A NEW CONTROL STRATEGY OF AN OFFSHORE INTEGRATED MMC MULTI-TERMINAL HVDC SYSTEM

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Abstract— *The modular multilevel converter (MMC) provides promising development for high-voltage direct current (HVDC) applications, including multi terminal HVDC (MTDC) and renewable energy integration. This paper, considering an offshore wind farm (OWF) integrated MMC MTDC system, investigates its start-up process with three main developments: 1) it further develops the mathematical model of MTDC with active networks and proposes a hierarchical start-up control scheme; 2) for the terminal which connects the OWF, it proposes a reduced dc voltage control scheme of mitigating the current surges with de-blocking the converter at zero voltage difference on sub modules (SMs) and proposes an overall sequential start-up control scheme for the offshore integrated MTDC; and 3) it analyzes and compares different start-up control schemes. To evaluate the proposed sequential start-up control scheme, an offshore MMC HVDC system is established on the RTDS. The simulation results verify effectiveness of the proposed scheme on the MMC MTDC system with two control paradigms, i.e., master–slave control and droop control, respectively. In comparison with different start-up control schemes, the superiority of the mitigation of voltage spikes and current surges are shown using the proposed scheme with less complexity and easier implementation.*

Keywords—Droop Control; Master–Slave Control; Modular Multilevel Converter (MMC); Multi-Terminal HVDC (MTDC); Offshore Wind Farm (OWF); Sequential Start-up Control

1. INTRODUCTION

Based on extensive research and applications, VSC technology has gradually achieved a high degree of maturity, and there have been numerous projects on VSC-based HVDC applications, including the applications of MTDC and renewable energy integration in recent years. There has been a variety of topologies with the VSC development. Among them, one of these, the MMC, has salient features and shows its strong competitiveness, which has been well recognized by research and applications. Since there are various vitality capacitors in the SMs of the MMCs, it is vital to precharge these capacitors amid the startup organize and the framework startup control is basic. In, a startup control conspires for the MMC was proposed. The proposed control plot depended on the control of a helper voltage source at the MMC dc-side. Notwithstanding, it is for the most part anticipated that would begin a framework without assistant sources, which spares space and expenses. In a startup strategy utilizing extra resistors was proposed. The resistors were associated on the converter arms and were embedded/circumvent to restrain the arm current. In any case, the extra resistive misfortunes were not anticipated. In a startup plot with a two-organize charging process for MMC was proposed. In spite of the fact that the proposed charging plan appeared to accomplish charging the voltage of every SM capacitor to the appraised an incentive without helper dc source, it had two fundamental issues. Initially, in the primary charging stage, the dc voltage was thought to be the evaluated esteem and the charging of the SM capacitors was from the dc side. Under this presumption, the proposed plot was legitimate for the MMC under inverter operations. Second, in the second charging stage, the proposed plot was that the SM capacitor voltages were charged to the appraised esteem when the SMs were deblocked. Be that as it may, the primary target of the start-up control of MMC is to pre-charge the SM capacitors to the appraised an incentive before they are deblocked. A start-up plot for MMC HVDC was proposed in including the computation of the restricting resistance, the setting of the rising incline of dc voltage and the reference setting of receptive power. In, a computation technique for the base restricting resistance was proposed. In, the elements of the SMs in the MMC amid the pre-charging process were examined and a streamlined tweak calculation was proposed for diminishing the present surges while deblocking the MMC. Hypothetically, a MMC can be deblocked at zero voltage contrast and the present surges under this condition are the littlest. Nonetheless, the control plot proposed in did not accomplish zero voltage contrast while deblocking the MMC. The start-up plans proposed above were altogether in view of two-terminal MMC HVDC frameworks. In, a three-terminal MMC HVDC framework in light of a genuine application was researched, and a control strategy of beginning the framework was proposed in detail. Be that as it may, these techniques were gotten as a theoretical approach, which depended on the investigation at methodical level. There was no investigation on the flow of the SMs in the MMC with no far reaching recreation comes about. Distinctive successive startup control was looked at in, while most examinations depended on recreations and the investigation were not complete with no numerical inductions. Thus, the startup control including the startup arrangement of MMC

MTDC frameworks merits our investigation and investigation. This task researches the start-up procedure of an OWF coordinated MMC MTDC framework with the primary commitments given as takes after.

