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Enhanced multi-terminal HVDC grid management for reliable AC network integration

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Abstract

This paper presents a secondary control for MTDC systems to update the DC voltage and converter power references of the VSC stations operating under droop control, in order to eliminate the large power deviation from their desired reference power. The rated values of the VSC station used as reference does not take into account the power losses in the converter, DC line and the voltage drops in the DC transmission lines. This creates a constant difference between rated DC voltage reference and actual DC voltage value of the VSC station. This difference is multiplied by the droop gain of the VSC station, hence causing power deviations in the MTDC grid system. In this paper a secondary control is implemented for a four-terminal HVDC system modelled in EMTDC/PSCAD, to demonstrate the reduction in power deviation by the proposed secondary control.

1 Introduction

Offshore wind energy is seen as the most promising source of electricity generation for achieving the European renewable energy targets. A number of wind farms are under installation in the North Sea, and more are planned, to collect the huge potential of wind energy at significant distances from land. This will be extended to include the interconnection between the countries to form a MTDC grid [1].

The Voltage Source Converter (VSC) technology's capabilities of multi-directional power flow and control flexibility are fundamental to a MTDC grid system. With the systematic control of the VSCs and MTDC grid system, the integration of wind farms and interconnections between countries can be made more reliable to support the AC network. The VSC-based MTDC grid system is connected to shore by a common DC link. The active power flow through all the terminals need to be balanced to keep the DC link voltage constant, similar to the constant system frequency requirement of an AC system, for the stable operation of VSC stations. A combination of primary control strategies proposed for the DC link voltage control and power flow dispatch of the MTDC grid system including Master-Slave, Voltage Margin and Voltage Droop control are suggested in [2]–[5].

The main drawback of the Master-Slave control strategy with the Voltage Margin method is that only one VSC station controls the DC link voltage of the MTDC grid system. An outage in the DC link voltage controlling VSC station leads to failure of the whole MTDC grid system. In the case of the Voltage Droop control more than one VSC station share responsibility for the DC link voltage control, therefore, outage of any single VSC station cannot cause failure of the complete MTDC grid system. Hence, the Voltage Droop control is regarded as most suitable, because of the flexible control operation of the MTDC grid system, similar to the frequency droop control of an AC system.

Although, various advantages of the DC Voltage Droop control implementation in an MTDC grid system have been explored in the literature, little has been discussed on the issue of the power deviation from the desired reference power of the VSC station operating under the Droop Control, due to the difference in the DC voltage of the VSC stations. In [6], the impact of the DC line voltage drop on the power flow under Voltage Droop control is discussed in detail and an analytical expression is proposed to deal with this issue, but the references cannot be updated instantaneously.

Power balancing and maintaining the required power flows from the MTDC grid system is fundamental to its reliable integration with the AC network. Therefore, a secondary control of the MTDC grid system as proposed in [7], analogous to that in an AC grid system, needs to be implemented to compensate for this power deviation and instantaneously update the power and voltage references of the primary control of the VSC stations, in order to maintain the scheduled power flow dispatch from the MTDC grid system.

In this paper, a secondary control is proposed for the instantaneous update of the DC voltage reference to avoid the power deviation caused by the difference in DC voltage of the VSC stations due to the voltage drop in the DC lines. A comparison of two four-terminal HVDC grid systems modelled in EMTDC/PSCAD is presented, one without the proposed secondary control and another with the proposed secondary control. The results show that secondary control can update instantaneously the DC voltage references and hence the power deviations are reduced eliminated from the MTDC grid system.

2 Control Structure of MTDC grid

The MTDC grid control is reduced to the control of a single VSC station (as a fundamental unit of the MTDC grid system); similarly, the control of the AC grid is represented by the control of a synchronous generator. The similarities between the MTDC grid control structure and AC grid control structure is shown in **Error! Reference source not found.** The primary control of the MTDC grid system comprises an inner and an outer controller, analogous to the exciter and governor control of the AC grid system. The secondary control is introduced to supply updated references for primary control to avoid the power deviation and obtain scheduled power flow dispatch from the MTDC grid system.

