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Voltage Control of VSC-HVDC Transmission System for Offshore Wind Power Plant

[1] Maushmi Bankar, [2] Pawan Chandrakant Tapre [3] C.Veeresh
[1][2][3] Department of Electrical Engineering
S.N.D.College of Engineering & Reasearch Center, Nashik, India

Abstract: **— Wind power evolution in Northern Europe is foreseen to continue in the future with development of large-scale wind power plants (WPPs) on far offshore. Integration scheme of these WPPs to the onshore grids would grow from point-to-point connection to a transnational multi-terminal network where the transmission capacity serves both to evacuate the wind power and to facilitate power trading between countries. In such a situation, application of multi-terminal VSC-HVDC transmission is considered the favorable technological solution. A control strategy which capable of accommodating different dispatch schemes is however required. This paper presents a control strategy for dispatching power in the future transnational network situation. The control strategy is developed based on the voltage margin method and is customized to comply with different dispatch schemes possibly be applied in the future transnational network. The control strategy is implemented on a multi-terminal VSC-HVDC network representing the future transnational network and its capabilities are confirmed through simulation studies for normal and abnormal operations.**

Index Terms: **— wind power plants (WPPs) , VSC-HVDC MATLAB ,Fault Ride Through(FRT) methods.**

I. INTRODUCTION

Demand of electricity is ever increasing. Over the past decades, the increment in electricity demand has been largely balanced by capacity development of conventional generations. However, further capacity development of these generations to balance demand of electricity is considered unsustainable mainly due to limited resource of their primary energies and due to negative impacts they introduce to the environment. In order to meet the future demand of electricity as well as to replace ageing existing generations, a number of new generation technologies i.e. wind power, solar thermal, solar photovoltaic, biomass, biodiesel, tidal power and wave power, which make use of the renewable energy resources e.g. wind, solar, biomass, biodiesel, tidal and wave energy as their primary energy, have been developed. Wind power technology transforms kinetic energy in wind speed into electricity by utilizing a number of wind turbines. These wind turbines are installed in a particular area where the potency of wind energy is high and are linked together forming a wind power plant (WPP). At present, contribution of WPPs to electricity generation only covers a small percentage of the load. These WPPs are installed onshore and offshore close to the shore (less than 60 km). In the future, it is foreseen that a number of large capacity WPPs would be installed further offshore (more than 60 km) where high potency of wind energy and large space are available. In order to integrate the future far offshore WPPs into the onshore grid, long cable transmission would be required. Moreover, regarding the capacity of these WPPs, large transmission capacity would be required. For such a multi-terminal offshore network, where large power would be transmitted over long distance, application of high-voltage alternating-current transmission (HVAC) technology may be difficult to implement due to large amount of reactive power compensation required. Thus, an alternative is to use high-voltage direct-current transmission (HVDC) technology. Moreover, since the offshore network may act as a power pool where power may be injected to and extracted from the network at different nodes, flexibility to control direction of power whilst maintaining voltage in the network is required. For such a situation, implementation of voltage sourced converter HVDC(VSC-HVDC) technology is favorable.and voltages measured from one-end or two-end of the line [2]. Following the occurrence of a fault, the utility tries to restore power as quickly as possible. Rapid restoration of service reduces customer complaints, outage time, loss of revenue, and crew repair expense. All of these factors are increasingly important to the utilities facing challenges in today's market. To aid in rapid and efficient service restoration, algorithms have been developed to provide an estimate of the fault location. In this paper for the enhancement of the computational efficiency, instead of EMTP software, MATLAB software is used. Further, by using these voltages and currents phasor values, iterative method is used for calculating an accurate fault location. It is observed that Newton-Raphson based iterative method gives better results.