1) Regarding a MMC MTDC framework with dynamic air conditioning systems, the scientific model previously, then after the fact the deblocking of the converter is additionally formed on into a moment arrange circuit with the thought of the converter arm inductor. A progressive start-up control conspire is proposed. Considering the way that an OWF is an aloof air conditioning system before the finishing of its start-up, a start-up control procedure for the converter interfacing with the OWF with deblocking the converter at zero voltage contrast on SMs is proposed;

2) A four-terminal MMC HVDC framework is set up on the RTDS with one terminal interfacing with an OWF. The viability of the proposed consecutive start-up control conspire is confirmed by the reproduction comes about. The prevalence of the proposed conspire, as far as relieving the voltage spikes and current surges, than other control plans is thought about, and the simple execution of the proposed plot is displayed;

3) The proposed start-up control conspire is approved on the MMC MTDC framework with master– slave control and droop control, separately.

2. HVDC TRANSMISSION SYSTEM

2.1 INTRODUCTION

The decision for the installation of HVDC over HVAC involves capital investments and losses. A DC line with two conductors can convey an indistinguishable measure of energy from an AC line with three conductors of a similar size and protection parameters. These outcomes in littler impression and more straightforward plan of towers, diminished conductor and protection costs. Besides, line speculations are diminished by nonattendance of remuneration gadgets, since DC lines don't devour receptive power. Power misfortunes are lessened because of 30% decrease in conduction misfortunes, limited crown impact and littler dielectric misfortunes if there should arise an occurrence of a linkThe HVDC transmission technology base on high-power electronic devices is widely used nowadays in electrical systems for the transmission of large amounts of power over long distances.

The transformation from AC to DC and vice versa is realized by two converter types:

- Current-Source Converters (CSC);
- Voltage-Source Converters (VSC).

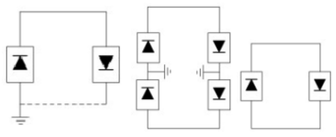
Traditional CSCs with mercury-arc valves were used since 1950s, until they were substituted by thyristors in the mid-1970s. On account of the fast improvement of self-commutated gadgets and smaller scale controllers, an option as VSC turned out to be monetarily attainable. Bringing about the principal VSC-HVDC venture introduced in 1997. Both converter innovations have diverse operational standards and points of interest and disadvantages. The choice of which alternative to choose relies upon the prerequisites of specific undertaking.

2.2 CONFIGURATION OF HVDC TRANSMISSON

Contingent upon practical perspectives, three principle HVDC arrangements appeared in Figure 2.1 are utilized.

Mono polar arrangement (a) - interconnects two converter stations by means of a solitary line, with the likelihood to work at both DC polarities. Ground, ocean or metallic conveyor can be utilized for return way.

Bipolar arrangement (b) - includes two conductors, working at inverse polarities. This outcomes in two free DC circuits, appraised at half limit each. Amid blackouts of one shaft, a mono polar operation can be utilized. This is the most widely recognized arrangement for current HVDC transmission.



(a) (b) (c)

Figure 2.1 - HVDC system configurations. (a) Mono polar. (b) Bipolar. (c) Back-to-back

- In Back-to-Back configuration (c) - the DC sides of two converters are directly connected, having no DC transmission line. This arrangement is used for the interconnection of asynchronous AC systems.

