IMPROVE PERFORMANCE ON AC FAULT RIDE THROUGH IN MULTITERMINAL HVDC TRANSMISSION SYSTEM SUPPLYING

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Abstract

Recently, there has been a fast development and deployment of wind energy to meet the increasing electrical power demand and to limit the use of fossil fuels. More and more wind farms are planned far from shore because of good wind condition and less visual impact. This is so called offshore wind farm (OWF). In such a situation, high voltage direct current (HVDC) transmission is a favorable option for integrating these OWFs to the onshore grid, because HVDC, compared with high voltage alternating current (HVAC), has lower losses and higher transmission efficiency. For HVDC transmission, voltage source converter (VSC) has some advantages over current source converter (CSC), e.g. independent control of active power and reactive power, bidirectional power transfer for fixed voltage polarity. When a fault occurs at the onshore ac grid which connects OWFs via VSC-HVDC, the active power cannot be fully transmitted to onshore grid, while OWFs still produce active power. The imbalanced power will increase the HVDC-link voltage. This increased dc voltage will lead to high electrical stress for the insulated gate bipolar transistor (IGBT) modules, capacitors as well as cables, and even damage them.

I.INTRODUCTION

The development of additional electrical interconnections is presently being planned by sea exploiting offshore grids, as it is documented in the European project ―Twenties‖ and in the Intelligent Energy Europe projects ―Offshore Grid and ―Trade Wind. In both cases, offshore interconnections are expected to provide two main requirements: the support to exchange power between ac areas and offshore wind power integration. The ac transmission of bulk power over long distances in offshore interconnections is technically limited by the high capacitance of shielded power cables. High-voltage direct current–voltage-source converter (HVDC–VSC) technology seems to be the most promising solution for offshore dc connections since it uses small harmonic filters, it allows the independent control of active and reactive power, bidirectional power flows, and voltage support and it is able to provide black-start capability . Regarding HVDC transmission, multiterminal dc (MTDC) grids are foreseen as an alternative solution to point-to-point connections, providing higher flexibility, increased redundancy and reduction of maximum power not supplied to onshore grids in case of dc disturbances.

A fully operational MTDC grid with offshore wind farms (WF) can be regarded as a large (virtual) power plant capable of providing ancillary services to mainland ac grids [1]. In this sense, it is expected that MTDC grids also provide fault ride through (FRT) capability for faults occurring in the mainland ac grid, in line with grid code requirements for onshore wind generators [2]. The analysis and performance evaluation of different control solutions for the provision of FRT requirements in point-to-point HVDC systems equipped with VSC. In any case, the dc voltage rise due to the onshore VSC power transfer reduction during the ac grid fault is the major concern for the development of any control strategy. the authors propose five methodologies to dissipate/accommodate dc grid power in order to control the dc voltage rise. Excepting the solution based on the installation of dc chopper resistors, the other methodologies rely on a fast communication channel between onshore and offshore converter/wind turbine and involve: active power reduction output through offshore converter current control, wind turbine power set-point adjustment, offshore grid frequency adjustment and offshore ac grid voltage controlled reduction. the authors propose a strategy to control the dc voltage rise during the ac grid fault by de-loading the offshore WF proportionally to the dc voltage rise. However, this strategy assumes the use of a communication link between the offshore converter and each wind turbine. Also, the installation of dc grid chopper resistor has been contemplated as an alternative.

II. HIGH-VOLTAGE, DIRECT CURRENT (HVDC)

2.1 High voltage transmission

High voltage is used for electric power transmission to reduce the energy lost in the resistance of the wires. For a given quantity of power transmitted, doubling the voltage will deliver the same power at only half the current. Since the power lost as heat in the wires is proportional to the square of the current for a given conductor size, but does not depend on the voltage, doubling the voltage reduces the line losses per unit of electrical power delivered by a factor of 4. While power lost in transmission can also be reduced by increasing the conductor size, larger conductors are heavier and more expensive. High voltage cannot readily be used for lighting or motors, so transmission-level voltages must be reduced for end-use equipment.

