Sardinia and Italy is tapped at Corsica. This is a 50 MW parallel connected tap with two 100 kV six pulse thyristor bridges connected in series. A series tap was rejected for two reasons (i) the operating current due to frequency control can be as low as 10% of the rated current. This increases the voltage rating of the series tap. (ii) A series tap in inverter operation reduces voltage at the main inverter terminal, requiring increased extinction angles. This is harmful to mercury arc valves as the probability of arc-through increases.

Commutation failure at Corsica can result in overcurrents of 7 p.u. Smoothing reactors of 2.5H are chosen to limit the overcurrents due to disturbances in the AC system.

Quebec-New England link from Radisson in Quebec to Sandy Pond in Massachusetts with a converter at Nicolet became operational in 1992 with two inverters and one rectifier of capacity 2250 MW. While it was planned to integrate an existing two terminal HVDC link (from Des Canton to Comerford) with this system to form a 5 terminal MTDC system, this plan was dropped. Other plans to introduce MTDC system [13] was also shelved. The setback to planning for MTDC was primarily due to the inadequate preparation in the development of control and protection concepts required for reliable system operation.

9.4 CONTROL AND PROTECTION OF MTDC SYSTEMS

There are several methods of control in MTDC systems. Only parallel MTDC systems are considered as these involve complexities in extending the existing control methods. The various methods suggested are reviewed below.

9.4.1 Current Margin Method

This is most widely considered and the natural extension of control philosophy in a two terminal system. One of the converter station which is operating at the angle limit (minimum α or minimum γ) determines the DC voltage (dependent on the AC voltage and the tap ratio). The remaining terminals operate as current controlling terminals. The current through the voltage setting terminal (say n) is given by

$$I_n = -\sum_{j=1}^{n-1} I_j \tag{9.1}$$

where n is the number of terminals. In the above equation, the inverter currents are treated as negative, while the rectifier currents are treated as positive. The current controlling terminals operate with a voltage margin which may become zero or negative during disturbances in the AC system. As even small disturbances can affect the voltage margin, it is necessary to maintain the current and power distribution in the system with minor changes, during the disturbances. This is possible if current control is also provided at the voltage setting terminal (or slack terminal) such that it tries to maintain the same current as before. Because of measurement errors and the requirements of a smooth transition from angle (or voltage) control to current control, the current reference at the voltage setting terminal (VST) is chosen to satisfy the following equation:

$$\sum_{j-1}^{n} I_{jref} = I_{\text{margin}} \tag{9.2}$$

where I_{margin} is positive quantity.

The converter with the lowest voltage ceiling always acts as a voltage setting terminal. The changes in the voltage setting terminal due to disturbances in the AC system are called mode shifts. Uncontrolled mode shifts can be minimized by selecting a terminal with highest short circuit ratio as the voltage setting terminal. Due to the negative resistance characteristics of the constant extinction angle control, it would be advisable to choose a rectifier terminal as VST. The magnitude of the current margin is critical as converters of lower ratings can be overloaded when operating at angle limit.

The central controller that regulates the current orders at all the converter stations is termed as Current Reference Balancer (CRB) and is shown in the analog version in Fig. 9.7. Here, the current orders calculated from local power controllers are adjusted in order to satisfy Eq. (9.2). The limits on the current orders are taken into account in balancing current references. The actual implementation of CRB can be performed by using microprocessors.

Satisfactory operation of MTDC systems requires a reliable central CRB that operates at all times. This requires reliable two way communication between a central station and each converter station. If there is loss of a station and this information is not communicated, the system operation is adversely affected. In case of loss of a rectifier station, the power transfer is interrupted by voltage collapse. In case of loss of an inverter station, other stations will be overloaded.