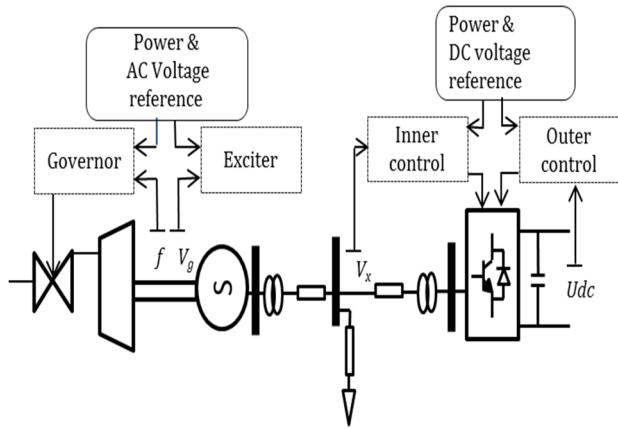


Figure 1: AC and MTDC grid control structure comparison

2.1 Primary Control

The primary control maintains the basic VSC station operation by the inner controller, and ensures the co-ordinated balance operation of the MTDC grid system as a whole through the outer controller. The detailed primary control structure of the MTDC grid system is shown in Figure 3.

The inner controller uses synchronously rotating dq reference control, explained in [8] [9], which decouples active and reactive power control to provide independent active and reactive power control at each VSC station, similar to how the governor and the exciter provide independent control in the AC grid system.

The outer controller can be operated under various modes of operation according to the requirements of the MTDC grid system. The operation modes include: constant active power or constant DC link voltage; constant reactive power or constant AC voltage. The control mode that most closely resembles the frequency droop control of the AC grid system is DC voltage droop control [10] as shown in **Error! Reference source not found.**

The implementation of the DC droop controller is given by:

$$P_c = P_{c\text{ref}} + R (U_{dc\text{ref}} - U_{dc}) \quad (1)$$

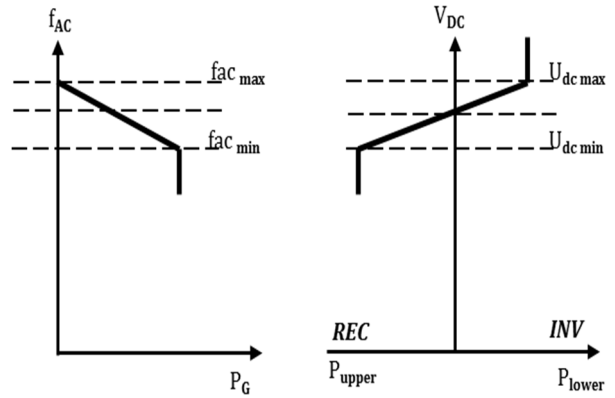


Figure 2: Primary droop control comparison of AC and MTDC grid

where, P_c is actual power at the Point of Common Coupling (PCC) of the VSC station, $P_{c\text{ref}}$ is desired reference power, R is the droop gain of the DC voltage controller, U_{dc} is the actual DC link voltage at the VSC station and $U_{dc\text{ref}}$ is the rated DC link voltage for the VSC station.

However, when rated DC link voltage values are used for $U_{dc\text{ref}}$, this does not take into account the voltage drops in the transmission line. The difference, when multiplied by the droop gain of the DC voltage controller, produces a large deviation in the actual power P_c of the converter station. To avoid this power deviation a power flow analysis can be performed to produce an appropriate DC voltage reference by keeping one VSC station as voltage regulator as suggested in [10], whereas, with the proposed secondary control described in this paper, it can be achieved instantaneously without the need for power flow analysis.