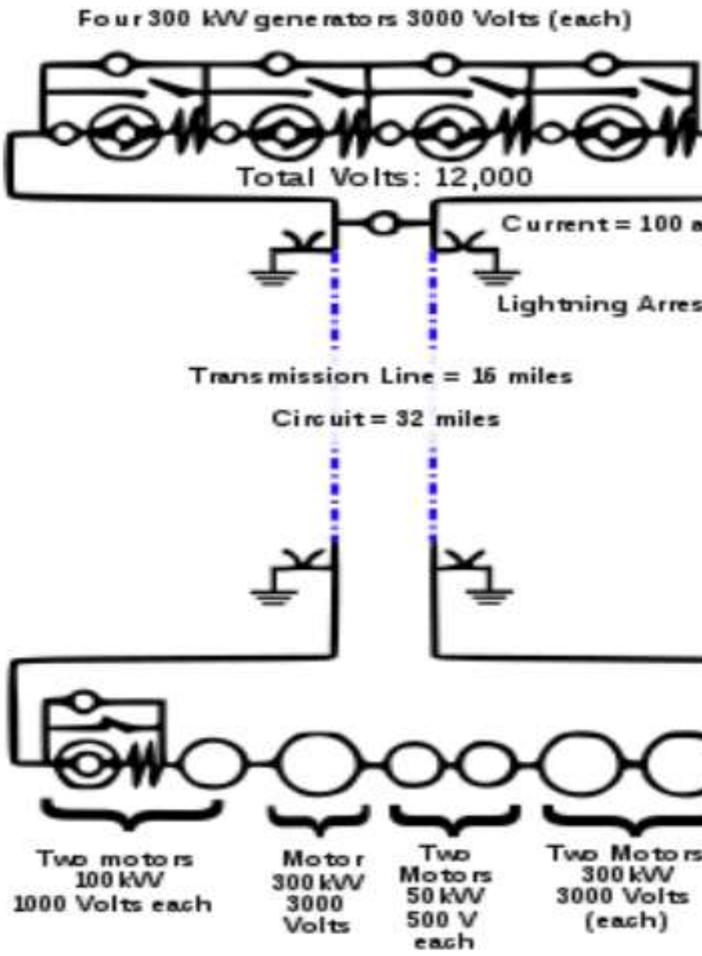

Fig1.Schematic diagram of Thury HVDC transmission system.

2.2 Offshore Wind

Transformers are used to change the voltage levels in alternating current (AC) transmission circuits. Because transformers made voltage changes practical, and AC generators were more efficient than those using DC, AC became dominant after the introduction of practical systems of distribution in Europe in 1891 and the conclusion of the War of Currents competition at the same time in the US between the direct current (DC) system of Thomas Edison and the AC system of George Westinghouse. Practical conversion of power between AC and DC became possible with the development of power electronics devices such as mercuryarc valves and, starting in the 1970s, semiconductor devices as thyristors, integrated gate-commutated thyristors (IGCTs), MOS-controlled thyristors (MCTs) and insulated-gate bipolar transistors (IGBT).

Offshore wind power refers to the construction of wind farms in bodies of water to generate electricity from wind. Stronger wind speeds are available offshore compared to on land, so offshore wind power's contribution in terms of electricity supplied is higher, and NIMBY opposition to construction is usually much weaker. However, offshore wind farms are relatively expensive. At the end of 2012, 1,662 turbines at 55 offshore wind farms across 10 European countries were generating electricity enough to power almost five million households. Offshore wind power refers to the construction of wind farms in bodies of water to generate electricity from wind. Unlike the typical usage of the term "offshore" in the marine industry, offshore wind power includes inshore water areas such as lakes, fjords and sheltered coastal areas, utilizing traditional fixed-bottom wind turbine technologies, as well as deep-water areas utilizing floating wind turbines. A subcategory within offshore wind power can be near shore wind power.

