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A Comparative Analysis of Primary Control in Multi Terminal HVDC Transmission Systems

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Abstract –*With recent developments in power electronic technology, high-voltage direct current (HVDC) transmission systems have emerged as a viable option for power transmission, mainly across long distances. In this paper, we proposed five terminal HVDC systems as more than two terminals. Multi-terminal high-voltage DC systems are appealing methods for linking offshore wind farms to alternating current (AC) networks. While frequency is a worldwide signal in AC grids, DC voltage can be thought of as its dual in MTDC systems. Unlike frequency, however, DC voltage cannot be equal across the MTDC system. One of the major issues with MTDC systems is the control of DC voltage. Due to intermittent nature of wind, optimum regulation of MTDC systems in the presence of offshore wind farms to minimize MTDC system loss while considering scheduled electricity is a difficulty. Here we considered the control methods of voltage margin and voltage droop methods. The VMM is considering at the cable to ground fault in the middle of a DC cable and VDM is consider at the cable to ground fault very close to a converter. A comparative analysis of control methods with a sliding mode control, the system response is fast and with very small overshoot. Effectiveness of the approach proposed is demonstrated by simulations performed with MATLAB/SIMULINK.*

Keywords – MTDC, HVDC, Sliding mode control (SMC), Proportional Resonant (PR), VMM, and VDM.

1. INTRODUCTION

Because of advancements in power electronics, voltage source converter-based HVDC (VSC-HVDC), also known as light HVDC, has recently emerged as a demanding option to line commutated HVDC for transmitting power over long distances and between asynchronous links. Among the various choices, the VSC-HVDC is particularly suitable for integrating offshore wind farms into the AC grid since it offers appealing features such as reactive power assistance for wind farms, relatively smaller sized filters, and black-start capabilities. VSC-HVDC has an advantage over line commutated HVDC in multi-terminal HVDC networks because it can change the direction of power flow without reversing the voltage polarity of the DC cables. Because renewable energy sources are typically located in remote locations, multi-terminal VSC-HVDC systems offer additional economic and technological advantages over standard AC systems. One of the issues with these approaches is that they employ proportional-integral (PI) controllers, which are linear controllers that are dependent on grid parameters. Because of the intermittent nature of the wind, it is unavoidable for HVDC grid converters to run at different operating points if maximal power extraction from the wind is the goal. Furthermore, the short circuit ratio (SCR) value of the connected AC grids can fluctuate due to line disconnection, etc. Furthermore, disconnecting a converter or a DC line can cause a change in the power system's topology. As a result, a control mechanism that is resistant to changes in model parameters, system topology, and operating point is necessary. This section's HVDC system is a non-linear system. Furthermore, it is assumed that each terminal makes use of local information as well as estimated values of other terminals' parameters. As a result, a nonlinear controller that is not sensitive to model uncertainty, such as sliding mode control (SMC), can be an appealing option. External disturbance rejection and quick dynamic reaction are two further advantages of SMC.

One of the most significant issues is keeping the DC voltage across the grid within acceptable limits. DC overvoltage may cause converter damage, whereas DC under voltage may reduce converter controllability. The HVDC grid functions similarly to a power pool. That is, if the grid's power balance is not maintained, the DC voltage will shift. Injecting active power into the HVDC grid raises the DC voltage, whereas removing active power lowers the DC voltage. The voltage margin method (VMM) and voltage droop method (VDM) are the most well-known methodologies among those presented. All or some converters in VDM engage in DC voltage control by altering their injected active powers based on a preset droop. When this approach is used, the steady-state DC voltage deviates from the pre-disturbance values. In contrast, in VMM, one converter is responsible for maintaining the desired DC voltage level, while the other terminals run in constant power mode. When the DC voltage controller converter is no longer capable of supplying or extracting the active power required to control its DC voltage, another converter acts as the slack converter. A margin must be considered between the terminals' reference DC voltages. The converter is put under a lot of strain during the transition between these two reference voltages. Sliding mode control (SMC) is a variable structure control that was developed for systems whose dynamics can be modeled using ordinary differential equations. SMC has characteristics such as parameter insensitivity, external disturbance rejection, and fast dynamic response.