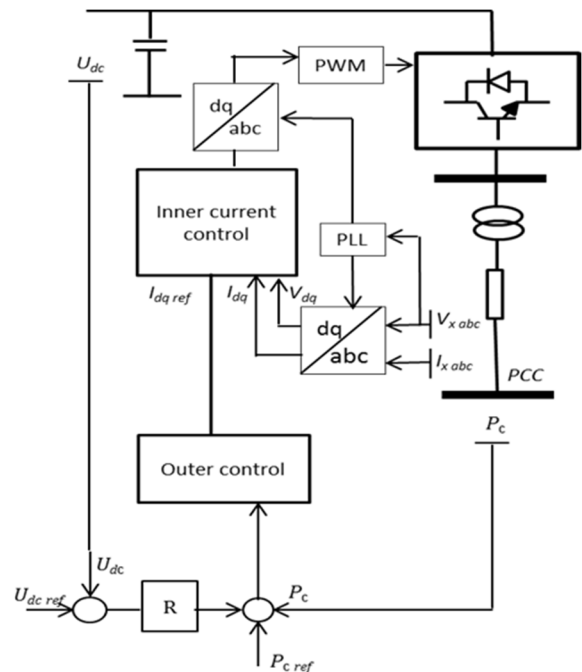


Figure 3: Detailed primary control structure of the MTDC grid system

2.2 Secondary Control

The secondary control is implemented to update the reference to the desired value, which will eliminate the difference between the actual and rated reference DC link voltage, so that actual power at the VSC station can be maintained near to the reference value. Since, in steady state the actual measured values of the DC link (U_{dc}) account for the voltage drop in the transmission and represent the true DC link voltage reference, so the relationship between rated reference and updated reference can be given as:

$$U_{dc\ updated} = U_{dc\ ref} + \Delta U_{dc} \quad (2)$$

where,

$$\Delta U_{dc} = U_{dc\ ref} - U_{dc} \quad (3)$$

The difference (ΔU_{dc}) between rated $U_{dc\ ref}$ and actual U_{dc} is added to the rated $U_{dc\ ref}$ to acquire the updated DC link voltage reference ($U_{dc\ updated}$). This will eliminate the steady state power deviation due to the DC voltage drops in the transmission line.

Similarly, the power references ($P_{c\ ref}$) can be changed to produce the updated power reference ($P_{c\ updated}$), in order to account for the power losses in the VSC station. In steady state, when the DC link voltage references are updated to the $U_{dc\ updated}$, the power deviation at the VSC station represents power losses in the VSC station and DC transmission line.

$$P_{c\ updated} = P_{c\ ref} + \Delta P_c \quad (4)$$

where,

$$\Delta P_c = P_{c\ ref} - P_c \quad (5)$$

Once the difference (ΔP_c) between the desired $P_{c\ ref}$ and actual P_c is added to the desired $P_{c\ ref}$, the updated power reference ($P_{c\ updated}$) will take into account the losses of the VSC station and DC line; hence steady state power deviation due to the VSC station and DC line losses will be reduced. **Error! Reference source not found.**, shows implementation for secondary control.

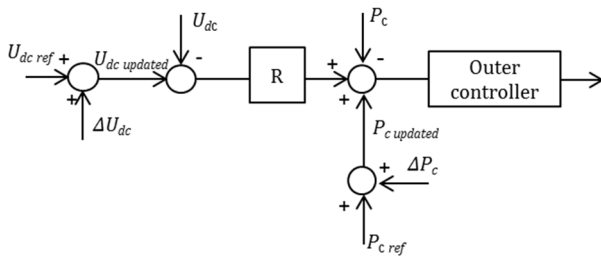


Figure 4: Secondary control implementation

3 System configuration

The hypothetical four-terminal HVDC model with every terminal connected to each other shown in **Error! Reference source not found.** has been simulated (to get a simple representation of a meshed network) in EMTDC/PSCAD simulation software to verify the proposed secondary control. The VSC station1 (terminal-1) is set on Power Control mode, whereas the other three VSC stations (VSC2, VSC3 and VSC4) are set to DC voltage Droop Control.

