ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Control Strategies For Interconnected Transmission Systems With Off-Shore Wind Farms

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Abstract:

This paper presents control strategies based on a communication-free framework that were developed in order to allow DC grid-connected off-shore WF and interconnected AC areas on providing advanced system services such as: a) primary frequency regulation, b) inertial behavior emulation, c) Fault Ride-through (FRT) capability. The association of the control strategies for primary frequency regulation and FRT has culminated in the design of the coordinated approach for increasing the DC grid reliability by allowing its operation following the disconnection of one onshore HVDC converter. The presented control strategies rely on local controllers to be housed in off-shore and onshore High Voltage Direct Current - Voltage Source Converter (HVDC-VSC) as well as on WT. The local controllers operate autonomously providing the adequate regulation based on quantity variations.

Index terms:

off-shore wind farms, HVDC, FRT, Voltage Source Converter.

INTRODUCTION:

The modernization of electrical power systems is walking toward the adoption of endogenous energy resources for electricity generation. The wherefores for that approach are based on economic and environmental aspects. Strategically, it is necessary to create alternatives to walk in the direction of external energy independence (namely from oil gas and coal suppliers) and to reduce the Green House Gases (GHG) emissions in the electric power sector.

The recent statistics from EREC, the European Union is progressing towards the imposed goals of 20% for renewable-based electricity generation, also called as Renewable Energy Source in Electricity (RES-E). The envisioned wind energy contribution can only be attained with the adoption of off-shore Wind Farms (WF). Aware of that necessity, European Commission has published a communication [16] defining a set of action to foster off-shore wind integration. A key motivation topic for this thesis is already mentioned in this document as a challenge on "Dealing with bottlenecks and power balancing in the onshore electricity grids".

To overcome the costs associated to the off-shore WF infrastructure, envision an electrical infrastructure - the off-shore grid - which should allow not only the connection of off-shore Wind Power but also increase the flexibility of operation of interconnected mainland countries through the creation of additional channels for active power flows thus, allowing further electricity market expansion. That way, the costs of deployment of connection infrastructures should be shared among the stakeholders (off-shore WF owners and electricity markets).

The predicted massive off-shore Wind power integration through HVDC technology as well as the inter-AC onshore areas power exchange through the DC grid infrastructure, is potentially dangerous from the AC mainland grid dynamic security perspective. The main reason for that is related to the fact that o shore WF connected through the HVDC technology are de-coupled from the AC grid in terms of voltage and frequency. So, they are not able to sense AC onshore grid disturbances and consequently are unable to provide adequate response.

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Some studies have investigated the possibility of equipping o shore WF with point-to-point fast communication channels to transmit onshore grid AC voltage and frequency measurements. However, the transposition of this concept to a DC grid becomes challenging due to the number of off-shore WF and AC onshore grid connections requiring several point-to-point connections (between all the intervenient).

SYSTEM DESCRIPTION:

The MTDC grid provides the interconnection of “N” offshore WF to “M” mainland collection points. In order to evaluate the dynamic behavior of the MTDC grid, including the HVDC–VSC stations and offshore WF, it is necessary to develop adequate models for simulating the operational characteristics of the overall system. Modeling system components will allow the identification of the most appropriate decentralized control strategies in order to provide FRT capability in MTDC grids.

It is important to highlight that the major dynamic phenomena to be analyzed in this paper are associated to faults occurring in the mainland ac grid. Therefore, a RMS modeling approach is assumed, where losses, harmonics and fast switching transients of the converters are neglected. Taking into account this general consideration, the next ssub-sections present a brief description of the adopted models.

Wind Generator:

Regarding the offshore WF, two most common generator technologies with FRT capability were considered in order to demonstrate that the FRT control schemes for the MTDC grid proposed in this paper are effective. For the first case, offshore WF were assumed to be equipped with permanent-magnet synchronous generators (PMSG) interfaced with the ac offshore grid via an ac/dc/ac full converter. For this case a lumped model was adopted according to the approach described.

For the second case, offshore WF was assumed to beequipped with DFIG, which are modeled according to the approach presented. The control approach discussed is able to effectively reduce the transient rotor andstator currents in DFIG by allowing a controlled increase ofthe rotor speed following voltage sag, thus improving its FRTperformance.