2.2.1 VSC-HVDC TRANSMISSON

Despite the fact that customary CSC-HVDC transmission is settled for high power and voltage appraisals (normally up to a few GW and ±800 kV), it is anticipated, that starting now and into the foreseeable future the VSCs will be prevailing later on high power HVDC interconnections because of various preferences in monetary and specialized highlights. The principle points of interest of VSC-HVDC over CSC-HVDC are condensed,

a. Independent responsive power control at the two terminals, plausibility of four quadrant operation (Figure 2.2). The disposal of responsive power pay gadgets brings about critical impression decrease;
b. Dynamic support of the AC network voltage. Operation as STATCOM expands exchange capacity and solidness of the AC network;
c. Possibility of association with the feeble and latent networks. Low short out limit necessities of the AC matrix. Since a VSC can be considered as a virtual synchronous generator, it can be utilized for framing seaward AC authority frameworks for wind control parks;

The common design of present day VSC-HVDC transmission framework is appeared in Figure 2.3. Two DC conductors of inverse extremity interconnect two converter stations. The extremity of the DC-connect voltage continues as before while the DC current is turned around when the heading of the power exchange must be changed.

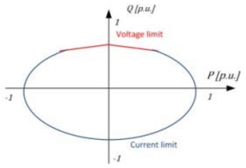


Figure 2.2 - Active-reactive locus diagram of VSC-HVDC transmission

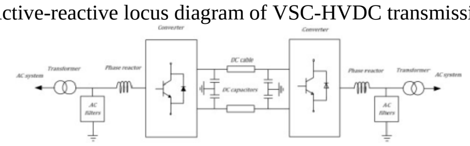


Figure 2.3 - VSC-HVDC system configuration

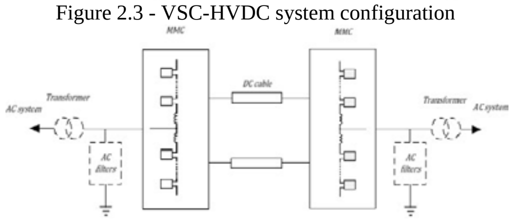


Figure 2.4 - MMC-HVDC system configuration

The DC side capacitors guarantee support and sifting of the DC voltage. The converter AC terminals are associated with stage reactors and consonant channels. The stage reactors guarantee control of energy trade between the converter and AC framework, the restriction of blame streams and hindering of current sounds showing up because of PWM. The AC channels diminish music content on the AC transport voltage.

Hypothetically all the multilevel topologies displayed in this section can be utilized as a part of VSC-HVDC setups. Be that as it may, because of the intricate structure, voltage adjusting issues and conservative contemplations, the majority of the genuine uses of VSC-HVDC frameworks depend on the demonstrated two-level and three-level NPC converter innovations With the presentation of MMC, the application ranges of VSC-HVDC transmission can be expanded altogether. Because of the various points of interest, for example, particularity, expanded proficiency and dependability that MMC presents, it intends to substitute the current VSC-HVDC topologies in the closest future.

2.3 GRID CODE REQUIREMENTS OF HVDC SYSTEMS

The Grid Code is an official document which governs the relationship between the participants of the electrical system. Its fundamental reason for existing is to give the base specialized, plan and operational determinations for the power era, transmission and dispersion as a piece of a huge system. The vast majority of the national Grid Codes are centered around AC control frameworks, having exceptionally shallow front of DC interconnections or not specifying them by any means. Also, the specialized and matrix association details for HVDC frameworks are not institutionalized at exhibit. In any case, data with respect to DC interconnections is given in the UK Grid Codes. The principle viewpoints with respect to operational and control necessities, and in addition blame ride-through requirements for HVDC are abridged underneath.

2.3.1 Operation requirements

Since the AC grid is a dynamic framework, its primary parameters, for example, voltage at various system focuses and recurrence are subjected to variety because of progress in control adjust and structure of the lattice. These varieties to some degree ought not influence the operation of the HVDC transmission. The base operation capacities are characterized.

