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A DROOP CONTROL DESIGN FOR MULTITERMINAL HVDC OF OFFSHORE WIND FARMS

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***Abstract*— To automatically coordinate between different converters in a multiterminal HVDC (MTDC) system, droop control techniques have been adopted as an effective means without the need for fast communications between units. The droop control design is mainly dependent on the line resistances. Converting existing ac transmission lines to an ex- tended multiterminal three-wire bipolar HVDC system can be considered a cost-effective way to interconnect dispersed offshore wind farms to onshore ac grids instead of building new bipolar HVDC systems. This paper shows that the equivalent resistance of a three-wire bipolar system changes based on the operational mode. Two types of MTDC systems are considered in this work, namely, radial parallel and meshed parallel systems. Different simulation studies have been conducted to validate the results of the presented analysis. The modification to droop control design of an MTDC equipped with a three-wire bipolar system is then presented to tackle this resistance variation with the operating condition.**

***Index Terms*— offshore wind power, three-wire bipolar HVDC, Droop control, multiterminal HVDC.**

I. Introduction

The multiterminal VSC-HVDC system can connect multiple offshore wind farms with conventional grids via undersea cables. The control of the VSC in MTDC system is typically based on appropriate voltage current characteristics suitable for the operating mode [1]. Different control methods are covered in the literature, such as voltage margin, master slave, and dc voltage current droop control. Among these control techniques, the dc voltage current droop control is preferable as it enables power flow control without the need for fast communication between converters which is a significant advantage over other control methods [2]. The design of the corresponding droop constants is successfully illustrated in. The dc voltage current droop control approach has been ex-tensely addressed in literature dc voltage droop control is used for balancing power in dc grid considering dc line drops. In offshore wind generators are used to provide inertia and primary frequency control to the onshore gridby means of communication-free control methodology [3]. Thismethodology is based on dc voltage control using power andfrequency droops at the onshore converter and frequency regulation at the offshore converter. A droop control scheme for MTDC is presented .The droop gains are selected based on frequency response performance characteristics such as the desired voltage errors [4]. However, the transmission efficiency, which is a significant operational factor in transmission systems, was not considered in the design of the aforementioned droop gains. Although, the control method presented in is based on optimal power flow in MTDC in order to minimize line losses, the need for an effective communication system may limit its application. In it was also shown that the droop gain design is mainly dependent on the line resistances [5] [6]. A methodology to design the required droop controller to ensure maximum efficiency in the HVDC system while avoiding communication between different converters was presented. It has been shown that, if the power is shared between offshore feeders in an inversely proportional fashion to their resistances, the required voltages at the grid side converters will be the same. This condition yields a minimum system copper loss [7].

II. RELATED WORKS

A. *Three-Wire Bipolar HVDC Equivalent Resistance*

Here, the value of the equivalent resistance of the three-wire bipolar HVDC system is calculated for the two possible operational modes (two-wire and three-wire modes). In case of the three-wire mode the dc equivalent circuits of the system, where each line is represented by an equivalent resistance.

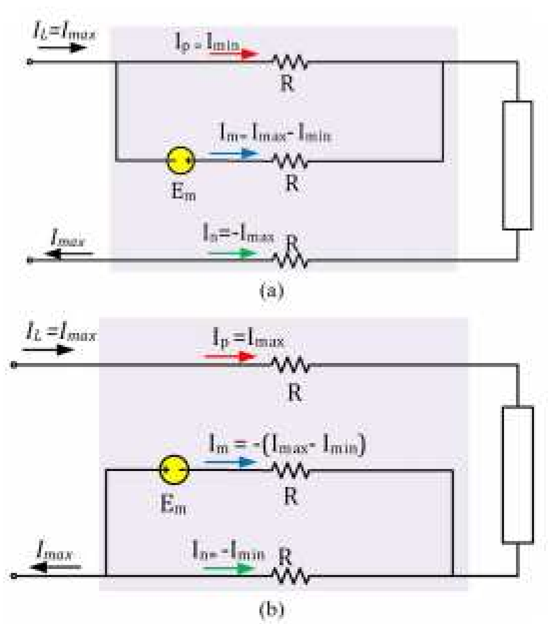


Fig: 1 Steady-state equivalent circuit of the three-wire bipolar transmissionLine when (a) and are turned on and (b) and are turned on.