III.MODELING AND CONTROL OF MTDC GRIDS

Therefore to improve the voltage stability of the passive industrial network, this section presents two major ride through methods, which comprise of a modified current control strategy (MCCS) and a frequency hysteresis control (FHC). These are designed based on the conventional ac voltage control (CAVC) with VSC at the receiving end.

Modified Current Limit Strategy:

In orthodox power systems, the reactive power flow and the ac voltage are connected closely because of the inductive characteristics of high voltage transmission lines. The variation of reactive power in the system may have a high effect on the ac voltage of the power grid [23]. When, the VSC-HVDC is delivering to passive industrial loads, the rectifier station works on the dc voltage control mode. In case of faults in the sending side, there is an ac voltage drop in the grid and the current of the VSC rectifier reaches the limit. As a result, the VSC at the grid end is incapable to uphold the dc voltage. The change of the active power may cause deviations in the dc voltage, causing a disturbance of the ac voltage at the PCC; meanwhile the ac voltage in the passive system is modulated from the dc voltage of the VSC-HVDC [22]. Thus, during severe faults, the active power will have high impact on the ac voltage of the passive industrial installations. Alternatively, the reactive power is still critical for the voltage stability of the passive system. Therefore, an analysis should be done to investigate that whether the active power or the reactive power is responsible for the deviation of the ac voltage at the receiving end.

IV.PROPOSED APPROACHES FOR FRT PROVISION IN MTDC GRIDS

A. Introduction

The converter current limits are responsible for reducing the onshore HVDC–VSC active power injection capability during voltage sags. Offshore WF commonly operates in a maximum power extraction philosophy and offshore HVDC–VSC injects the incoming power into the dc grid. Therefore, during an ac mainland fault, a significant power reduction occurs in the HVDC–VSC terminal connected to the faulted area. Without the use of any specific strategy (which are addressed hereafter), the offshore WF will remain operating under a maximum power extraction strategy. Consequently, the dc power imbalance will result on dc over voltages in the different MTDC grid nodes depending on the pre-disturbance active power flows and on the MTDC grid topology [6]. Nonetheless, dc over voltages must be controlled in order to avoid equipment damages and provide the expected flexibility in terms of FRT capability.

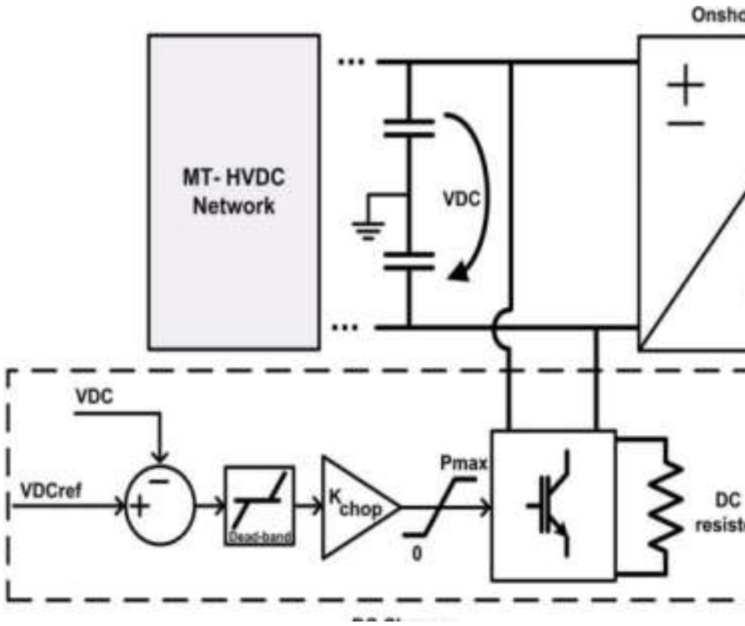

Fig 2. Control scheme of onshore dc chopper resistor.

In order to mitigate the dc voltage rise effect, three control strategies are proposed and tested. The first one consists on a conventional solution based on dc chopper resistors installed at onshore VSC-level and is considered as a reference case. The other two strategies rely on innovative communication free solutions that exploit the control flexibility of both offshore HVDC–VSC converter stations and wind generators to perform fast active power reduction at the wind generator level. These control strategies are based on the implementation of local control rules at offshore converter stations and at wind turbine generators and are intended to avoid the use of solutions based on dc chopper resistors.