The connection of the converter dynamic power and the lattice recurrence for both inverter and rectifier modes is appeared in Figure 2.5. It can be watched, that in inverter mode, when framework recurrence is diminishing, dynamic power yield can be lessened just by 5% of appraised. In opposite, dynamic power input must be lessened up to 40% while amending.

Figure 2.5 - Active power/frequency ratio

2.3.2 Fault Ride-Through requirement

Fault ride-through capacity is characterized as the capacity of the power converter to withstand diverse sorts of flaws. As indicated by the converter must stay steady and associated with the framework without stumbling for a nearby strong three-stage or any lopsided short out blame for up to 140ms. Each point on hold speaks to framework voltage level and the related time span which converter must remain associated. At the point when voltage level is beneath the line, converter disengagement is permitted.

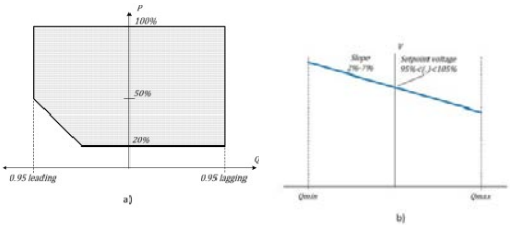


Figure 2.6 - (a) Reactive power requirements. (b) Voltage control requirements

Endless supply of the blame and inside 0.5 seconds of the reclamation of the voltage to the 90%, dynamic power yield ought to be re-established to no less than 90% of the pre-blame level.

3. HVDC MMC

3.1 INTRODUCTION

In this chapter the most common multilevel converter topologies are review. Particular concentration is address in the Modular Multilevel Converter, central for this project. Several modulation strategies related for MMC are also review. Then, an overview of HVDC systems is presented.

3.2 REVIEW OF MULTI LEVEL CONVERTER TOPOLOGIES

Multilevel Converters have been a topic of research for more than three decades and are still a developing technology.A few diverse multilevel topologies have been proposed. Some of the most common multilevel topologies are:

- Neutral-Point Clamped (NPC)
- Flying Capacitor (FC)
- Cascaded H-Bridge (CHB).
- Modular Multilevel Converters (MMC)

3.3 MODULAR MULTI LEVEL CONVERTER

The MMC topology depends on an arrangement association of indistinguishable components, called sub-modules or cells. Each sub-module speaks to the fundamental segment of the MMC, appeared in Figure 3.4-a. The arrangement association of sub-modules in one stage is known as leg. The leg is partitioned into upper and lower arms to such an extent that the quantity of the sub-modules in each arm is equivalent.

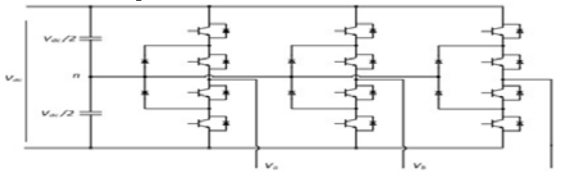


Figure 3.1 - Topology of three level NPC converter

As per the test contemplates performed in assessing the capacitor adjust and exchanging misfortunes, the half-connect topology is the most great topology to be executed in the sub-modules when bidirectional influence change is required. In this undertaking, the term sub-module alludes to a half-connect framed by two bidirectional switches with against parallel diodes and a DC capacitor as appeared in Figure 3.3-b. The capacitor goes about as a vitality cushion and a voltage source.