A controlled voltage source is connected in series with the modulating pole to emulate the injected voltage by the CRC, which compensates for the voltage difference. At any instant, the modulating pole may be connected in parallel either to the positive or the negative poles. Hence, the voltage across the parallel lines should be equal.

$$R_{eq\ m} = \frac{RI_{\min}}{I_{\max} - I_{\min}} = R\frac{(2-\sqrt{3})I_{\max}}{(\sqrt{3}-1)I_{\max}} = 0.366R$$

(1)

$$R_{\text{line}} = R + R \,\|\, 0.366R = 1.268R.$$

(2)

The ratio of the power transferred by the three-wire bipolar HVDC to the power transferred using conventional bipolar HVDC is 1.366. Thus, the power transfer of the three-wire bipolar structure can be increased by 36.6% over the regular bipolar structure without exceeding the system thermal limit.

$$P_{3w} = 2V \times 1.366\ I_{\text{limit}}.$$

(3)

In power-sharing mode, the converters are operating with a dc voltage droop characteristic defined by the droop gains, provided that their currents are less than their maximum limits. Thus, the selected droop gains affect the power transferred by each converter. In the following subsections, dc voltage current droop control is employed using a three-terminal radial parallel HVDC system.

B. Droop Gain Design

For the sake of simplicity, a three-terminal HVDC system will be considered to explore the proposed concept in radial parallel systems. In this system, the power generated from an equivalent offshore wind turbine is transmitted to the onshore side via an undersea cable. The total power is then divided between lines 1 and 2 that transmit power to the grid through two VSCs. Line 1 is assumed to be a three-wire bipolar line while line 2 is a conventional bipolar HVDC line. In the proposed droop gain control design methodology, the effect of resistance change on the droop gain selection to ensure certain power sharing between the two lines is considered.

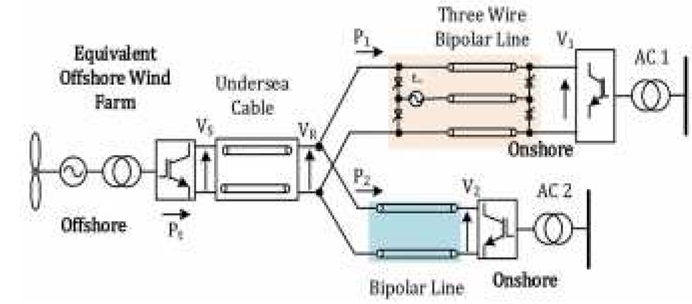


Fig: 2 offshore wind farm grid-integration using a three-terminal HVDC system.

C. Simulation Results for Radial Parallel MTDC System

Based on the multiterminal VSC-HVDC system given IN MATLAB/SIMULINK model is built to simulate the whole system. The transmission lines and cables are simulated using the built in models under the Sim Power Systems toolbox. To avoid long simulation time, averaged models are used for the VSCs to simulate the power converters. For the grid side converters (VSC1 and VSC2), dc voltage controllers are usually employed under power sharing.

TABLE I
RADIAL PARALLEL MTDC SYSTEM PARAMETERS

	Line 1 (TWBL*)	Line 2 (BL**)	Cable 3
R (Ω/km)	0.044	0.0283	0.0018
L (mH/km)	0.37	0.347	0.1175
C (nF/km)	32.3	34.5	808
Length (km)	100	100	50
Conductor thermal limit (A)	1500	2000	4000

* Three-wire bipolar line.
** Bipolar line.