2. SYSTEM MODELING

Take a look at the five-terminal HVDC grid depicted in Figure 1. Converter 4 connects a wind farm to the MTDC system and harvests the maximum power from the wind farm; thus, it runs in CPM mode; nevertheless, it is assumed that this converter does not contribute to DC voltage management and instead follows wind changes. Except for converter 4, all converters in the VDM engage in DC voltage control. In order to reduce the short circuit current, reactors are connected in series with the DC connections. The behavior of the system is compared when the original VMM and VDM with SMC and SMC-PR.

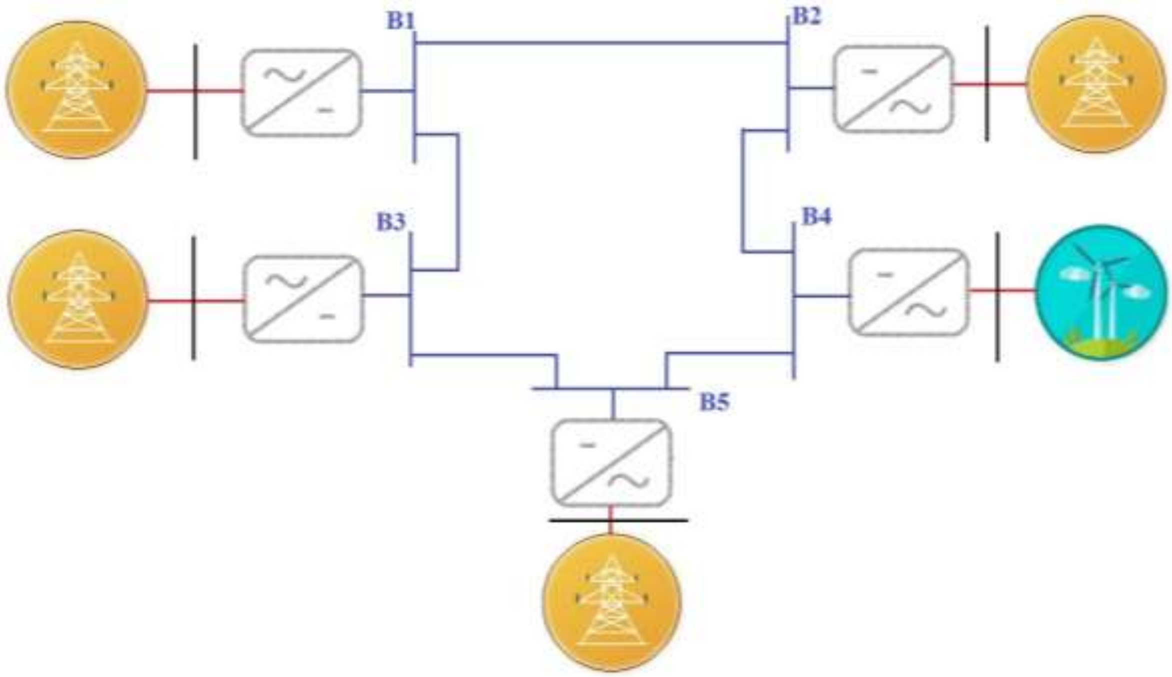

Fig.1. MTDC system with five terminals

To replace the standard control system, we suggest a sliding mode control system in this study. Both VMM and VDM approaches will be supported by the system. Figures 2-5 represent the block diagrams for the suggested SMC-PR approaches. Sliding mode control (SMC) is a variable structure control that was developed for systems whose dynamics can be modeled using ordinary differential equations. SMC-PR has characteristics such as parameter insensitivity, external disturbance rejection, and fast dynamic response. Given the quick dynamics of the MTDC system, SMC may be a viable choice for MTDC system control. Furthermore, even if the values of any of the system's parameters vary, SMC-PR still performs well.