B. Onshore DC Chopper

A dc chopper consists on a dc resistor controlled through a power electronic switch and it is installed at the HVDC–VSC onshore converter station as it is depicted in Fig6. A detailed sizing of a dc chopper-based solution for FRT compliance in MTDC grids is out of the scope of this paper (as previously mentioned, this type of solution is considered only as a reference case). Nevertheless, it depends on several factors, namely the MTDC grid power in-feeds (power in-feeds from offshore WF or from other mainland ac grid areas) as well as on the mainland grid connection points and its electrical distance. In this case, a simple approach based on a worst case scenario was considered. The worst case condition corresponds to a situation where all HVDC–VSC stations are operating at the nominal power. In case of a fault, healthy converters (connected to non-faulted ac mainland grids) are not able to increase their power injection and power dissipation in chopper resistors is required in order to mitigate the dc voltage rise. Based on this assumption, each dc chopper must be sized to dissipate the nominal power of the HVDC– VSC to which it is connected.

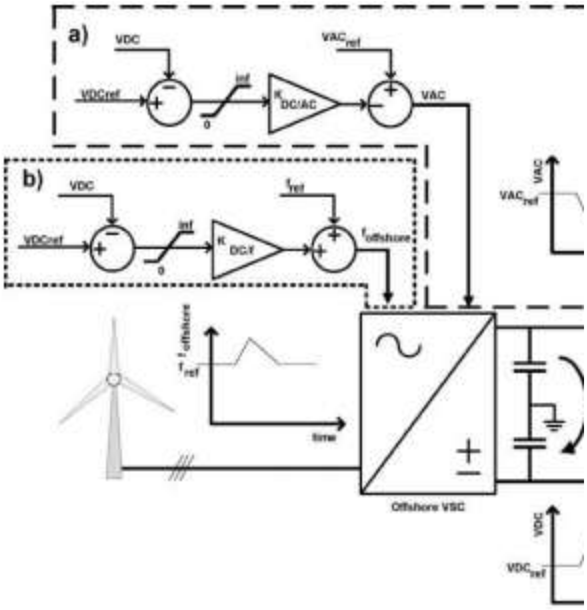

Fig3. Control scheme for FRT provision based on dc voltage

The activation of each dc chopper control strategy is based on a dc voltage threshold that will trigger power dissipation in the resistor. In terms of RMS system modeling, the dc chopper active power dissipation is locally regulated based on a proportional control rule having as input the positive dc voltage deviation (over voltage magnitude) [5]. The dc chopper de-activation occurs if: (1) the dc voltage reaches a value below the threshold activation level (eg.: after fault clearance) or; (2) the chopper resistor temperature overreaches the maximum value (thermal protection tripping), meaning that the resistor maximum energy dissipation capability has been overreached. This specific situation is often related to a permanent fault event and must be handle by additional control schemes to perform permanent active power reduction at offshore WF-level.

C. Local Controls at the Wind Generator Level

As previously mentioned, PMSG and DFIG were assumed to be used in offshore WF in order to demonstrate the feasibility and evaluate the performance of the proposed wind generators' active power control strategies. Regarding PMSG, the wind generator local control for fast active power regulation is set to dissipate active power proportionally to ac offshore grid voltage (case 1) or frequency variations (case 2). To achieve a fast response, it is assumed the power dissipation is made at the wind generator chopper resistor installed on the dc bus bar of the ac-dc-ac full converter [2], [6], while having the advantage of keeping the generator side decoupled from the transient phenomena. For the DFIG, the active power regulation is naturally achieved for the ac voltage regulation strategy, since the controlled voltage sag in the offshore ac grid leads to the generator de-magnetization, increasing slightly its angular speed and consequently reducing the injected power [23]. In this case, inrush currents resulting from the demagnetization of DFIG are a critical issue due to the current limits of the HVDC–VSC station connected to the offshore ac grid. In order to overcome this drawback, the control strategy presented in [3] is adopted, as it was previously mentioned. Compared to conventional DFIG control strategies, it presents the advantage of assuring a considerable limitation of the stator currents following the voltage dip, while limiting also the rotor current and avoiding the need of the crowbar. The control principle exploits the possibility of allowing the DFIG rotor speed increase in coordination with the control of the wind turbine pitch angle in order to limit the acceleration phase and to avoid stability issues. Regarding the frequency-based active power regulation strategy in the DFIG, a supplementary control is used in the speed control loop implemented in the rotor side converter which allows a rotor speed increase to achieve a fast reduction of active power generation.

