Fault Analysis And Protection Of Multi Terminal Mmc-Hvdc Oh Transmission Lines For Wind Farms Collection Grid

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ABSTRACT

The wind power industry today is exceptionally intrigued by arrangements that will bring down the expense of energy without bargaining the specialized exhibition of wind power plants to guarantee that wind power stays serious. In journey of high proficiency, power thickness and issues of mass force transmission over significant distance, necessity of full command over power transmission and developing revenue to fuse environmentally friendly power source into the grid has prompted build up another time of high voltage direct current (HVDC) transmission system. The interconnected voltage-source converter based multi-terminal high voltage DC systems system redundancy, higher flexibility and capability of exchanging power between multiple areas. Multi-terminal direct current grids give the chance of coincided interconnections between provincial force systems and different sustainable power assets to support supply dependability and economy. The modular multilevel converter (MMC) has become the essential structure block for MTDC and DC grids because of its remarkable highlights, i.e., modularity and adaptability. Accordingly, the MMC-based MTDC systems ought to be inescapably inserted into the current force system to improve system execution for wind structures gathering grids. Be that as it may, a few specialized difficulties hamper their viable applications and sending, including demonstrating, control, and protection of the modular multilevel converter - Multi-terminal direct current grids.

Keywords: Modular Multilevel Converter (MMC), High voltage direct current (HVDC), Multi-terminal direct current, fault analysis

2. INTRODUCTION

The overall energy utilization and request are expanding, rapidly because of the fast development of populace, industrialization and modernization. In light of this development growth after, various advancements are being applied and executed in various nations with the end goal of power enhancement and to increase the rate of electrification. Incorporating sustainable power advancements into the utility grid is quite possibly the most well-known strategies because of various reasons, for example, low support prerequisites, cost saving, financial and natural, and capacity abilities. The Wind innovation is among the sustainable power advances where usable power is created from the active energy of the wind through wind turbines and generators. Interest in seaward wind energy has expanded as of late. The quantity of introduced seaward wind turbines on the planet toward the finish of 2020 was 2052. The UK is driving seaward wind power establishment followed by Denmark and China. IEA Europe assessed that the introduced ostensible seaward wind force will arrive at 40 GW by 2020. Nonetheless, notwithstanding the assumption for high seaward wind power, the speed of advancement is more slow than anticipated. Take the UK for example, there was 46 GW of seaward ventures endorsed in 2012, anyway just around 10 GW has development responsibility. One of the specialized issues that restricts the extension of seaward wind power is the dependable and financial transmission of distant capacity to the inland grids. To conquer this test, two transmission innovations have been applied. They utilize traditional high voltage AC transmission or high voltage DC transmission. Correlation shows for a 100 MW evaluated system when transmission distance is under 60 km, that the HVAC system has less venture cost than the HVDC system; anyway when distance increments to over 90 km, the HVDC system will be less expensive. Hence it is significant to read HVDC advances for significant distance huge scope seaward wind energy transmission. This paper presents an audit on parts of converter innovations, facing difficulties, system level control procedures and organization geographies for modular multi-level converter (MMC) based multi-terminal HVDC systems.

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2.1 HVDC system

The excursion of DC transmission has started since 1897 when Edison prevailing to create low voltage DC supply and carried out in glowing fiber light. The guidelines for electrical force enterprises were being created, in the midst of major innovative conflict among AC and DC transmission technique, presented by George Westinghouse. Thusly, the appeal of high demand and transmission of power has compelled to understand the significance of power. The AC innovation was predominant around then as far as age, dependability, change, transmission voltage and has gotten favored decision of the electrical force enterprises. In like manner, first AC transmission connect in Hellsjon close to Ludvika in Sweden by ASEA bunch (presently known as ABB) was dispatched in 1893. From there on, the advancement of offending material that can withstand higher voltage has expanded extent of huge force transmission over more prominent distance. Then again, DC transmission drew consideration solely after the innovation of mercury bend valve in 1930 and its improvement proceeded. In 1954, the primary HVDC task of 20MW, 100kV over a distance of 98km through submarine link between territory of Sweden and island of Gotland was charged by ASEA/ABB bunch with static mercury valve. From there on, mercury circular segment valve spans having power dealing with ability up to 270MW were created till 1960s. Afterward, a few activities for example Elbe Project, Gotland I, Pacific DC Intertie and so on were introduced across the world, in view of mercury bend valve.