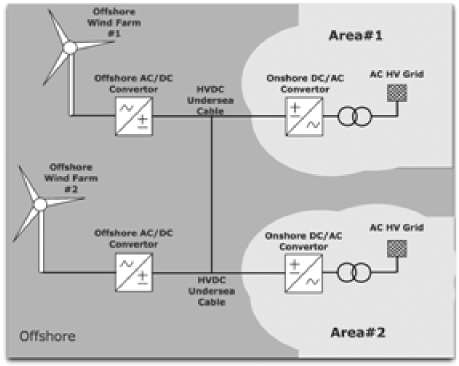

Fig 1: block diagram of system proposed

Offshore Converter: The offshore WF is assumed to be connected to an ac grid, whose voltage and frequency are controlled by the offshore HVDC–VSC station. Simultaneously, the offshore converter interfaces the WF network with the MTDC grid. From the ac side, it performs as a slack bus for the ac offshore grid by collecting all the generated power and delivering it to the dc grid.The converter model is implemented in the synchronous reference frame. The HVDC–VSC output voltages and values are set through PI controllers considering the voltage and current errors in the referred and reference frame.Onshore Converter: The onshore HVDC–VSC is responsible for interfacing the MTDC grid to the ac onshore grid and for the control of the associated dc terminal voltage (which thereafter leads to the control of active power being injected into the onshore ac grid). The dc voltage reference can be defined through a local droop controller.This converter was also modelled in the synchronous referenceframe through its main control loops. The converter output voltages and are set through PI controllers associated to the converter inner current control loops. The converter outer control loops provide the current reference through the error generated between the actual dc voltage and the reference dc voltage; the current referent is provided by another PI regulation loop that can be used for setting the converter reactive power or output voltage. For this specific case, the regulation was set to control the ac voltage magnitude at the VSC ac terminals.

FAULT RIDE THROUGH TECHNOLOGY:

The converter current limits are responsible for reducing theonshore HVDC–VSC active power injection capability duringvoltage sags. Offshore WF commonly operates in a maximumpower extraction philosophy and offshore HVDC–VSC injectsthe incoming power into the dc grid.

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Therefore, during an acmainland fault, a significant power reduction occurs in theHVDC–VSC terminal connected to the faulted area. Withoutthe use of any specific strategy (which are addressed hereafter),the off-shoreWF will remain operating under a maximum powerextraction strategy. Consequently, the dc power imbalance willresult on dc overvoltages in the different MTDC grid nodesdepending on the pre-disturbance active power flows and on the MTDC grid topology. Nonetheless, dc overvoltagesmust be controlled in order to avoid equipment damages andprovide the expected flexibility in terms of FRT capability.

In order to mitigate the dc voltage rise effect, three controlstrategies are proposed and tested. The first one consists on aconventional solution based on dc chopper resistors installedat onshore VSC-level and is considered as a reference case.The other two strategies rely on innovative communicationfreesolutions that exploit the control flexibility of both offshoreHVDC–VSC converter stations and wind generators to performfast active power reduction at the wind generator level. Thesecontrol strategies are based on the implementation of local controlrules at offshore converter stations and at wind turbine generatorsand are intended to avoid the use of solutions based ondc chopper resistors.

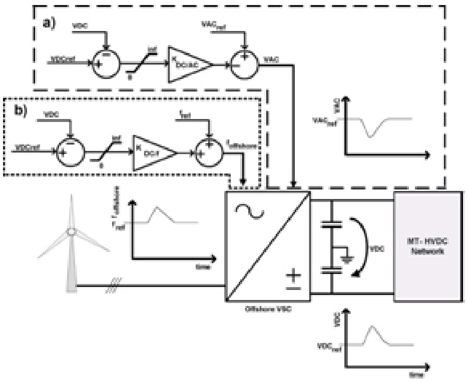

Fig 2: Control scheme for FRT

Modern wind turbines connected to ac grids in onshore applicationsare FRT compliant, coping with the requirements ofmany grid codes [12]. However, MTDC grids decouple the offshoreWF and the onshore ac grid. Therefore, in order to derivea communication-free solution to provide FRT in MTDC grids,strategies exploiting the dc overvoltages resulting from onshoreac faults can be advantageous. The main objective is the implementationof local controllers at the offshore VSC and at thewind generators enabling them to perform fast active power regulationas it is generally depicted in Fig. 2.