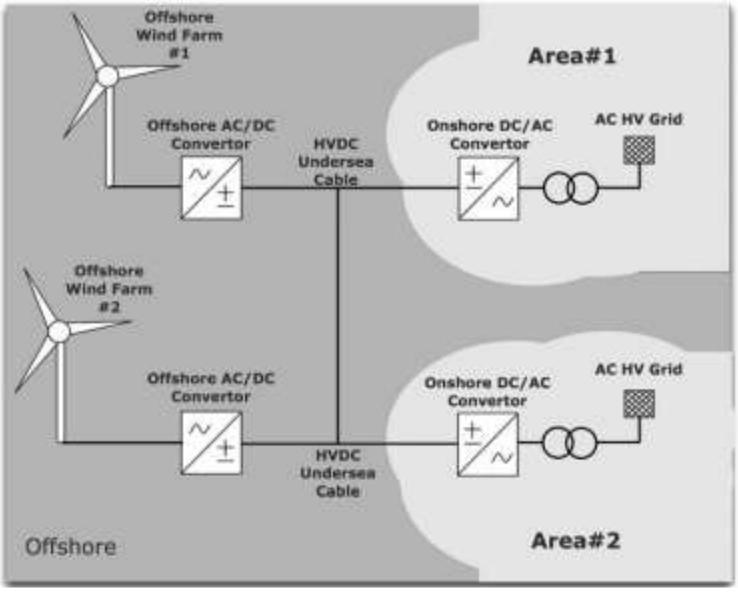

Fig.4. MTDC grid test system.

V. SIMULATION RESULT

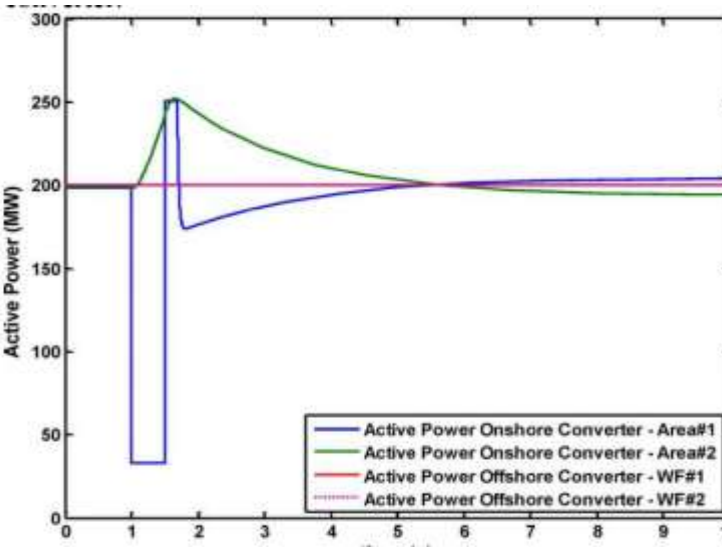

Fig 5. Active power flows on HVDC–VSC.