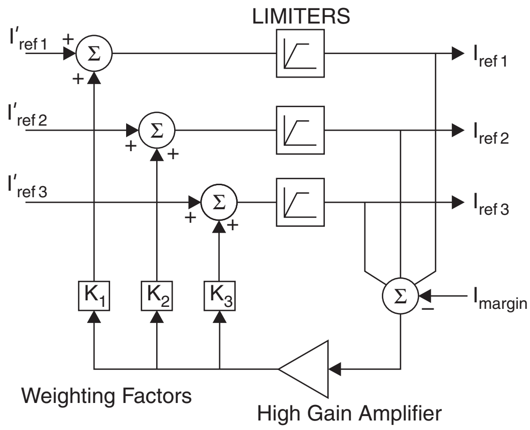

Fig. 9.7: Current reference balancer (*Source*: Reference 4)

In the current margin method, the change in the voltage setting terminal requires the operation of the tap changer in converter transformer to modify the voltage margin. This can be slow and results in less flexible control to deal with mode shifts. An improvement has been suggested by using a modified control scheme termed as voltage margin control method. In this method, all converter stations are provided with automatic voltage regulators (AVR) along with automatic current regulators (ACR). In the voltage setting terminal, AVR reference voltage is set to the rated voltage and in other stations, AVR reference voltage is set higher by an amount ΔE.

The operation of this control technique is illustrated by Fig. 9.8 which represents the control characteristics for a MTDC system with two rectifiers and two inverters. When the voltage setting terminal is shifted from INV2 to REC1, the voltage margin ΔE is added to the reference value at INV2 and subtracted from REC1. The voltage margin control method is also not free from the requirements of the centralized control and fast communication.

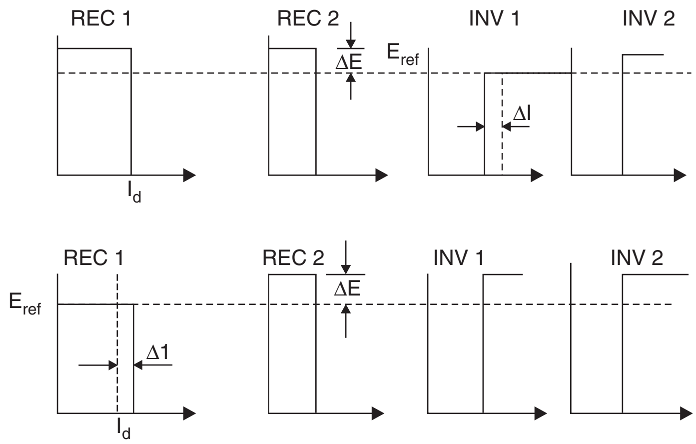

Fig. 9.8: Operation with voltage margin control method (a) VST = INV1 (b) VST = REC1

In order to facilitate the operation of MTDC systems even when there is failure of communication system, the following modifications to the basic current margin method of control have been suggested:

1. Voltage Limiting Control [1]
2. Use of Decentralized Current Reference Balancer (DCRB) [9]
3. Two ACR (Automatic Current Regulator) method [6].

These are discussed below.

9.4.2 Voltage Limiting Control

In the voltage limiting control method, the rectifier and inverter characteristics are arranged as shown in Fig. 9.9. The loss of a rectifier station does not have any significant effect on the system operation even in the absence of communication failure. The inverter currents are reduced in order to prevent voltage collapse. Also, the loss of an inverter station (operating on current control) would not overload the voltage controlling inverter because of its voltage reserve.

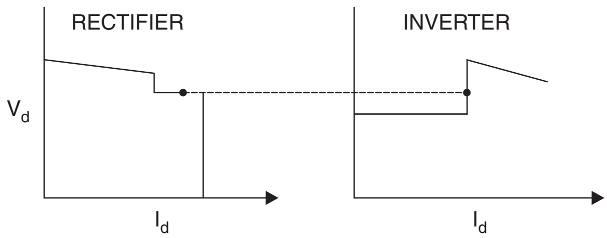

Fig. 9.9: Operation with voltage limiting method

The drawbacks of this scheme are (*i*) the disturbance in the AC system connected to an inverter station can result in other inverters getting unloaded (due to drop in the DC voltage). This may cause adverse effect on the AC systems supplied by healthy inverter stations, (*ii*) Two or more terminals can operate in the voltage controlling mode forcibly, in the case of loss of a terminal resulting in indeterminate distribution of currents in those terminals, (*iii*) Currents during DC line fault or commutation failure are likely to be higher without additional measures.