The envisioned controlstrategies exploitMTDC grid voltage rise in order to control(1) the offshore ac grid voltage or (2) the offshore ac grid frequency.The dc voltage rise can be used in orderto control the magnitude of the ac output voltage of the offshoreHVDC–VSC. Therefore it is suggested to include a local controlat the HVDC–VSC station that proportionally decreases the acvoltage as a function of the dc voltage rise in the converter dc terminal.

As previouslymentioned, PMSG and DFIG were assumed to be usedin offshore WF in order to demonstrate the feasibility and evaluatethe performance of the proposed wind generators' activepower control strategies. Regarding PMSG, the wind generatorlocal control for fast active power regulation is set to dissipateactive power proportionally to ac offshore grid voltage (case 1)or frequency variations (case 2). To achieve a fast response, itis assumed the power dissipation is made at the wind generatorchopper resistor installed on the dc bus bar of the ac-dc-ac full converter, while having the advantage of keeping thegenerator side decoupled from the transient phenomena.

SIMULATION RESULTS:

In order to characterize the MTDC grid operational issueswhen performing FRT and to evaluate the impacts and the performanceof the local control strategieswas used. Each offshore WF (eitherequipped with PMSG or DFIG generators was modelled by asingle equivalent machine with a power production of 200MW.Each HVDC–VSC station has a nominal apparent power of 250MVA. The test system was fully modelled in aMatlab/Simulinksimulation platform, according to the dynamic models of thecomponents that were previously described.

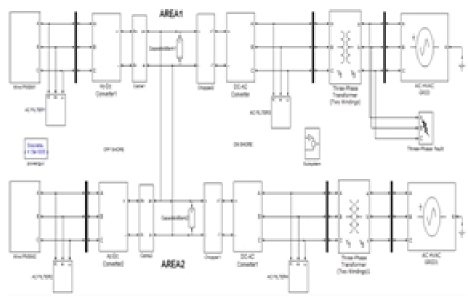
Fig 3: simulation circuit of MTDC system.

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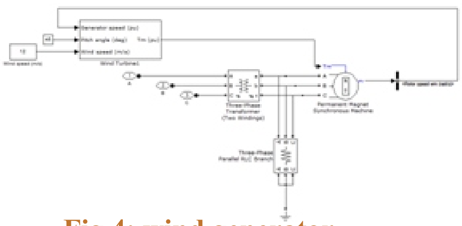