The mercury-arc valve converter experienced arbitrary disappointments because of converse voltage, this wonders is known as circular segment back, misfire etc.The breakdown in the control plan and terminating hardware were reason for these faults and these faults were more basic at the inverter end. Another serious issues related with mercury arc valves were enormous valve lobbies, high upkeep, need of sidestep valves and degassing offices, less adaptability in voltage rating, high warm up time, and decay of administrations which didn't allow exact expectation of mercury circular segment valve execution. Up to mid of 1960s, HVDC transmission was supported in circumstances where AC system experienced operational challenges like ocean crossing and so on Because of progression in power gadgets, number of providers, to be specific English Electric, BBC, Siemens, Hitachi, Toshiba, and Mitsubishi come up in the market of assembling strong state switch. The improved assembling innovation of strong state switches has made HVDC conservative and serious which gave a genuine lift to the utilizations of the HVDC power transmission. Ensuing advancement in high force semiconductors with the improved qualities made force change basic and savvy. In any case, there is a lot of likelihood of compensation disappointment in thyristor valve. The likelihood of recompense disappointment are limited by expanding least annihilation point allowed in the ordinary activity; nonetheless, it improves receptive force prerequisite. The DC-connect makes conceivable to trade power between the two asynchronous AC networks. The asynchronous interconnection by means of DC-interface separates interconnected part and can be utilized for any degree of force quality control like harmonic distortion, unbalance, flicker voltage and so on The asynchronous interconnection works with huge number of AC system to interconnect across the world, for example, Japan and South America HVDC interface which has diverse ostensible recurrence (50Hz and 60Hz).

2.2 Modular Multilevel Converter (MMC)

Majority high-voltage transmission systems have been founded on exchanging current. This can likewise be advocated by the viable utilization of ac transformers, which permit high voltage transmission, lessening Losses and higher effectiveness. There are, a few benefits to utilizing direct current for high-voltage transmission. They include: lower transmission losses, the ability to move more control over longer distance, decrease in capital expense and the capacity to interconnect two systems that are unsynchronized or utilize various frequencies. Substation intended to converter the AC power in to DC power at the each finish of a high voltage direct current (HVDC) transmission line. This converter station give control to improve the steadiness of the transmission system. The expense identified with fabricate and work a converter stations just as the misfortunes made by the exchanging components needed to upset or correct the influence at each finish of the DC line is extensive. Customary 2-level voltage sourced converter (VSC) create huge number of sounds and cause higher misfortunes contrasted with current-sourced converters (CSC) because of the quick exchanging of the IGBTs during activity. They likewise require an enormous number of switches associated in arrangement.

In most recent couple of years, another IGBT based VSC, the modular multilevel converter (MMC), has been industrially evolved and presents numerous benefits over past sorts of multilevel converters. Like:

- Modularity & Scalability.
- Higher reliability as the converter can work even when some switches or modules fail to work.

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- Lower switching frequency for individual level of voltage compared to conventional VSCs, to obtain the same waveform quality
- Significant decrease in size of the music produced, lessening and perhaps taking out the requirement for output channels.
- Very large number of levels are possible and further increase the performance of a converter.

HVDC transmission system is a significant and successful option in contrast to threephase ac transmission of electric control over significant distances. HVDC transmission has number of benefits over a three stage ac transmission system. Most significant benefit of HVDC transmission is to control dynamic force transmission precisely, while power stream control in ac lines can't be conceivable in the comparable manner. MMC innovation gives further decrease in the size of HVDC system because of the sinusoidal yield voltage, low sounds substance and lower the channel size necessity.