9.4.3 Decentralized Current Reference Balancing

This method is similar to the one described by Foerst et al. [1] without CRB and which operates on the current and voltage characteristics. DCRB is designed to allow rapid recovery of MTDC system operation following severe disturbances which require a momentary rundown of the DC system. The DCRB is supposed to permit the system recovery without coordinated centralized control of converters and even if one or more of the terminals is removed from service due to the disturbance.

The operation of the DCRB is illustrated with the help of a 3 terminal system with two rectifiers and one inverter. In the case of loss of one rectifier station, the characteristics of the remaining two converter stations do not intersect (see Fig. 9.10).

The object of the DCRB is to adjust the converter control characteristics around a preselected voltage level V_o in the manner indicated in Fig. 9.10. The slopes of the balancing characteristics σ_r and σ_i determine the relative adjustments that must be made to the current orders. In DCRB, the minimum and maximum current limits are preselected. The intersection of the balancing characteristics determines the steady state operation of the converters following a disturbance. The normal post-disturbance characteristics are also shown in Fig. 9.10 by solid lines. The current order required for this is locally determined by the balanced current and the specified current margin. In case of a rectifier, a fraction of the current margin would be added to the balanced current, while in the case of an inverter, a fraction of the margin would be subtracted.

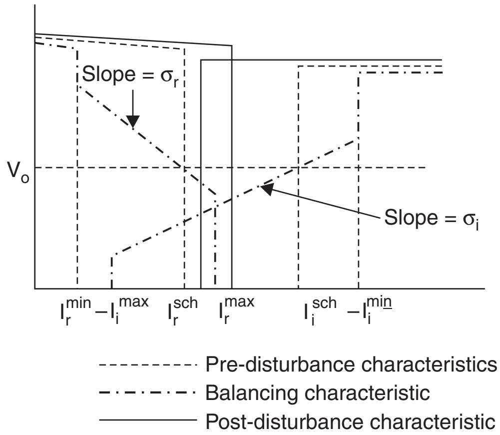

Fig. 9.10: Decentralized current reference balancing method

The slopes of the balancing characteristics along with the voltage level V_o are chosen, based on the considerations of voltage limits and magnitude of the variations in the DC network voltages during the balancing period.

Simulator studies have been carried out to demonstrate the functioning of DCRB and it is claimed that this technique is quite satisfactory in rapid restarting of the system with communication failure.

9.4.4 Two ACR Method

In this method, each-converter is provided with two automatic current regulators (ACR) and one voltage regulator. The rectifier and inverter control characteristics are shown in Fig. 9.11.

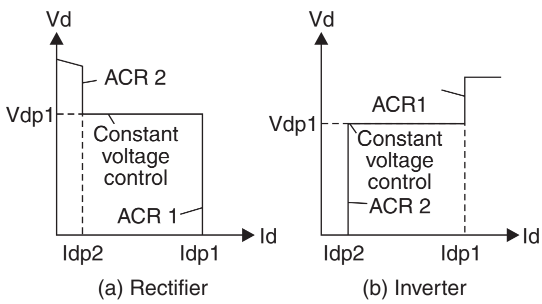

Fig. 9.11: Static $V_d - I_d$ characteristics of a converter in two ACR method (a) Rectifier, (b) Inverter

During the normal mode of operation, the rectifier station with the lowest voltage reference or the inverter station with highest voltage reference acts as voltage setting terminal (see Fig. 9.12). The remaining converter stations operate under the control of ACR1. I_{ref1} of the voltage setting terminal is set larger than the operating current (determined by other converters) by the current margin. The ACR2 operates during a contingency and its order can be fixed at the minimum operating current of the inverter.