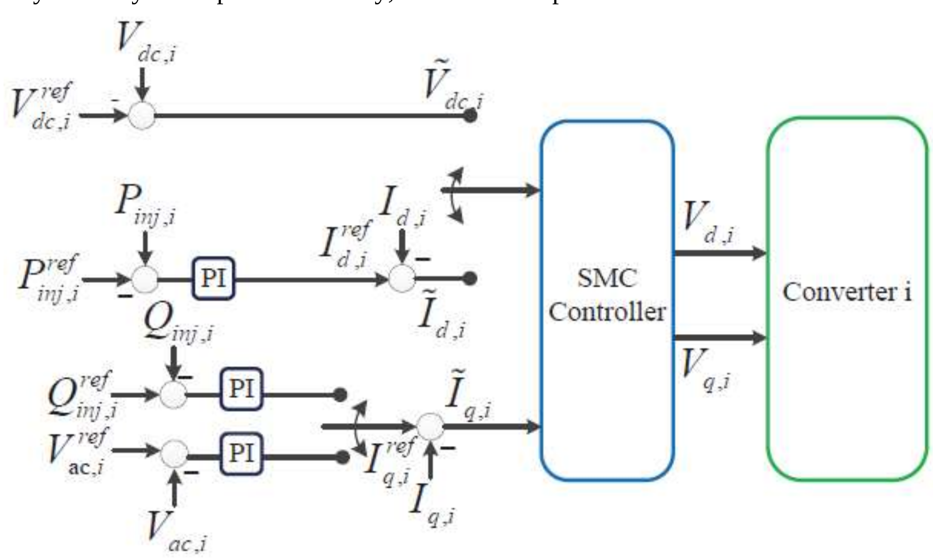

Fig.2. SMC VMM Controller

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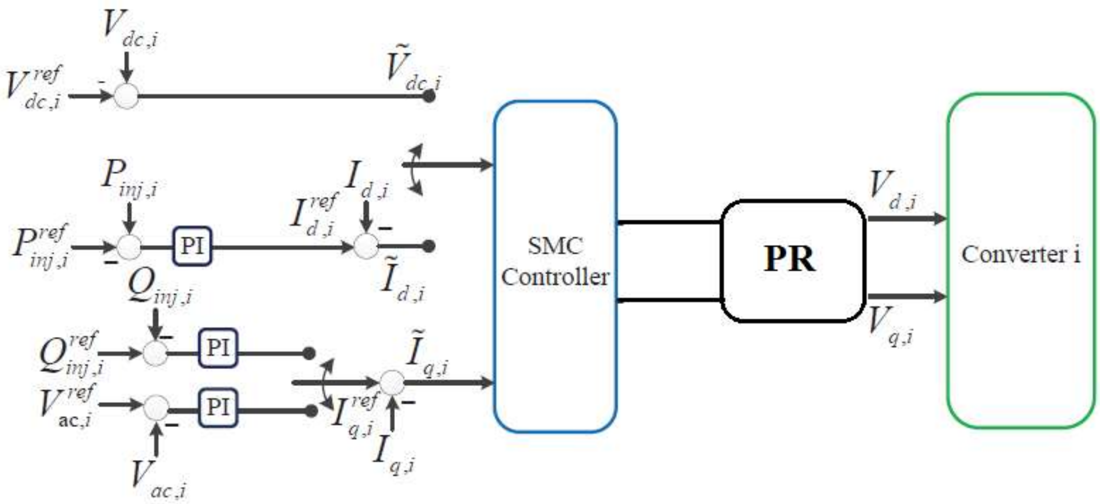