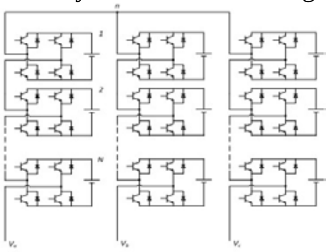
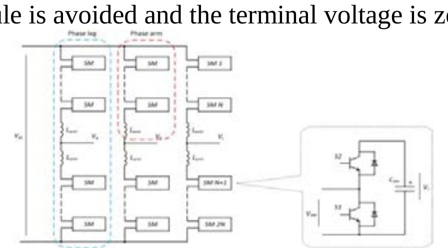


Figure 3.2 - Topology of Cascaded H-Bridge Inverter

Since all the sub-modules are indistinguishable, the operation guideline of MMC can be continued to the cell level operation. Each sub-module has two states relying upon the switch positions. At the point when the switch S1 in Figure 3.3-b is ON and the turn S2 is OFF, the sub-module is embedded into the circuit. The voltage between the terminals is equivalent to the capacitor voltage. At the point when the lower switch is ON and the upper is OFF the sub-module is avoided and the terminal voltage is zero.



(a) (b)

Figure 3.3 - (a) Topology of three-phase MMC (b) Half-bridge sub-module

Because of its plausibility to be scaled to high voltage levels, achievable effectiveness, simplicity of usage, low music yield and dependability, the MMC ends up being to be the most appropriate topology for present day HVDC applications.

3.4 MODULATION TECHNIQUES OF MMC

Multilevel modulation methods can be split into two main categories: Space Vector Modulation (SVM) and Voltage level Based Modulation; i.e. Carrier PWM (CPWM) and Nearest Level Modulation.

4. SIMULATION RESULTS

In order to verify the effectiveness of the proposed scheme, a four-terminal MMC HVDC system with one terminal connected with an OWF is established on the RTDS.

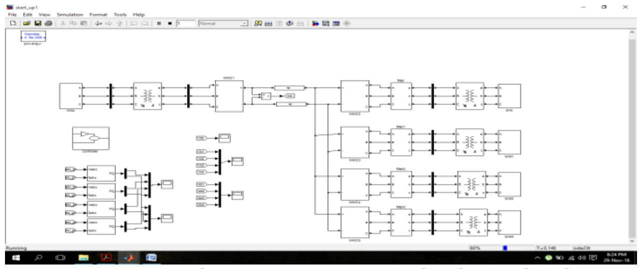


Fig:4.1- MTDC without a starting resistor and without reduced DC voltage control

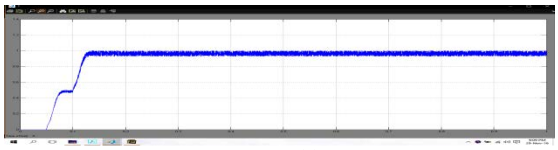


Fig:4.2(a)

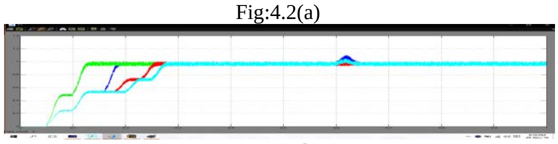


Fig:4.2(b)

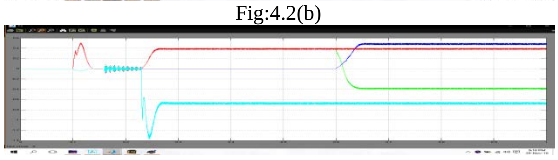


Fig:4.2(c)

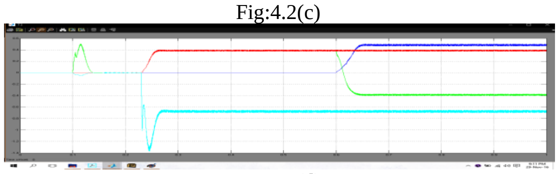


Fig:4.2(d)

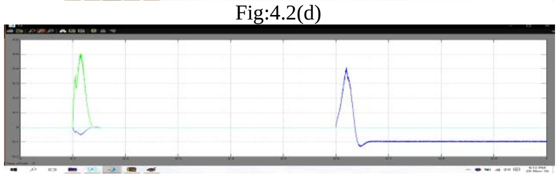


Fig:4.2(e)

Fig:4.2- MTDC without a starting resistor and without reduced DC voltage control (*Case A*): (a) MMC-2 DC side voltage, (b) SM capacitor voltages; (c) MTDC currents, (d) active power, and (e) reactive power.