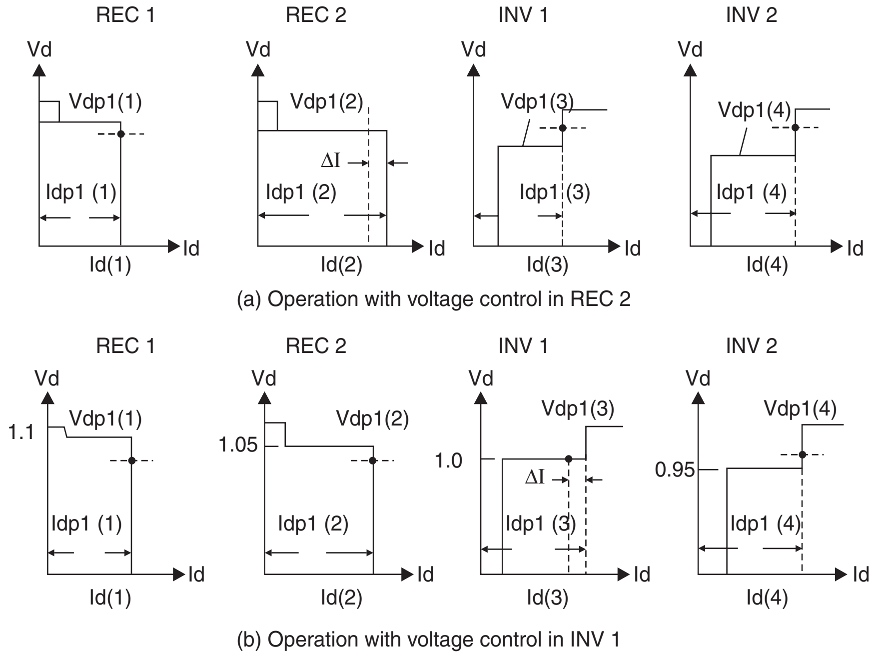

Fig. 9.12: Static V_d – I_d characteristics of a 4 terminal system (a) Operation with voltage control in REC2 (b) Operation with voltage control in INV 1

Without additional measures, the inverter may not be able to recover from a commutation failure. Voltage dependent current order limit (VDCOL) is introduced to overcome this problem. The operation of a 4 terminal system both during normal conditions and when one of the converter stations is shutdown, is shown in Fig. 9.13.

The rectifier with the highest voltage order and inverter with lowest voltage order are always controlled by ACR1, thus resulting in small power deviations during a disturbance. This can be utilized to prevent shutdown of a base station (such as a nuclear power station) or prevent interruption of supply to a critical AC system.

It is claimed that the two ACR method permits the use of DC circuit breakers to isolate a line fault or converter fault without coordination with control. The system operation following a disturbance is optimized by modifying the current orders from central controller.

The implementation of the controller is discussed in some detail in [6,12] using control block diagrams. The performance of this control technique has been studied using digital dynamic simulation and HVDC simulator.