A design case study based on the three-terminal HVDC system shown in Fig. 5 is carried out. The system parameters are given in Table I. Both grid-side converters are rated at 500 kV/1000 MW, which gives a maximum dc line current for each converter of 2000 A. Hence, the maximum undersea cable current will be 4000 A. Line 1 is a three-wire bipolar line. For line 1, the conductor thermal limit current is assumed 1500 A. For currents less than this limit, the line operates in the two-wire bipolar mode; however, for currents above this limit, three-wire bipolar mode is activated. The maximum current carrying capacity will be then equal 1.366 1500 2049 A, which approximately equals the current rating of converter 1. The thermal limit of line 2 is 2000 A.

D. POBLEM STATEMENT

As the MMC is used in high voltage and high power applications, the switching frequency must be limited for safe operation of IGBTs. At such sampling-to fundamental low frequency ratios, the dynamic performance of the control loops, i.e. AC side current control, becomes a challenge. Reduced switching frequency algorithms of current control should be used. The applied in HVDC system will be investigated in this thesis, so AC side current control of will also be studied and the control system mainly has two functions:

- Independent active and reactive power control following the desired values.
- Regulation of the dc-bus voltage at its nominal value.

Motivated by the promising future of the MMC and HVDC system for offshore wind power, as well as the technical challenges introduced above, this thesis will focus on the current control of MMC in HVDC systems especially on the wind farm side. The current control methods introduced in existing academic papers are reviewed first and some of the algorithms are simulated and compared.

III. PROPOSED SYSTEM

A. *Meshed Parallel MTDC Systems*

The MTDC system will be considered to explore the proposed concept in meshed parallel MTDC networks. In this system, the power generated from wind turbines (wind extracted wind power between ac grids (grid 1 and grid 2) with a desired ratio, which is controlled by the drooping gains at the grid side buses.It is worth nothing that the droop gain selection should be updated based on continuous online measurements of all currents. This entails an effective fast communication between differentunits, which is one of the main drawbacks of the meshed parallel systems. For radial systems, the droop gain selection can be done offline and does not depend on the input current variations.

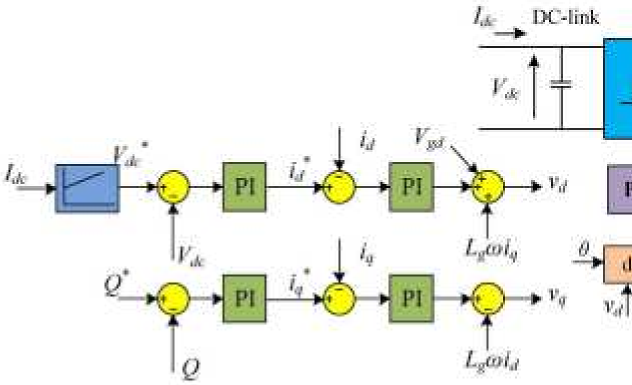


Fig: 3 Droop Control Design for Multiterminal HVDC of Offshore Wind Farms

The meshed parallel system given in is simulated with the same modelling assumptions given in Section.