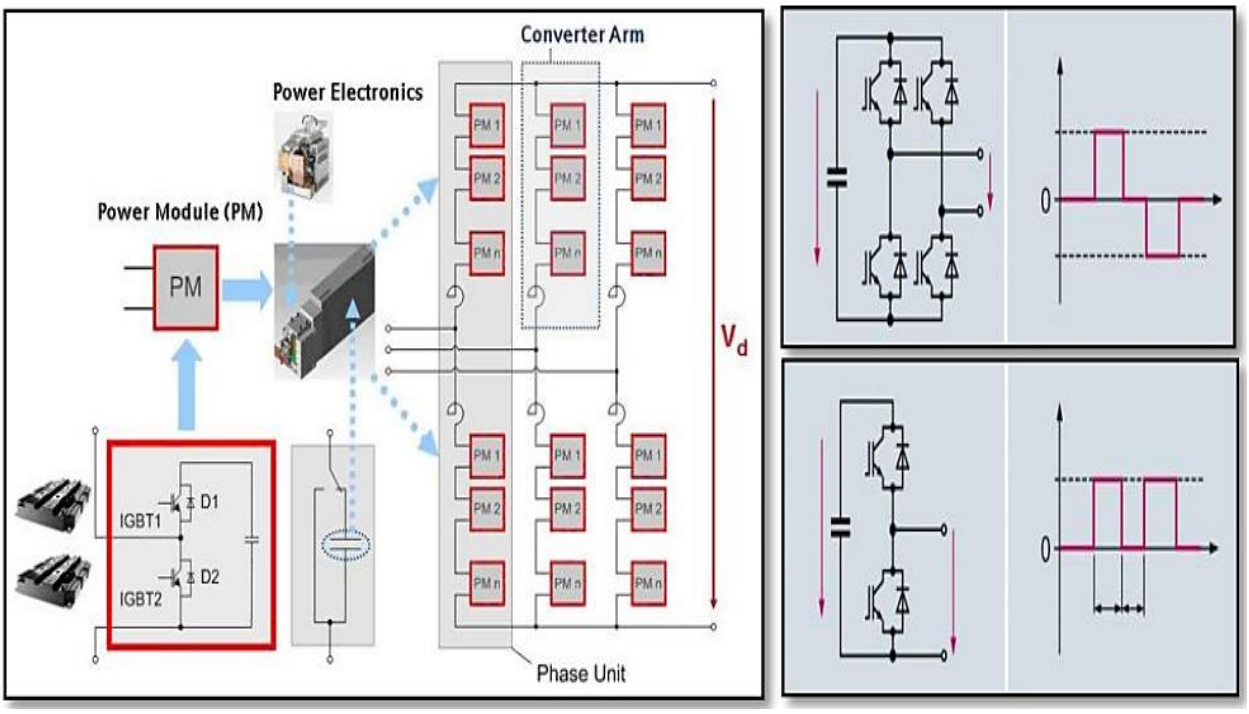

Figure2.1 Modular Multilevel Converters

Modular Multilevel Converters have an ordinary 6- pulse connect geography. One converter unit comprises of three identical stage units, each has two arm. Each arm contain number of sub modules or force modules. Every individual force module contributes just a little voltage step. The force modules are controlled exclusively to accomplish the necessary multilevel sinusoidal AC and smooth yield voltage waveforms. In this MMC half extension or full scaffold power geography is utilized show in Figure 2.1. Inside the half-connect type geography the force capacitor can be associated in one extremity to the terminals. Along these lines the DC voltage is consistently higher than the AC voltage. In MMC with full-connect geography the force capacitors can be associated with the terminals in one or the other extremity. Subsequently, the DC voltage is autonomous of the AC voltage. Here closest level control for the modular multilevel converter (MMC) is utilized. By utilization of voltage, sensor sub-modules capacitor voltages in MMC are estimated and arranged by the calculation. For quicker exchanging activity of the force device (IGBT) testing frequency is kept sufficiently high. Because of this the converter-yield voltage levels and sounds in the voltage cycle will be influenced. The noise of the converter yield voltages are investigated by hypothetical estimations and dynamic simulations. Both of the outcomes bring up that the uniform testing recurrence of the reference voltage significantly affects the yield voltage level sand THDs in MMC geography with the NLC adjustment.

3. LITERATURE REVIEW

Bhaskar Mitra et al (2020): This paper clarifies about the HVDC transmission for admittance to seaward sustainable power: an audit of innovation and deficiency identification strategies. The consistently expanding interest for electric power has in part been met with admittance to seaward sustainable power, like wind and flowing energy. With the improvement in power devices, high-voltage direct current (HVDC) transmission is

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taking over as the essential decision for associating seaward age to on-shore grids. Voltage source converter (VSC)- based HVDC is set to turn into the foundation of the multi-terminal DC grids supplanting the traditional line commutated converter organizations. VSC-HVDC networks offer the adaptability for HVDC grids to be associated as traditional AC grids in a fit organization. Headway of innovation has prompted the improvement of the modular multilevel converter which has higher productivity contrasted with the two-level VSC arrangements. They are slowly turning into a mainstream decision. Despite the fact that VSC-based grids offer a differed scope of benefits, it is exceptionally powerless against DC faults. Numerous plans of breakers have been licensed throughout the long term and different methods have been proposed for their control. This examination expects to audit the accessible plans of HVDC terminals, the accessible assurance gadgets and the security and control strategies for HVDC breakers. By contrasting the cutting edge advances that are right now accessible, this investigation expects to address the exploration issues and the extra innovative work that should be done.