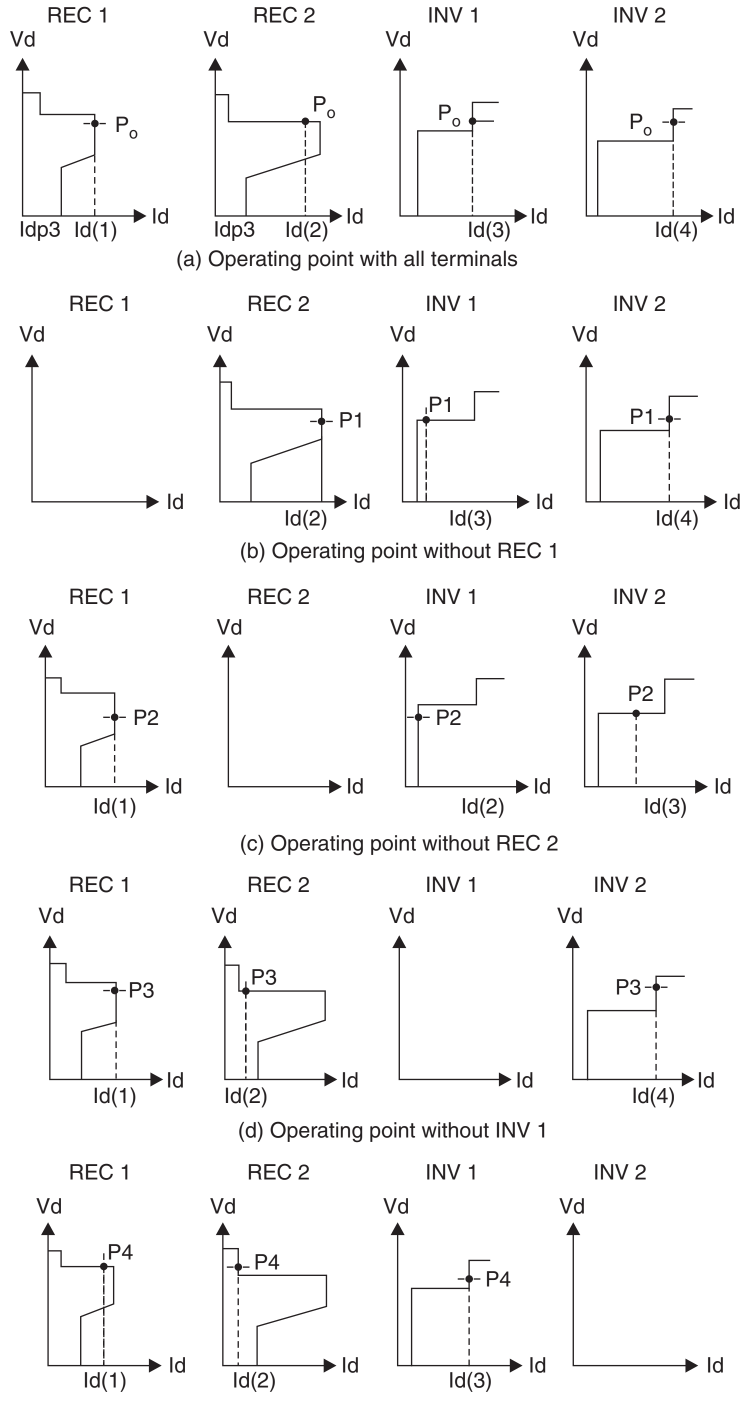

Fig. 9.13: (a) Operating point under normal conditions (b) Operating point without REC 1 (c) Operating point without REC2 (d) Operating point without INV 1 (e) Operating point without INV 2

9.4.5 Protection of MTDC Systems

One of the issues under discussion regarding MTDC system operation is the evaluation of protection requirements and coordination with control.

Conceptually, the system can be shut down following a fault in DC line or converter station and the faulted component isolated using high speed disconnect switches. The system can be restarted after adequate time for deionization of the arc path (in case of short circuits).

System reliability considerations dictate the need for fast clearing of fault with minimum disturbance to the healthy parts of the system. The DC breaker ratings can be minimized by utilizing the intervention of fast current controls to reduce the magnitude of the fault currents.

The detection of DC line faults gets complicated in a mesh system. A major problem is the large drop in the DC voltage even for distance faults. This requires fast detection and clearing of faults to maintain power transfers. Differential type of protection or directional sensitive measurements of the currents can be used to locate the fault. Communication would be required in both methods.

DC switches would be required primarily for parallel MTDC systems and particularly in mesh systems to utilize the improved security provided by such configurations.

9.5 STUDY OF MTDC SYSTEMS

The planning, design and operation of MTDC systems require detailed study using simulation tools. The new control and protection concepts have been formulated using HVDC simulators. The performance of the controllers are judged not only under normal conditions with changing load conditions, but also under disturbances caused by faults in the AC system and DC lines.

