Power Flow Analysis in HVDC Grid System

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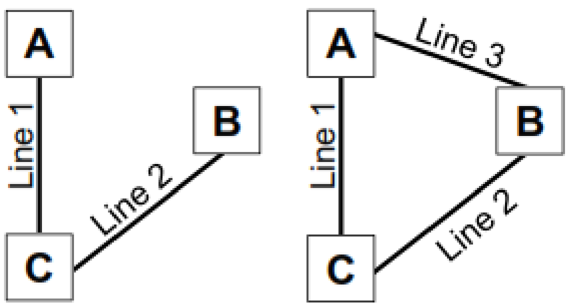
ABSTRACT: The DC grid has less degrees of freedom when compared to AC grid which restricts the power flow ability. To overcome the situation an auxiliary DC voltage controller can be installed which will vary the voltage at its terminal in order to provide additional degrees of freedom. Benefits of adding such controller on DC line is hence studied in this paper. The region of operation of a system with and without controller is compared. Three terminal system with three transmission lines and four terminal system with five transmission lines are studied and region of operation is compared in this paper.
KEYWORDS – DC grid, auxiliary dc voltage controller, power flow analysis, 3-terminal system, 4-terminal system

I. INTRODUCTION

Multi terminal HVDC grid has been an interest since the earlier days of DC transmission. Developing a DC grid would allow easy connection of wind turbines and solar panels offering flexible power transmission. Multi terminal HVDC is considered in super grids because the transmission routes include submarine cable crossings along the Atlantic seaboard of Europe and the Mediterranean Sea which are more economical by HVDC. DC cables are more suitable for underwater and underground transmission which applies for offshore wind farms and for urban transmission. Three main converter topologies for HVDC system are the thyristor-based converter, also called traditional HVDC is used for bulk power transmission system, voltage-source converter (VSC) based on IGBTs and the third topology is a new configuration based on multi-level converter. However, it is required to evaluate if such improved system would give sufficient benefits to justify its cost. The objective of this paper is to evaluate the benefits of an auxiliary dc voltage controller inserted on a transmission line using 2 case studies. Initially, the dc grid is composed of 3 terminals and a system with 4 terminals is also explored.

II. SYSTEM ANALYSIS

In the 3-terminal system shown in Fig. 1(a), terminals A and B are fixed-power terminals and terminal C is the voltage regulator. The scenario can be an interconnection between two countries via submarine dc cables (link A-C) and a wind farm is connected onshore to C by link B-C. In the perspective of developing a dc grid, a third line can be installed between terminals A and B as shown in Fig. 1(b).



(a) 2-Line dc grid. (b) 3-Line dc grid.

Fig. 1. DC grid configurations with 3 terminals.

The 3-line system shown in 1(b) is upgraded with an auxiliary dc voltage controller as shown in fig.2

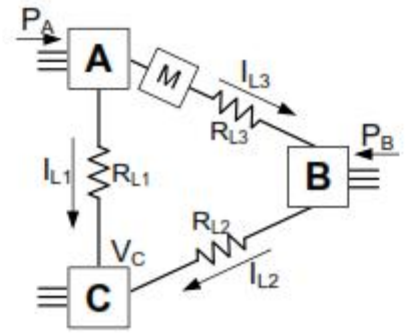


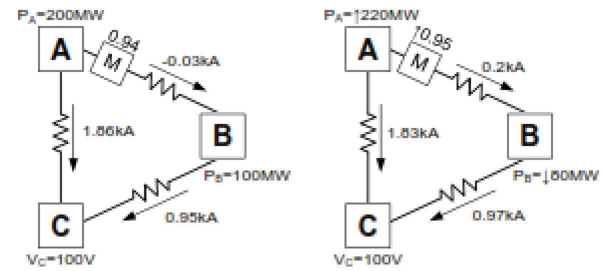
Fig. 2. Studied 3-terminal dc grid with an auxiliary dc voltage controller.

TABLE-I
3-Terminal Grid Transmission Line Parameters

Transmission line	**Resistance[□]**	**Current limits[KA]**	**Distance[KM]**
Line-1	6	2.1	173
Line-2	3	1.1	107
Line-3	4	1	142

The dc grid without the auxiliary dc voltage controller is solved with 2 lines and then with 3 lines. The transmission line parameters are listed in Table II

A. 3-Terminal DC Line



(a) With M=0.94, the operation is similar to the 2-line configuration. (b) Variation in power injection.

Fig.3 Three terminal system with auxiliary DC voltage controller

The analysis of the 3-terminal system is done by solving power equations. The starting point is the voltage of the DC voltage regulator (Vc=100V). In order to determine if the operating point is valid, line currents are calculated using line resistances and terminal voltages only. The equations of line currents from fig.1 are

$$I_{L1}= (V_A-V_C)/R_{L1}$$
$$I_{L2}= (V_B-V_C)/R_{L2}$$
$$I_{L3}= (V_A-V_B)/R_{L3}$$

In 3-terminal system region of operation and current sensitivity are calculated. Current sensitivity is calculated by partial derivative of the line currents. Also, by using the above line currents, power at the terminals are calculated. For defining the operating point and if the current limits are exceeding, firstly line currents are determined.