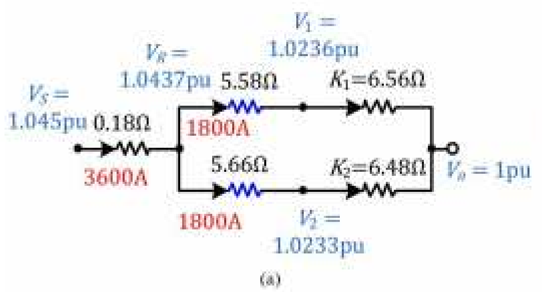


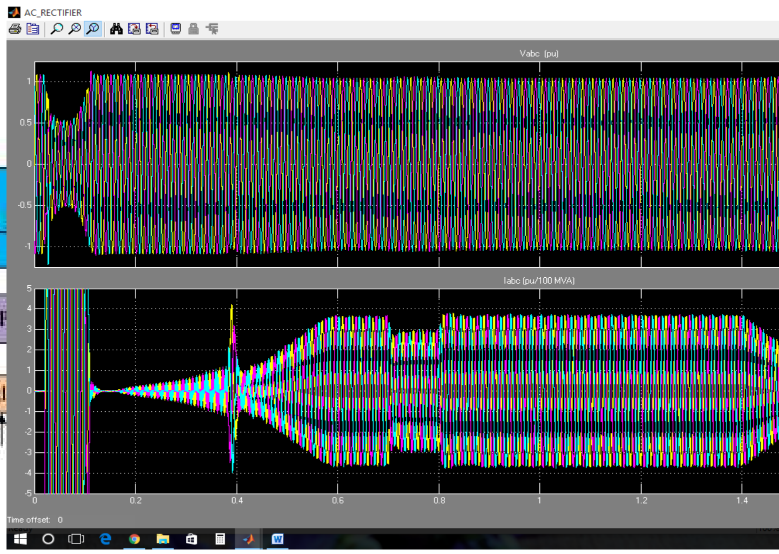
Fig: 4 DC power flow for the simulated case study. (A) Three-wire operational model. (B) Two-wire operational mode.

The same controller given in is used to control the grid side voltage converters. As mentioned in the previous subsection, the droop gain design in meshed system not only depends on the network topology, but also is affected by the input/output currents injected to the system. The cases given by for two-wire operation and for three-wire operation are simulated. In the simulated case study, the power injected by the wind side converters is assumed to vary in steps such that the wind side currents and are first assumed zero. At 5 s, and currents are increased to 1000 and 600 A, respectively, which is the case represented by (two-wire mode). At 10 s, they are increased again to 2000 A and 1000 A, which represents the case given by shows the injected grid currents, which are both equal to 800 A, and then after 10 s they are both equal to 1500 A. The corresponding bus voltages are given by. The line currents of different poles of the TWBL are .Before 10 s, this line is operating under its two-wire mode, while it is switched to the three-wire mode when the input wind currents are increased after 10 s. The corresponding equivalent line currents of other connecting lines between buses.

IV. RESULT AND DISCUSSION

Converting existing ac transmission lines to an extended multiterminal three-wire bipolar HVDC system can be considered a cost-effective way to interconnect dispersed offshore wind farms to onshore ac grids instead of building new bipolar HVDC systems.

A. *WAVEFORM*



. To automatically coordinate between different converters in a multiterminal HVDC (MTDC) system, droop control techniques have been adopted as an effective means without the need for fast communications between units. The droop control design is mainly dependent on the line resistances. This paper shows that the equivalent resistance of a three-wire bipolar system changes based on the operational mode. The modification to droop control design of an MTDC equipped with a three-wire bipolar system is then presented to tackle this resistance variation with the operating condition. Two types of MTDC systems are considered in this work, namely, radial parallel and meshed parallel systems. Different simulation studies have been conducted to validate the results of the presented analysis.

V. CONCLUSION

The equivalent line resistance is approximately reduced by 36.6%. The droop gain design is carried out for both radial parallel and meshed parallel MTDC systems. This paper presents a methodology to design a voltage–current droop controller for an MTDC system with a three-wire bipolar HVDC transmission line. It has been shown that switching from two-wire mode to a three-wire mode of the three-wire bipolar line affects the equivalent line resistance.In case of radial MTDC systems, the line currents, mainly depend on the line resistance (in power-sharing mode), the corresponding droop gains of the VSCs should be updated to ensure distributing of current with the desired sharing ratio. However, their values can be obtained offline. On the other hand, a meshed MTDC system necessitates an online algorithm to update the droop gain constants with any variation in input/output current magnitudes and/or line resistance variation.

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