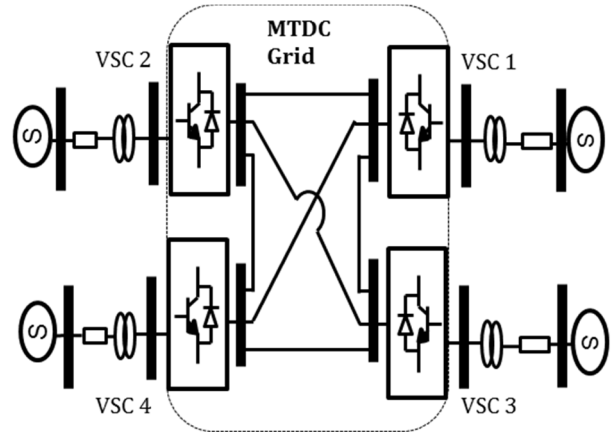


Figure 5: Four terminal HVDC system

Two different scenarios have been simulated; one without secondary control and the other with secondary control implemented to demonstrate the reduction in the steady state power deviation with the proposed secondary control. Finally, a change in power flow pattern is simulated to show the balance distribution of power in the MTDC grid system under disturbance conditions. The AC grids are represented by their aggregated models.

The parameters used have been inspired from [10], $R_{cable}=0.01\Omega/km$, $C=5\ \mu F/km$, $R_{DC}=40\ MW/kV$, $P_{c\ Rated}=100MW$ each and $U_{dc\ Rated}=50kV$ each. The lengths of the cables are given as; $l_{12}=150km$, $l_{14}=170km$, $l_{13}=100km$, $l_{23}=150km$, $l_{24}=120km$ and $l_{34}=100km$.

Table 1 shows the set reference taken for the four VSC stations in the steady state operation condition.

Table 1: Reference values used for simulation

VSC stations	VSC1	VSC2	VSC3	VSC4
$P_{c\ ref}$ (MW)	-90	10	30	50
$U_{dc\ ref}$ (kV)	-	50	50	50
R_{DC} (MW/kV)	-	40	40	40

4 Simulation results

4.1 MTDC system under droop with no secondary control

The first simulation is performed with set reference from Table 1; here the DC voltage reference for the three VSC stations under DC Droop control is the rated DC link voltage. It can be observed from Figures 6 and 7 that power deviations are proportional to the difference between the reference DC voltage (i.e. $U_{dc, ref} = 50\text{kV}$) and the actual DC voltage (U_{dc}). Table 2 shows deviations in power by the difference of the in the DC link.

Table 2: Power deviations and DC voltage difference

VSC Station	VSC1	VSC2	VSC3	VSC4
P_c (MW)	-90	8.76	50.126	31.34
U_{dc} (kV)	-	49.625	50.002	49.973
ΔP (MW)	0.0	-1.24	0.126	1.34
ΔU (kV)	-	-0.375	0.002	-0.027