II. VARIOUS TYPES AND COMPARISON

2.1 Multi-Terminal VSC-HVDC Systems

A multi-terminal VSC-HVDC system contains of three or more converter stations that are linked together by a dc transmission network. Multiterminal VSC-HVDC systems is a relatively new research field, which has been attracting increasing attention since the turn of the century . A transmission network that includes many interconnected points and transfer power across great distances is often referred to as a ―super grid‖. Recently, discussions about a multi-terminal VSC-HVDC system that constitute to an

European dc super grid have emerged. An European dc super grid could be embedded in a conventional ac grid and provide a strong backbone to existing ac networks, along with all the benefits of VSC-HVDC technology (e.g., the ability to address issues of power transmission, asynchronous network interconnections, and stability support). Within a dc grid there can at most be one converter station assigned to constant dc voltage control mode, the other converter stations are assigned to active power control mode. If there are two converters with constant dc voltage control, there will be hunting phenomena. The converter station assigned to dc voltage control mode is often referred to as the dc slack-bus . The dc slack-bus needs to ensure keeping the dc voltage constant and compensating for all power unbalances in the dc grid including losses. for N converter stations,

$$0=\sum_{n=1}^{N} Pi + \sum_{n=1}^{N} PLi + PL, dc \qquad (1)$$

where Pi is the active power flow at the converter bridge of station i, PLi is the losses in converter station i, and PL,dc is the dc line losses. Because of the dc slack-bus configuration at one station and active power control configuration at other stations there will not be any steady state power deviations in the power controlled at the VSC-HVDC terminals.

2.2 Comparison of cost for HVAC and HVDC cable transmission:

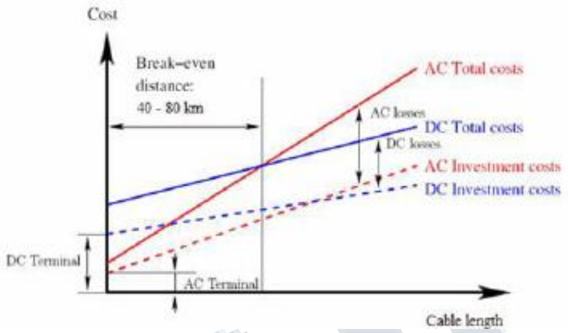

Figure2.1:Comparison of cost for HVAC and HVDC cable transmission

Regarding the transmission requirements, there are two options of cable transmission technology may be applied i.e. high-voltage alternating-current (HVAC) and high-voltage direct current (HVDC). Utilization of HVAC technology is more favorable than HVDC for short transmission distances. It is because, for such distance, HVDC technology introduces higher investment cost mainly due to its requirement to employ components for ac to dc conversion and vise versa. Contrarily, for long transmission, HVDC technology is preferable. It is due to, as the length increase, the amount of reactive power compensation required by HVAC transmission grows, and thus, for transmission longer than a particular distance, the total cost introduced by HVAC i.e. investment cost and cost due to reactive power compensation, would be higher than that by HVDC. The break even length between HVAC and HVDC transmission technology is relative and may vary depending on the capacity requirement of the transmission. Nevertheless, in general, the value lies between 40 km to 80 km . Therefore, in the case of a future transnational network, implementation of HVDC transmission is preferable.

III. METHODOLOGY

3.1 Fault Ride Through methods for VSC-HVDC connected WPP :

In a situation where the WPP is connected via a point–to-point VSC-HVDC transmission, such as during a voltage dip at the grid connection, the WPP power delivered by the corresponding inverting converter is reduced significantly. While the WPP is continuously injecting power into the dc link, the power imbalance will occur in the link. During power imbalance, the excess power in the dc link is stored in the dc capacitors and as the result the direct voltage will rise. The increase in the direct voltage may reach an endangering value if no preventive action is subsequently taken.

In order to prevent the direct voltage rises to a dangerously high value in the aforementioned situation, FRT methods may be applied i.e. energy dissipation and WPP power reduction. In the first method, a dc chopper is applied to dissipate the WPP excess power in a resistor during the voltage dip. The second method is accomplished by reducing the WPP power in order to restore the power balance in the dc link and can be achieved by fast signaling, voltage reduction and frequency modulation.