Some of the typical problems that have been considered for study are as follows:

1. Operation of small inverter taps connected to weak AC systems
2. Integration of existing HVDC converter stations in MTDC systems without major modifications in control
3. Evaluation of communication, reactive power and filtering requirements
4. Security of power transfer without fast communication links
5. Power and reactive power modulation strategies in MTDC systems.

Some of the conclusions from studies carried out [8] indicate the type of problems that can be anticipated in the operation of MTDC systems connected to weak AC systems.

1. Large smoothing reactor may be required to help in the recovery of a small inverter from AC faults.
2. The speed of recovery of the entire MTDC system depends upon the recovery of the small tap, if it is still connected to the system following clearance of a fault.
3. It is necessary to consider the effect of mode shifts and develop additional protection sequences, particularly for faults in DC line.
4. The provision of VDCOL at each rectifier is beneficial and its characteristics have to be adjusted suitably.

With a good knowledge of HVDC controls and their accurate modeling, HVDC simulators (both physical and digital) can be used to analyze problems and search for solutions. For example, during the tests for parallel operation of the two bipoles in Nelson River HVDC transmission system in Manitoba, Canada, in 1985, it was observed that there was a current oscillation of 6 Hz in the two inverters although the current in the two rectifiers was steady. The V_d–I_d characteristics for the rectifiers and the inverters are shown in Fig. 9.14 (*a*) and (*b*) respectively. The operating voltage is also shown here, which indicates that the inverter 2 operates in the mode of current error dependent gama (γ) control mode. In simulating the system using EMTDC program with a generic modeling of the controls, it was not possible to identify the source of the (oscillation) problem. However, from the knowledge of the actual valve group controller (provided by the manufacturer) it was possible to identify the source of the problem to a particular $K/(1 + sT)$ type delay block in the actual controller. By decreasing the time constant T from 22 ms to 3 ms, it was possible to eliminate the current oscillation problem in the real system. Incidentally, the digital program also allows one to experiment and determine how the oscillations are initiated from a stable operating point. In this case, changing the tap ratios from the set point initiated the low frequency current oscillations [15].