In this case, the MTDC is started without starting resistor and without reduced dc voltage control. Simulation results are shown in Fig. 5.2.

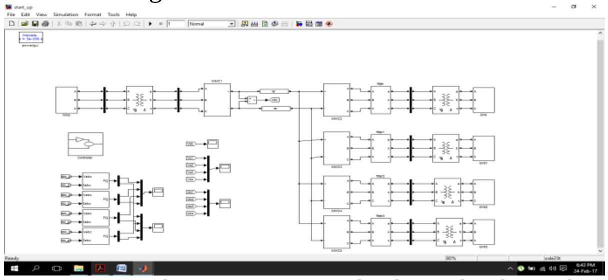


Fig:4.3- MTDC with a starting resistor and without reduced DC voltage control

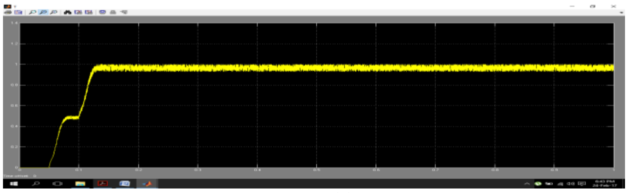


Fig:4.4(a)

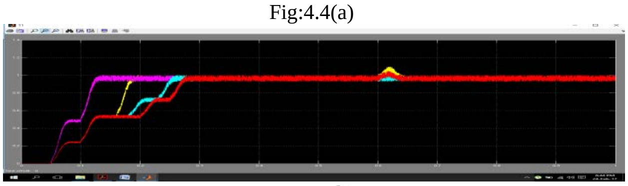


Fig:4.4(b)

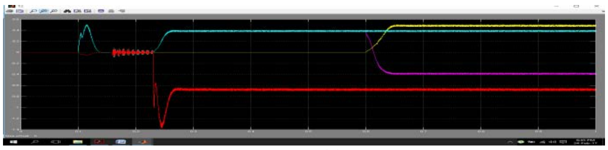


Fig:4.4(c)

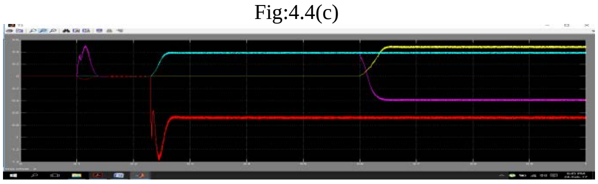


Fig:4.4(d)

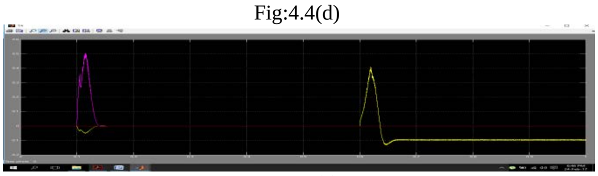


Fig:4.4(e)

Fig:4.4- MTDC with a starting resistor and without reduced DC voltage control (*Case B*). (a) MMC-2 dc side voltage. (b) SM capacitor voltages. (c) MTDC currents. (d) Active power. (e) Reactive power.

In this case, the start-up sequence is similar to that of *Case A*, except that the starting resistor is used. Simulation results are shown in Fig. 12.