Fig.3. SMC-PR VMM Controller

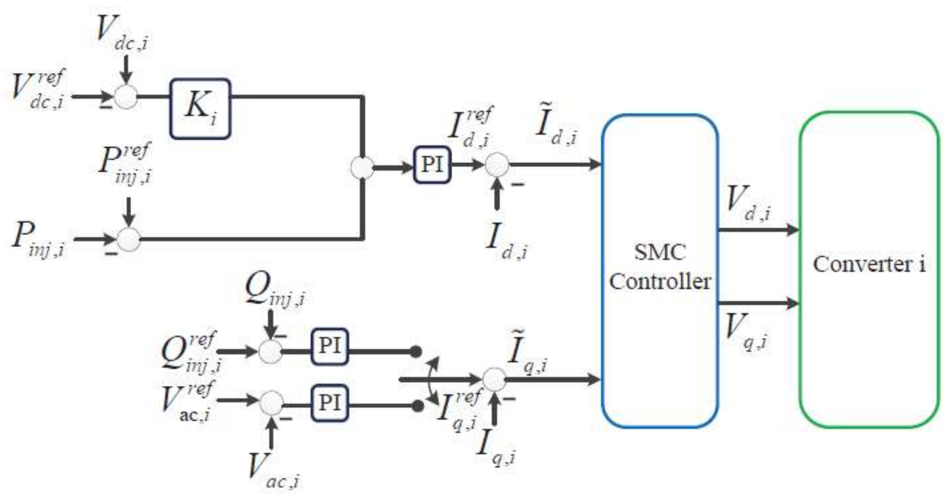

Fig.4. SMC VDM Controller

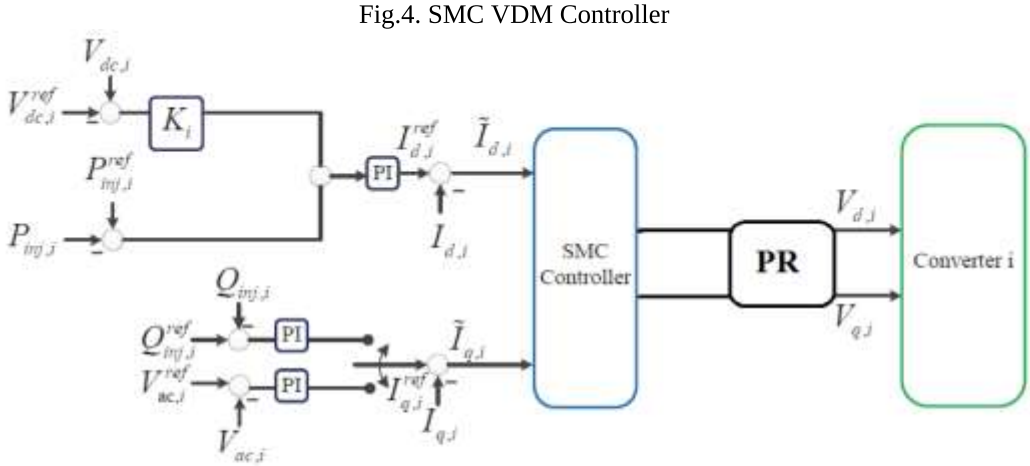

Fig.5. SMC-PR VDM Controller

3. SIMULATION RESULTS

MATLAB/Simulink simulations results are presented at MTDC system connected to four AC grids and one offshore wind farm. In this a primary control is the main aim to control the DC voltage and power in the MTDC system. One of the most significant issues is keeping the DC voltage across the grid within acceptable limits. DC overvoltage may cause converter damage, but DC under voltage may reduce converter controllability. The HVDC grid functions similarly to a power pool. That is, if the grid's power balance is in balance. If the DC voltage is not maintained, it will change. The grid raises the DC voltage while taking active power from it, lowering the voltage.

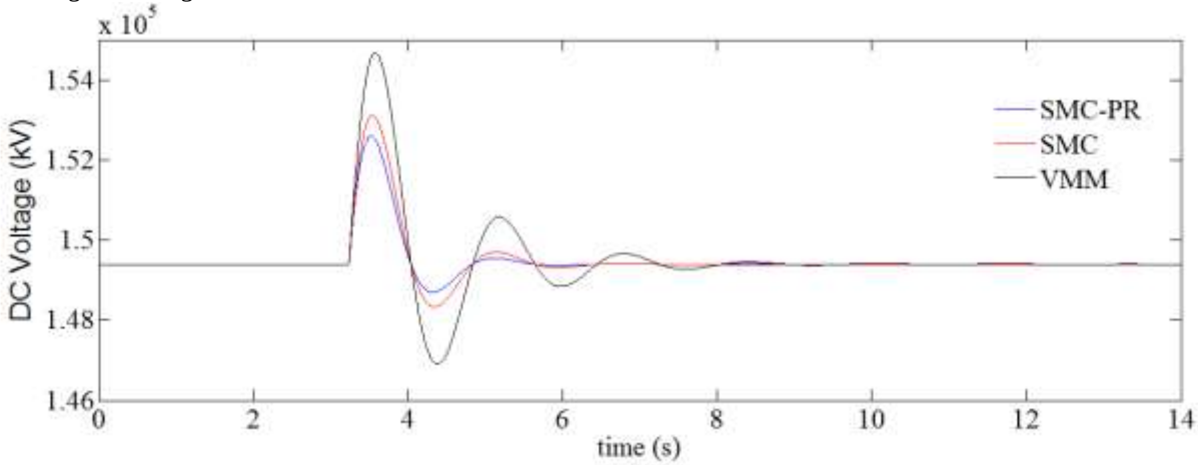

Fig.6. waveforms of DC voltage at Converter 4 VMM, SMC, SMC-PR.