Fig 4: wind generator

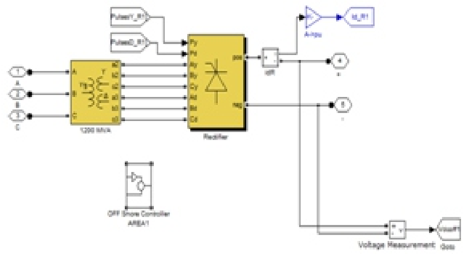

Fig 5: offshore converter

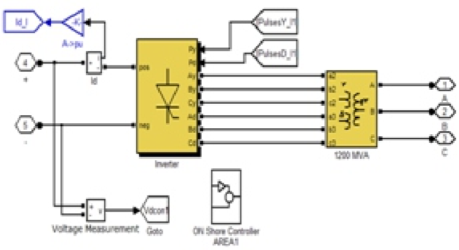

Fig 6: onshore converter

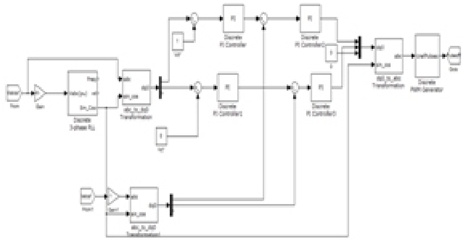

Fig 7: offshore controller

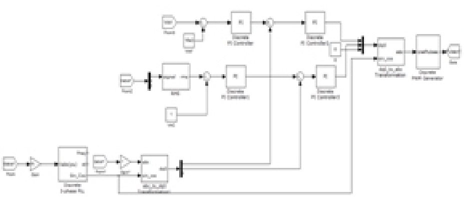

Fig 8: onshore controller

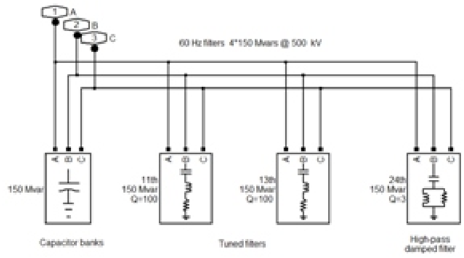

Fig 9: filter circuit

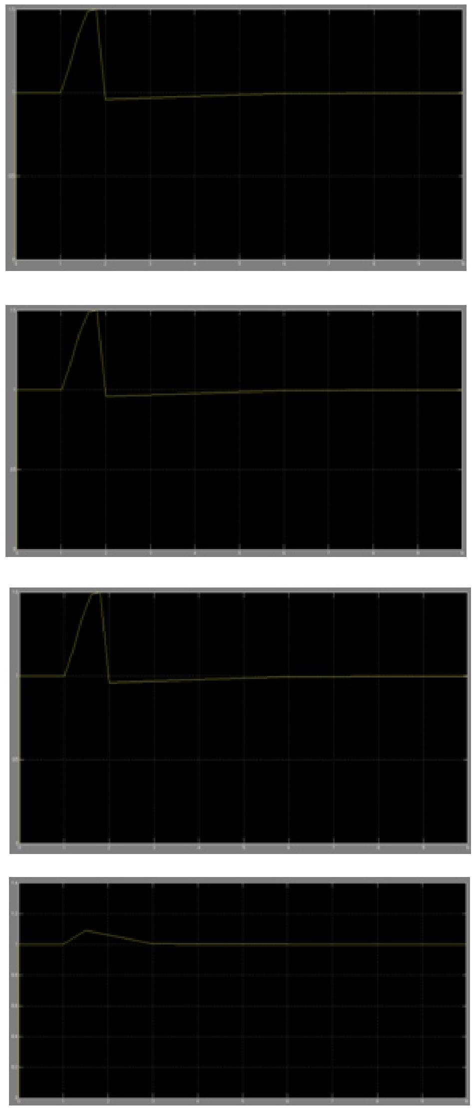

Fig 10: DC voltage profile at the MTDC grid terminals

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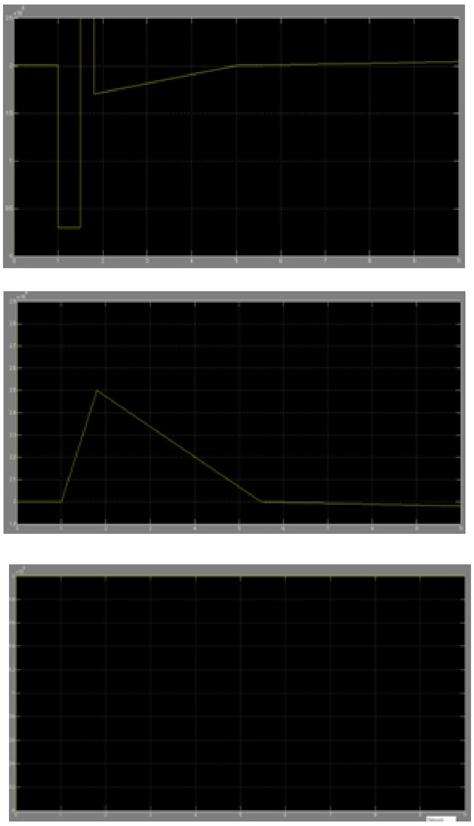
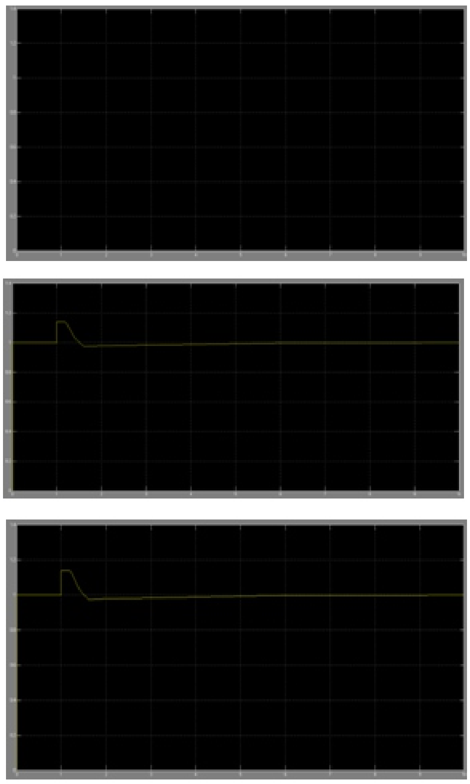


Fig 11: Active power flows on HVDC–VSC.