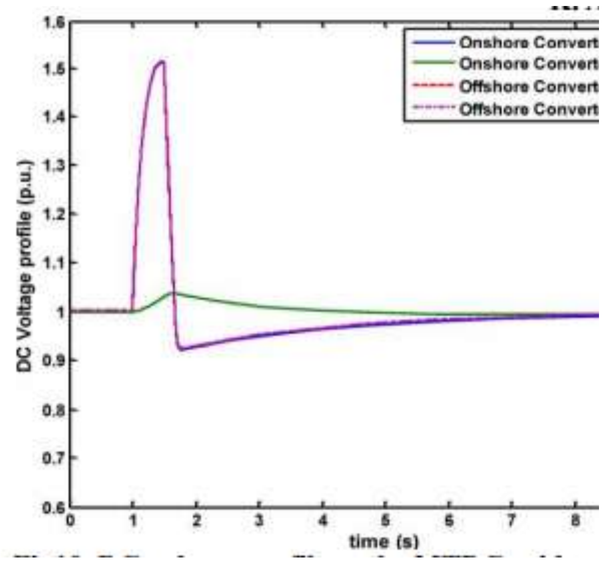

Fig 6. DC voltage profile at the MTDC grid terminals

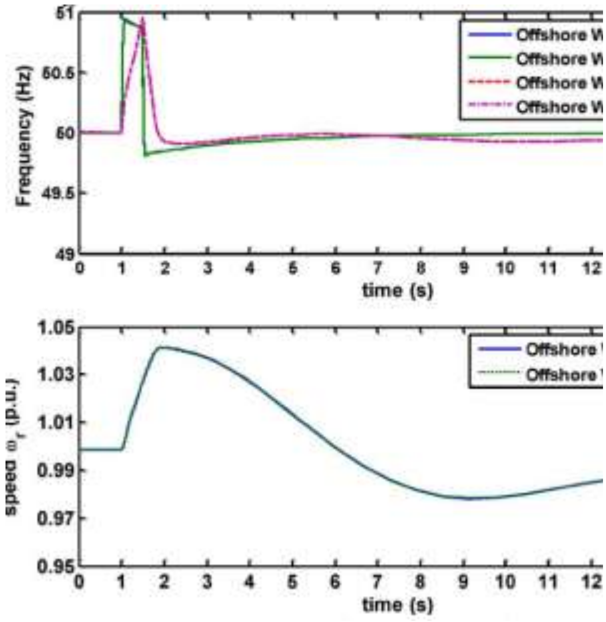

Fig 7. Frequency and DFIG speed at offshore WF (PMSG and DFIG)

VI. CONCLUSION

This paper is to design control strategies to improve the voltage stability of the VSC-HVDC based passive industrial installations. By the analytical result that the main cause influencing the ac voltage of the passive system is the reactive power, the control techniques that comprise of the modified current control strategy and the frequency hysteresis control are taken. The purpose of selecting the MCCS is that in steady state and transient conditions, the reactive power transmitted from the inverter of the VSC-HVDC, the q axis component of the VSC current. When the MCCS is added to the outer control loop of the inverter, the setting can be met better in order to increase reactive power output of the VSC. From MCCS basis, an additional frequency control is proposed. The purpose of the FHC is to reduce the set frequency of the VSC at the receiving end according to the measurement of the ac voltage in the passive industrial system. In this manner, the control effect of the MCCS can be enhanced. The decrease of the set frequency can lead to an increase, which in turn increases the reactive power output. The simulation verifications were carried out during a metallic single-phase fault and a metallic three-phase fault respectively. By studying the simulation results, it can be concluded that,1)when a metallic single-phase fault occurs at the sending end of the VSC-HVDC system, the ac voltage of the passive industrial system drops certainly. When the VSC at the receiving end is working on CAVC controller, the ac voltage does not fall back to its pre-fault level after the fault clearance. Whereas, with the MCCS the voltage will be stable after the fault clearance. The voltage stability can be improved further when the MCCS and FHC are added to the VSC controller accordingly. 2) During a metallic three-phase fault, the ac voltage in the passive system cannot keep stable under the VSC controller with the MCCS. While with the FHC, a voltage collapse is avoided, this means that it is likely to decrease the set frequency of the VSC at the receiving end to ride through severe faults. Since SVPWM technique is added to this control by which it reduces Total Harmonic Distortion (THD) to some margin. Hence from above, the control strategies proposed in this paper could improve voltage stability of the passive industrial installations efficiently.

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