In this scenario, we're examining at a cable-to-ground problem in the middle of cable B3-B4. At t = 3.6 s, the fault occurs. We employed a DC reactor to simplify the design of a DC breaker. At t = 3.602 s, we suppose the fault is cleared by unplugging the cable. It is important to note that in VMM, the controller of converter 1 controls Vdc, while the controllers of the other converters control their injected active powers. SCR = 1 is chosen as the selected SCR value of connected AC grids. As seen in the figures, SMC-PR can track wind variations very quickly and with very minor deviations in DC voltage. Disconnection of a converter, on the other hand, generates enormous oscillations in the VMM, SMC and SMC-PR-controlled systems, whereas SMC-PR controllers can adjust the voltage very quickly and with low oscillation.

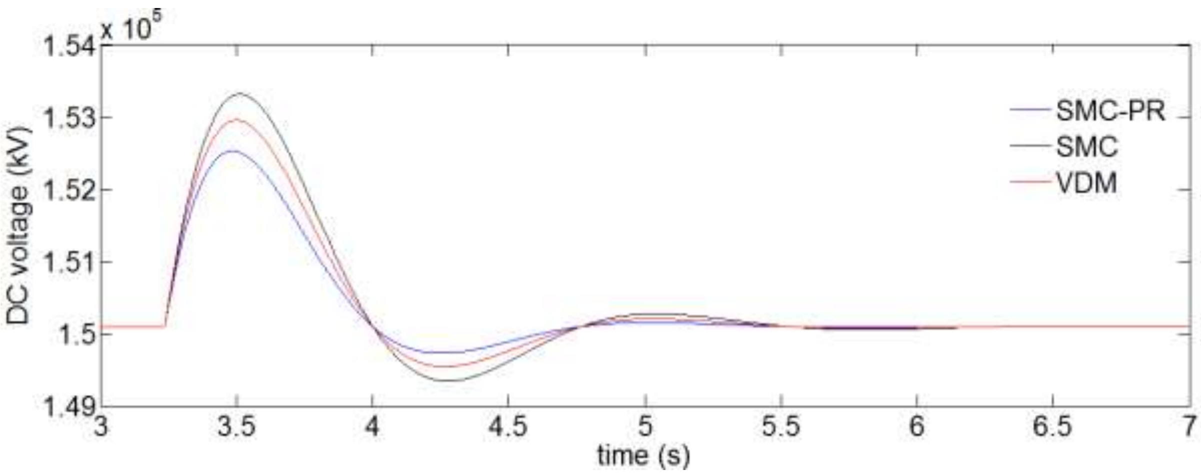

Fig.7. waveforms of DC voltage at Converter 4 with VDM, SMC, SMC-PR.

In this scenario, we analyze another disturbance, a cable-to-ground short circuit at cable B1-B2, which is extremely close to the converter 1. The fault occurs at t = 1 s and is cleared by unplugging the cable at t = 1.002 s. This also causes a change in the system's topology. Given its position and the system's specified SCR, we anticipate that this issue will cause higher DC voltage deviation. Both VMM and VDM exhibit greater oscillatory responses than the replies, as shown in these images. By implementing the SMC-PR controller, the oscillations are reduced and settling time will be less.

CONCLUSION

We explored the primary control and AC-DC expansion planning challenges of multi-terminal high-voltage direct-current systems here. The SMC controller was VDM and VMM compatible. The findings were compared to systems controlled by VMM and VDM controllers. It was demonstrated that the response time of an MTDC system with SMC-PR is very quick and has very minimal oscillations. Furthermore, it is less sensitive to changes in the SCR, operating point, and system topology. The system's behaviour has been investigated when it encounters problems in the HVDC grid, changes in the operating point, and the disconnection of a converter. When compared to VMM, VDM, and SMC, it has been demonstrated that SMC-PR techniques can manage the DC voltage in an HVDC grid relatively quickly, with a shorter settling time, and with less overshoot over a wider range of SCR values. Furthermore, when a converter is disconnected and the operating point and topology change, systems equipped with SMC-PR controllers have much lower overshoot in their reaction.

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