B. 4-Terminal DC Line

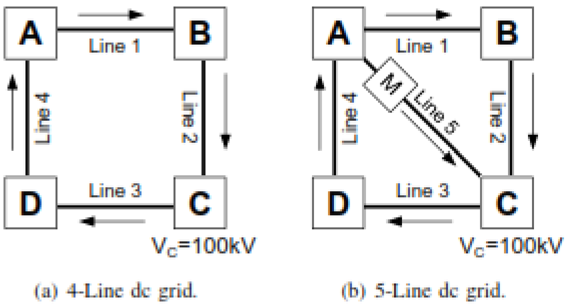


Fig.4. (a) 4-terminal system with four lines (b) 4-terminal system with five lines

In 4-terminal system with five lines, a similar analysis is done as that in 3-terminal system. The initial 4-terminal system is composed of 4 transmission lines system as shown in fig.4. Terminals A, B and D supply 100MW each which gives a total of 300MW injected to terminal B (neglecting transmission losses). The line current capacities for those lines are defined by adding a margin of 10% on the current values calculated for this scenario. A fifth line with an auxiliary dc voltage controller is added to the dc grid between terminal A and C as shown in Fig. 4(b). Here, only the region of operation and the current sensitivity are analyzed due to the increase of complexity generated by the augmented grid size.

Using the same procedure as for the 3-terminal dc grid, the region of operation is calculated for a dc grid composed of 4 terminals and 5 transmission lines for two cases: with and without the auxiliary dc voltage controller on line 5 at terminal A. Since the set of points is composed of 3 variables (P_A, P_B, P_D), it is natural to represent the region of operation in terms of volume.

III. REGION OF OPERATION

The region of operation for both 3-terminal system with three lines and 4-terminal system with five lines are determined. Also, the region of operation for 4-terminal system is found to be in terms of volume as it contains set of three variables (P_A, P_B, and P_D).

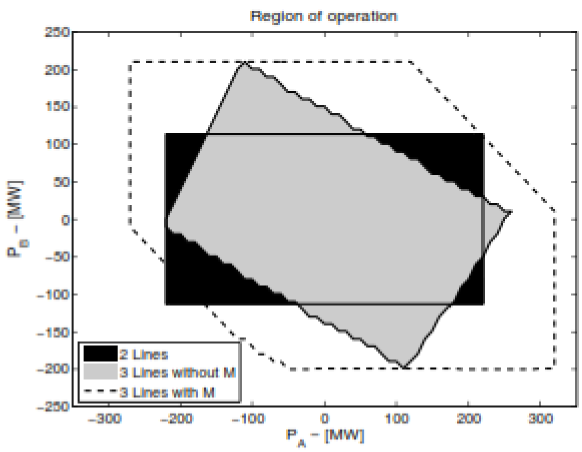


Fig.5.Region of operation of 3-terminal system

As shown above in fig.5 the region with light gray coloured matter is for 3-line system without inserting auxiliary DC voltage controller, black coloured region is for 2-line system and the dotted region is for 3-line system with addition of auxiliary DC voltage controller into the system. This illustrates that the insertion of the auxiliary dc voltage controller will enlarges the area offering more options to transmit power. The increase is significant compared to the system without M.

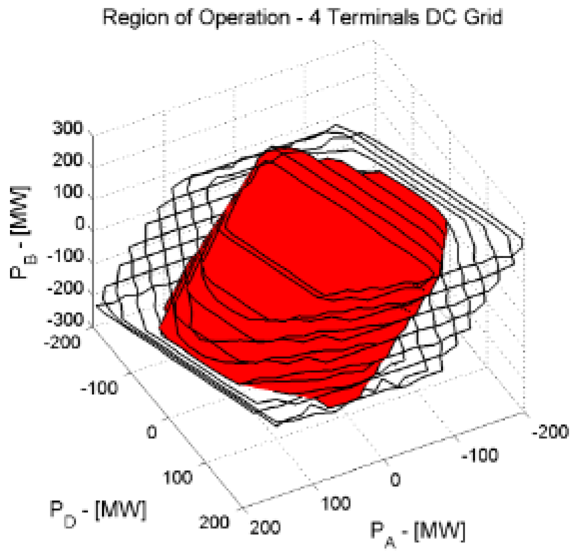


Fig.6. Region of operation for 4-terminal system

A similar analysis is done for 4-terminal system with five lines as in 3-terminal system and the region of operation is found to be in terms of three variables, that is a volume as shown in fig.6. The inside volume is the 5-line system without the auxiliary dc voltage controller and the contour lines shows the operating region with it. It is clear that the volume has expanded. A slice of the volume for P_B =100MW. The area is larger but not significantly in the first quadrant (positive P_A and P_D). This situation can be possibly explained by not having the auxiliary dc voltage controller at the optimal location in the dc grid. However, the insertion of the auxiliary dc voltage controller improves the operability over the 4 quadrants.

IV. CONCLUSION

In this paper, the analysis of two topologies with and without an auxiliary DC voltage controller has been investigated for 3-terminal system with three transmission lines and 4-terminal system with five transmission lines and adding such controller shows a great benefit on power flow distribution. The current sensitivity and region of operation are calculated for both topologies and the point of operation in case of a line inserted with an auxiliary DC voltage controller is extended while offering flexible power transmission. Hence it is beneficial to insert an auxiliary DC voltage controller into the DC line. Also, suitable topologies for an auxiliary DC voltage controller can be extended for future scope.

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