Fast signaling is established between the WPPVSC and the WPP through a communication link. During a voltage dip, the control systems in the WPPVSC sense the endangering increase in the direct voltage and signal the control systems in the WPP to quickly reduce the WPP power. For a severe voltage dip, the direct voltage may rise very quickly and thus a fast execution is required. However, due to the use of communication, the signaling process experiences a communication delay and thus a fast execution may be difficult to achieve.

WPP power reduction by voltage reduction is accomplished by quickly reducing the WPP bus voltage. This is done by the control systems in the WPPVSC and can be performed as long as the WPPVSC is assigned to control the WPP bus voltage and the WPP employs wind turbine with power electronic converter. The power electronic converter of this wind turbine commonly has current limit slightly above its rated current. When the direct voltage rises above a threshold value, the voltage controller in the WPPVSC quickly reduces the amplitude of the converter voltage in order for the WPPVSC to absorb the reactive power from the local WPP grid. This action causes the WPP bus voltage to drop. The WPP is thus operated at its current limit and the power it delivers is reduced. It should be noted that for the method to work properly, the capability of the wind turbine power electronic converter to provide voltage support should be disabled.

In the frequency modulation method, the frequency of the WPP local grid is increased when the direct voltage level increases above the threshold value. This action is performed by the frequency modulator in the WPPVSC. As in the case of the voltage reduction method, this method is applied for a WPP consisted of wind turbine with power electronic converter. In the wind turbine power electronic converter, a PLL is commonly employed to continuously measure the actual phase angle of the bus voltage required for the transformation of the phase quantities into the *dq* quantities and vise versa. The same PLL can be used to continuously measure the actual WPP grid frequency. A controller, say the frequency controller, which translates the frequency increment into power reduction order is required to be installed in the wind turbine power electronic converter for the WPP to sense the changes in frequency. The output of this controller is applied to reduce the active power reference value for the active power controller in the wind turbine power electronic converter.

3.2 FRT methods for multi-terminal VSC-HVDC

In the multi-terminal VSC-HVDC case, the occurrence of a voltage dip on one of the grid connections does not necessarily lead to an abnormal rise in the direct voltage since it is possible that there is more than one converter assigned to compensate for power imbalance in the dc link. However, since the task specified for the converters may change during operation, implementation of FRT method is still required.

The energy dissipation method and the frequency modulation method are implemented in the multi-terminal network model. It is based on the following considerations. First, the energy dissipation method is robust. Moreover, by installing the dc chopper at the GSVSC, the capacity required for the dc chopper may not be as large as the rated capacity of the WPP but is more dictated by the rated capacity of the GSVSC. Second, considering the reliability of the FRT method, one of the WPP power reduction methods is added. Third, in a future transnational network, it might be possible that some electric devices are required to be installed in the WPPVSC to acquire controllability of the wind turbine connections remotely from the shore. The operation of the devices may depend on the actual voltage of the WPP bus. In such a situation, the application of the frequency modulation method is more favorable than the voltage reduction method.

In a future transnational offshore network, it is possible that two grids are connected onshore via an ac tie line. In the case when the grids are strongly connected, a voltage dip occurring at one grid may influence a voltage dip on the other grid. Thus, during the voltage dip, the direct voltage at the GSVSCs of the corresponding grids may rise high. The action of a dc chopper installed at one of the GSVSCs may not be to control the direct voltage at both GSVSCs. The direct voltage at the other GSVSC may still be high especially if the two GSVSCs are spaced by a long dc transmission. Based on that consideration, in a multi-terminal network model, the dc chopper is installed on each of the GSVSCs while the frequency modulation method is implemented at each of the WPPs and the WPPVSCs.

IV. CONCLUSION

In this paper we have seen the cost comparison of HVAC and HVDC system basedon which we use the HVDC system also the multiterminal VSC-HVDC system and fault ride through methods which can be used to control the voltage of power plant during severe terrestrial grid faults by switching the grid side converter from operating mode to power reduction mode.

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