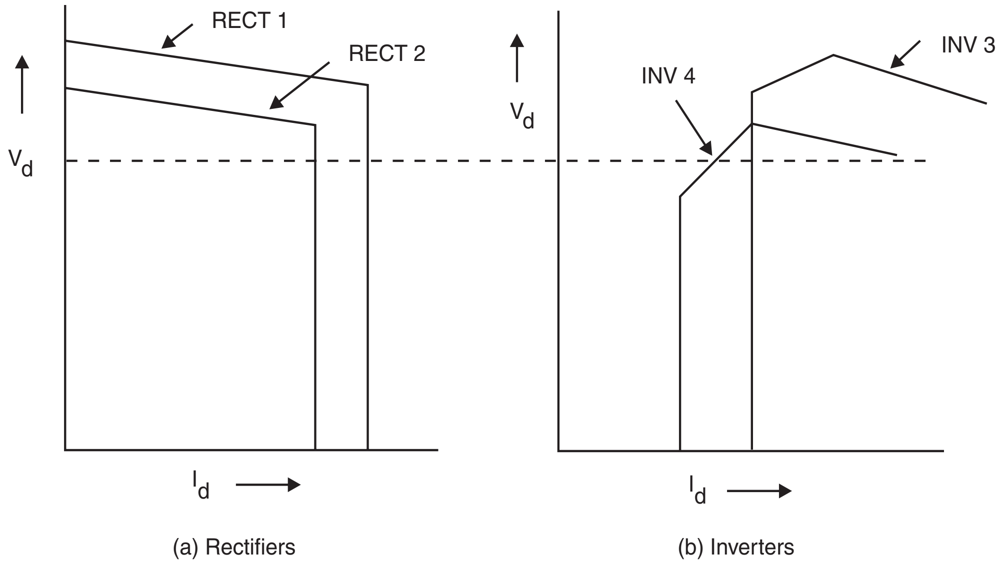

Fig. 9.14: Multiterminal characteristics

A HVDC simulator study of a four terminal MTDC system indicated the possibility of adverse interaction between the control and DC network dynamics. This can result in multiple mode shifts in rectifiers following a remote three phase fault at a rectifier [23]. A commutation failure at the small inverter results in the total DC current (from the rectifiers) diverted into the faulted inverter due to voltage drop in the inverter caused by the commutation failure. The transient current is even higher due to the discharge of line capacitances. The peak current can be limited partly by the use of higher smoothing reactor. However, it is difficult for the inverter to recover even when the AC system is strong. The system recovery is made possible by initiating Force-Retard (FR) on the rectifiers (increasing α to values above 90°, say 145°) as done in the case of DC line faults in a two terminal system. FR can be initiated without tele-communications since the collapse of the DC voltages at the rectifiers can be used as signals for the protective action. After a pre-determined time, the converter firing angles are returned to their normal values at a controlled speed. However, there is still a danger of a subsequent commutation failure at the small inverter due to current overshoots. The characteristics of a VDCOL at the inverter have to be carefully chosen to avoid this problem.

9.6 MULTI-INFEED DC SYSTEMS

Although multiterminal DC systems are not yet common, it is possible that more than one HVDC link feeds into the same load area [16-18]. In reference [16], an attempt was made to answer the question of possible limits of HVDC power supplied to an AC system. The author identified two major issues that can affect the limits–(*i*) current harmonics injected by the converter and (*ii*) compensation of reactive power. The first issue is closely connected with the generation of non-characteristic harmonics and the possibility of harmonic instability (which is essentially the phenomenon that results in the sustained non-characteristic harmonics due to AC-DC system interactions). According to [16], this is mainly dependent on the frequency dependence of the AC system (including the AC filters) impedance viewed from the converter terminals and not necessarily dependant on the Short Circuit Ratio (SCR). Harmonic instability can occur even at higher SCR. Incidentally, there was also a belief earlier that the problem of harmonic instability was completely solved after the development of Equidistant Pulse Control (EPC) scheme of firing pulse generation. However, this assumption is also not valid. There could be adverse harmonic interactions even with EPC.

The second issue of reactive power compensation is related to the problem of voltage instability and voltage flicker (caused by switching a filter or capacitor bank). This is primarily dependent on the SCR and the problem can be aggravated at low SCR. There is also the problem of overvoltages caused by load rejection which can be tackled by applying SVC or STATCOM for reactive power compensation.

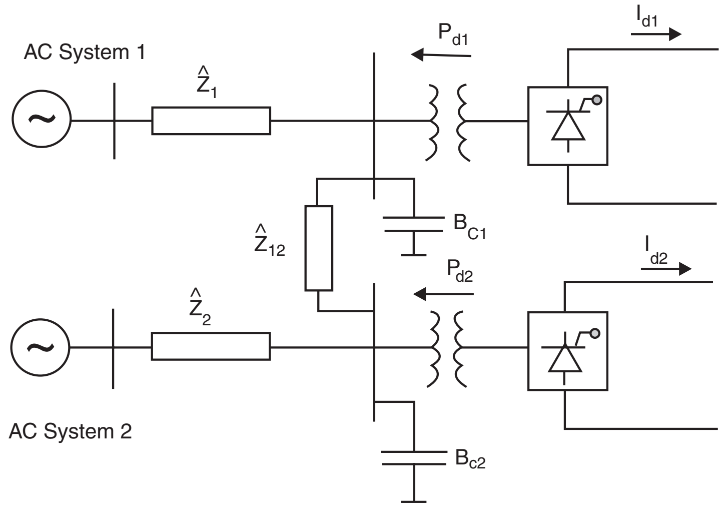

Fig. 9.15: A multi-infeed system

References [17] and [18] formulate the problem of MIDC systems by considering the system shown in Fig. 9.15. The AC system shows an equivalent circuit based on Thevenin impedances.