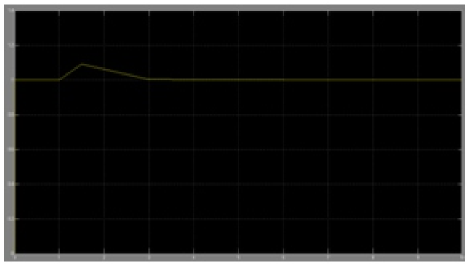


Fig 12: DC voltage profile at the MTDC grid terminals with onshore chopperresistors.

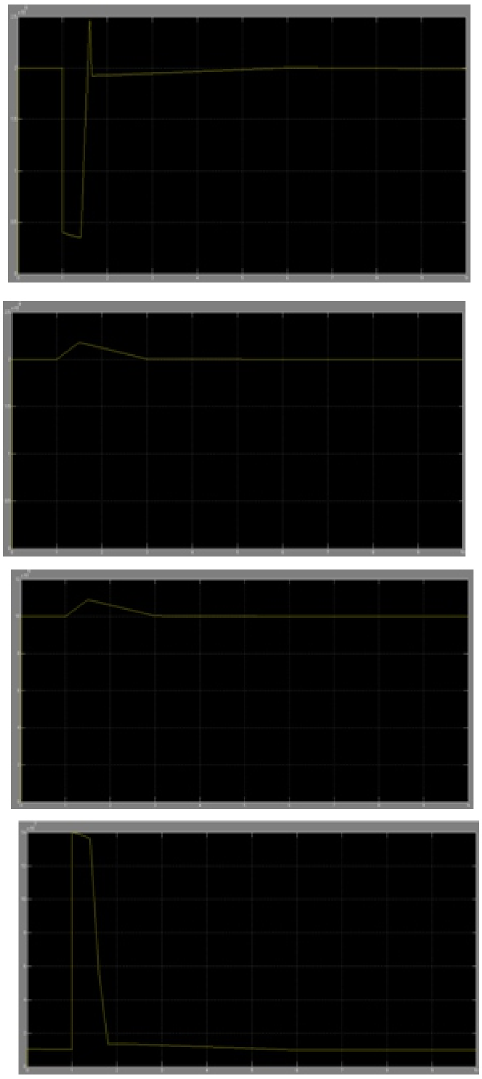


Fig 13: Onshore converter and dc choppers active power.

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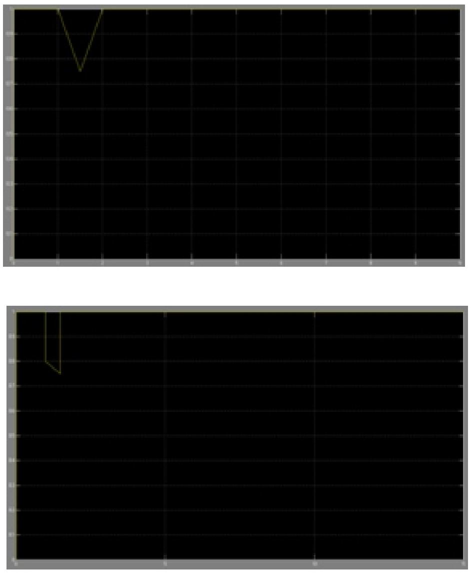

Fig 14: AC voltage profile at offshore network

CONCLUSION:

This paper provides a discussion on the identification and-development of communication-free control strategies for FRTprovision on MTDC grids interconnecting offshore WF with acmainland grids.The classical solution based on the use of onshore chopperresistors is an effective solution that can be easily implementedsince its control is based on local measurements. Although theuse of such strategy fully decouples offshore WF from themainlandac fault, which is benefic regarding the reduced stress conditionsfor the wind turbines, the size of the required dc chopperresistors my hinder its application from an economical point ofview.The major advantage of these strategies relies on less investmentregarding the implementation of the required control functionalities.

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