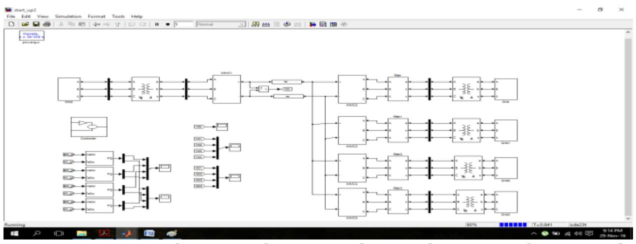


Fig:4.5- MTDC with master-slave control using the proposed sequential start-up control

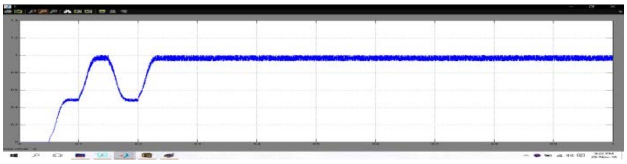
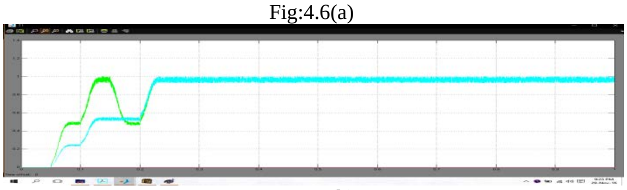


Fig:4.6(a)



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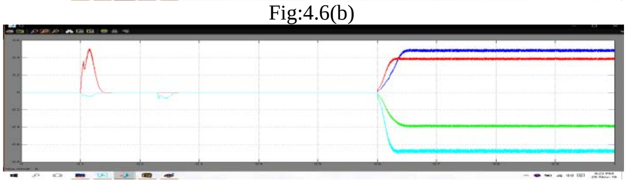

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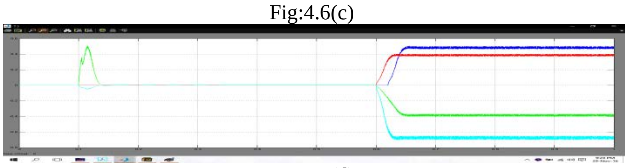

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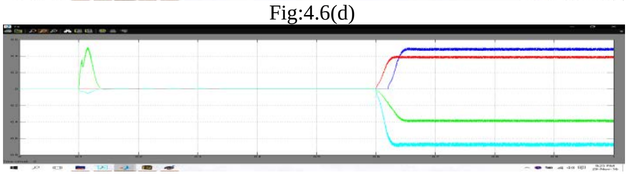


Fig:4.6(e)

Fig. 5.7- MTDC with master-slave control using the proposed sequential start-up control (*Case C*). (a) MMC-2 dc side voltage. (b) SM capacitor voltages. (c) MTDC currents. (d) Active power. (e) Reactive power.

In this case, the start-up sequence is similar to that of *Case B*, except that the reduced dc voltage control is applied, that is to say, the proposed sequential start-up control is applied. Simulation results using the proposed sequential start-up scheme are shown in Fig. 14.

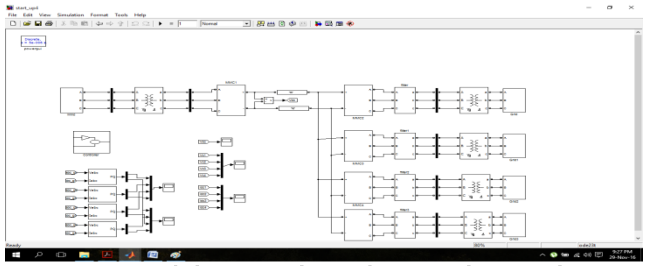


Fig:5.7- MTDC with droop control using the proposed sequential start-up control

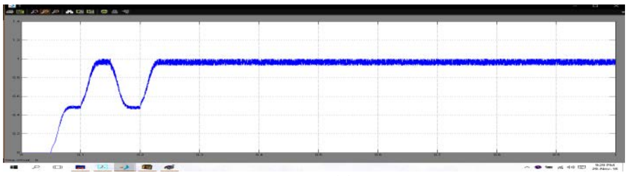


Fig:5.8(a)

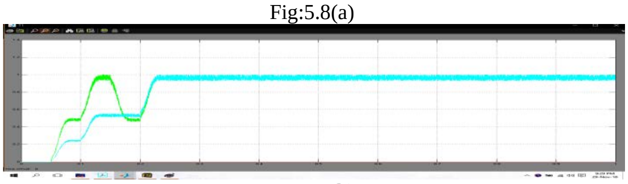


Fig:5.8(b)