The interaction between the two HVDC converters that may belong to two different HVDC links can be ignored if the impedance Z_{12} is large compared to Z_1 or Z_2. Thus, in a large network with several embedded DC links, the DC control design can be made based exclusively on SCR at the AC connection point, without considering the other DC links, if the transfer impedances between the commutation busbars are high [18].

The control strategies at the rectifier and the inverter have a bearing on the voltage stability of the system. Current control rather than power control at the rectifier improves matters while constant DC voltage control at the inverter is much better than constant extinction angle control.

The interactions among inverters in close proximity requires coordinated design of controllers. The voltage distortions caused by persistent commutation failures in one inverter, also affect the other inverter. The VDCOL characteristics of one inverter that decide the speed of recovery following DC faults can affect the voltage at the inverter.

The control and protection in MIDC systems must be carefully designed to avoid adverse interactions. Interestingly, a BTB link interconnecting two asynchronous AC systems can introduce low frequency current oscillations in a nearby rectifier [23]. For example, even if the nominal frequencies of the AC systems interconnected by a BTB link are same, there can be variations in the frequencies. If one frequency is 50 Hz while the other is 49 Hz, the DC link with 12 pulse converters will have voltages of frequencies 600 Hz and 588 Hz. This can result in the AC bus voltages having a 12 Hz frequency component and the current controller in the rectifier in proximity can react to this. Such oscillations have been observed in HVDC simulator studies [23].

9.7 MTDC SYSTEMS USING VOLTAGE SOURCE CONVERTERS

The VSC based HVDC transmission is ideally suited for multiterminal operation due to the following advantages:

(1) The power reversal in a converter is achieved by current reversal which is easily arranged by control action without having to use mechanical switches to reverse the polarity of the converter connections to the conductor in a parallel MTDC system.

    In line commutated converters, the power reversal requires voltage reversal and this implies that the converter has to be connected to the conductor of the opposite polarity.

(2) There is no problem of commutation failures in an inverter based on VSC. A VSC based inverter can even supply passive loads.

(3) The use of Pulse Width Modulation (PWM) eliminates low frequency harmonics and simple AC filters can be supplied.

(4) There is no need for reactive power compensation of VSC. Actually, a VSC can supply reactive power and can help in the control of the AC voltage.

However, it is to be noted that harmonic interactions can occur in VSC also and the choice of the circuit parameters and control design must consider this problem. However, the problem is likely to be less complicated compared to LCC.

One of the drawbacks with VSC is the problem of handling DC faults. Since DC capacitors can discharge into the fault, the protection must disconnect the converter from the line or block the firing pulses to the converter and trip the converter. In the case of LCC rectifier, the action of forced retard (FR) can help in clearing the fault by deionization of the fault arc. This difference in the action of LCC and VSC rectifiers has prompted the application of hybrid MTDC schemes [20], with LCC rectifiers and VSC inverters. Of course, when a terminal has to operate in either of the two (rectifier or inverter), obviously VSC is the choice.

Note that in the case of cable transmission, the probability of DC faults is less (although any cable fault can be non-self healing).

In urban areas, the increasing demand of power is generally met by importing from distant generators. The application of DC transmission has the advantage of not contributing to short circuit levels (the increase in short circuit levels would require upgrading the ratings of switchgear). Thus, introduction of MTDC systems based on VSC in urban areas is quite attractive.

9.8 SUMMARY

Although the concept of MTDC systems has been discussed for a long time, the implementation has been very limited. The complexities in control and protection have deterred many utilities from experimenting with MTDC system operation. Introduction of MTDC systems requires extensive R & D activities to solve the problems associated with MTDC systems. Meanwhile, it has been recognized that MTDC systems have similarities with MIDC systems in terms of operational issues. It is anticipated that emerging technology of VSC-HVDC transmission can help solve many of the problems and encourage utilities to introduce MTDC systems.

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