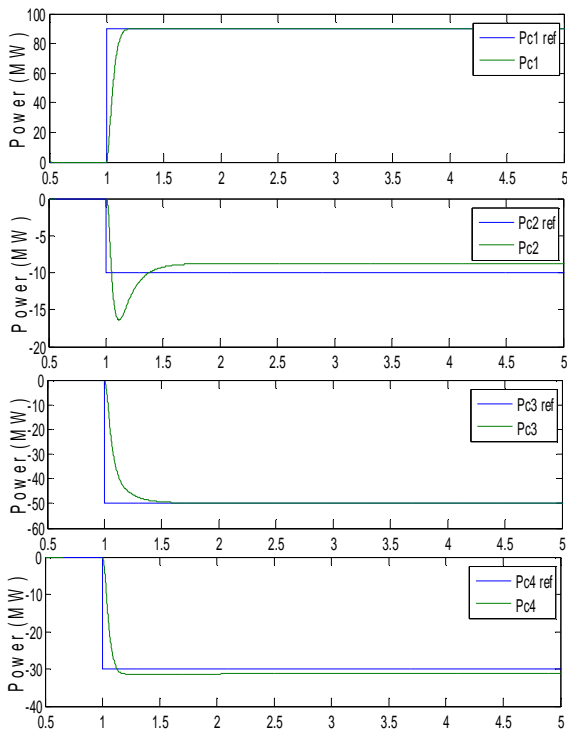


Figure 6: Actual and reference power without secondary control

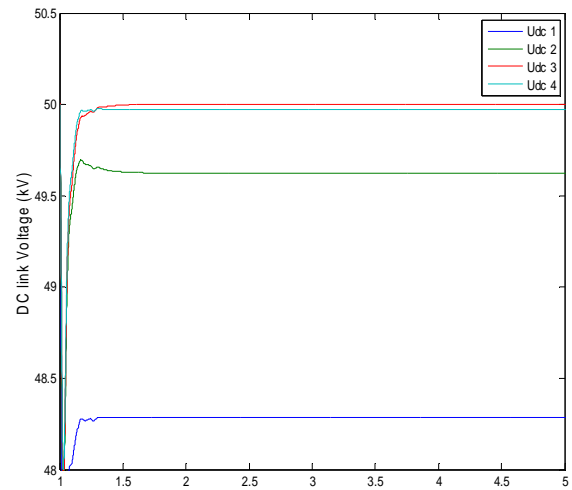


Figure 7 DC link voltages without secondary control

4.2 MTDC system under droop with secondary control

In the second simulation, the secondary control is applied and the DC link voltage references for the three VSC stations (VSC2, VSC3, VSC4) are updated according to the voltage drops in the DC transmission line. Figures 8 and 9 show that power deviation of the VSC station is reduced and precise power flow can be obtained from the MTDC grid system without need of references being updated through the DC power flow analysis.

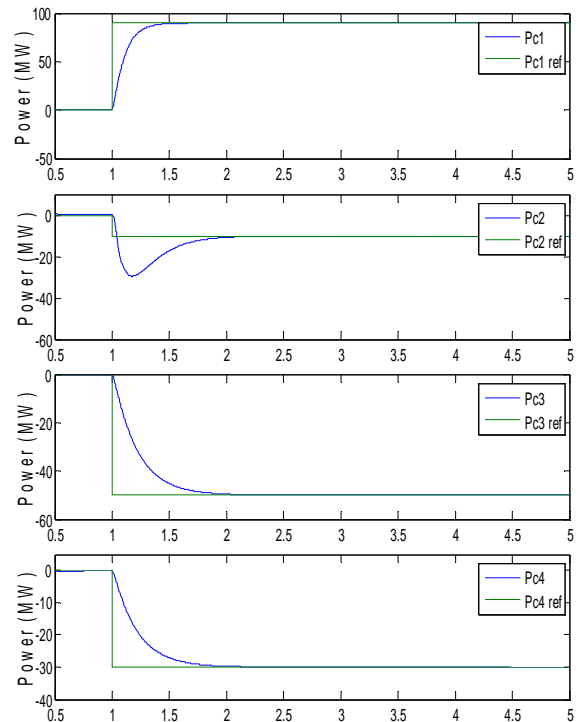


Figure 8: Actual and reference power with secondary control

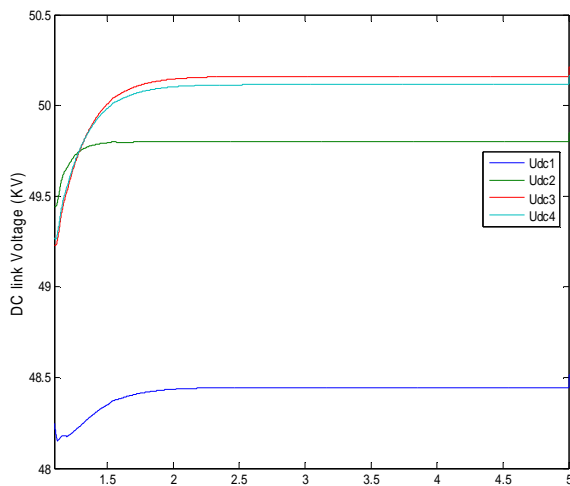


Figure 9: DC link voltages with secondary control

5 Conclusion

In this paper a secondary control has been proposed to update the DC voltage and converter power references of the VSC stations operating under droop control, in order to reduce the large power deviation from their desired reference power. It is observed that DC voltage rated values of the VSC station used as reference causes power deviation in the MTDC grid system. The proposed secondary control can provide updated references for primary control to avoid the power deviation and obtain scheduled power flow dispatch from the MTDC grid system.

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