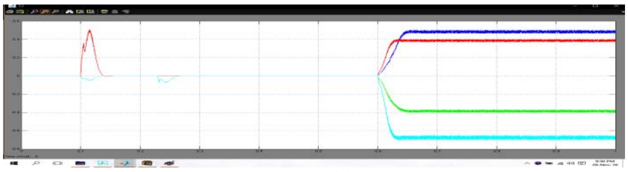
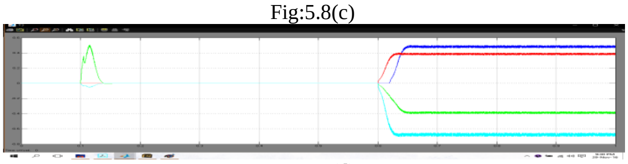


Fig:5.8(c)



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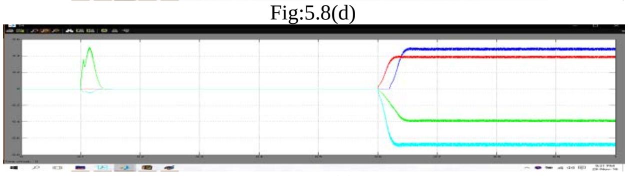

Fig:5.8(e)

Fig:5.8- MTDC with droop control using the proposed sequential start-up control (*Case D*). (a) MMC-2 dc side voltage. (b) SM capacitor voltages. (c) MTDC currents. (d) Active power. (e) Reactive power.

5. CONCLUSION

This paper has investigated the start-up control of an OWF integrated MMC MTDC system. After the derivation and analysis of the mathematical models on both the active and passive networks connected MMCs, a hierarchical control scheme for the active network connected MMCs and a reduced dc voltage control scheme for the OWF connected MMC have been proposed. The combination of both schemes forms an overall sequential start-up control scheme. A four-terminal MMC HVDC system with one terminal connected with an OWF has been established on the RTDS. The system with either master-slave control or droop control can be well started using the proposed control scheme with small voltage spikes and current surges. In comparison with the start-up control schemes with/without starting resistor and half dc voltage control, the superiority of the proposed scheme has been observed. This project has also discussed the potential development on the proposed scheme and the importance of the sequential start-up for the MTDC. The proposed sequential start-up control scheme has less complexity and is easy to realize. Although half dc voltage control scheme may not be applicable for every MMC MTDC projects, the reduced dc voltage control scheme can be applied for all of them.

REFERENCES

[1] B. Anderson and C. D. Barker, “A new era in HVDC?,” Inst. Elect. Eng. Rev., vol. 46, no. 2, pp. 33–39, Mar. 2000.

[2] J. Dorn, H. Huang, and D. Retzmann, “A new multilevel voltage sourced converter topology for HVDC applications,” in Proc. CIGRE Session, Paris, France, 2008, pp. 1–8.

[3] N. Flourentzou, V. Agelidis, and G. Demetriades, “VSC-based HVDC power transmission systems: An overview,” IEEE Trans. Power Electron., vol. 24, no. 3, pp. 592–602, Mar. 2009.

[4] H. Wang, G. Tang, Z. He, and J. Yang, “Efficient grounding for modular multilevel HVDC converters (MMC) on the AC side,” IEEE Trans. Power Del., vol. 29, no. 3, pp. 1262–1272, Jun. 2014.

[5] G. Bathurst and P. Bordignan, “Delivery of the Nan'ao multi terminal VSC-HVDC system,” in Proc. IET 11th Int. Conf. AC DC Power Transmission, Feb. 2015, pp. 1–6.

[6] CIGRE Working Group B4.52, “Feasibility of HVDC grids,” CIGRE Technical Brochure. Paris, Apr. 2013.