W. Leterme et al (2020): This paper proposes a decreased model for a modular multilevel converter (MMC) that can be utilized to assess the primary transient after a short out flaw in a DC grid. Detailed modelling of a MMC includes an enormous number of electrical hubs, henceforth requiring high computational exertion. Reduced converter models have been proposed in the writing. Nonetheless, estimation times can in any case be high for enormous grids. The decreased model proposed in this paper depends on a RLC-circuit that models the capacitive release period of the MMC during DC faults. Consequently, it very well may be utilized to proficiently assess issue recognition measures that should act inside the primary transient. By performing transient reproductions for a post to-shaft shortcoming at the converter terminals, the appropriateness of the model to address the MMC during faults is illustrated. Moreover, it is appeared by transient recreations that the model can satisfactorily address the impression of venturing out waves because of faults in a multiterminal system.

4. PROPOSED METHODOLOGY

For the bulk transport of power over large distances, high voltage direct current (HVDC) innovation is liked over HVAC technology. Presently, for the most part highlight point HVDC associations are utilized. To empower the mass presentation of environmentally friendly power into the force system, HVDC grids dependent on voltage source converter (VSC) innovation are thought of. HVDC-based transmission lines permit the interconnection of ages from wind, sun oriented, and flowing plants from far away shore or far off areas, in this manner limiting the misfortunes supported during transmission.

4.1 MMC fault behavior

In VSC HVDC, the reaction of a converter to a DC issue can by and large be separated into a detached release period of the capacitors followed by uncontrolled infeed by the AC side. For the MMC geography, two viewpoints are of primary significance for the deficiency conduct. To begin with, the DC capacitor is disseminated into various submodules that are associated in arrangement. An illustration of a half-connect submodule is appeared in Figure 4.1. By obstructing the IGBTs of the submodules, further release of capacitors is forestalled. Contingent upon the submodule geography, the flaw current is taken care of by the AC side (for example half-connect geography) or can be for all time hindered (for example full-connect geography). Second, reactors are remembered for every converter arm to lessen circling flows. During short out faults, these reactors limit the pace of ascent of the issue current during the release of the submodule capacitors. The DC shortcoming current, arm flows and AC current for one converter leg of a half-connect MMC for a post to-shaft issue applied straightforwardly at converter terminals. For this figure, the boundaries of the converter have been taken. The flaw begins at 10 ms and the IGBTs are not obstructed. It tends to be seen that the upper-and lower arm flows are at first equivalent. During this stage, the current is just provided by the submodule capacitors. After around 2 ms, the AC current begins to take care of in. Albeit these models lessen computational intricacy of the converter, the reenactment time for these models can in any case be huge for huge DC grids. Additionally, EMTP-programming isn't entirely adaptable for mimicking countless shortcoming circumstances.

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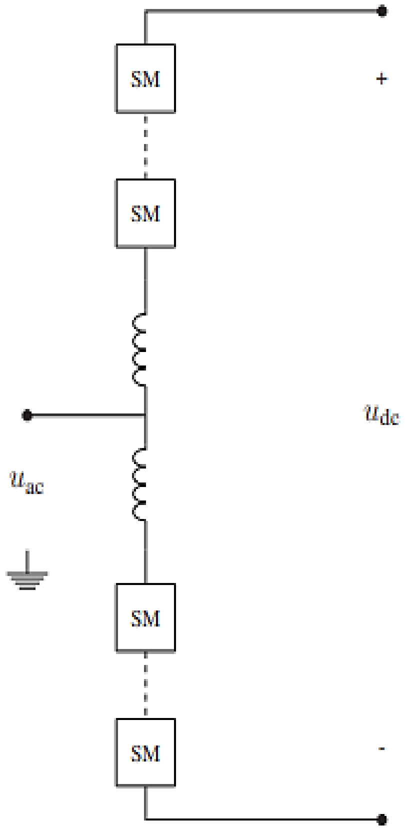

Figure 4.1 MMC converter leg

4.2 Modular multi-level converters for HVDC systems in wind farms

The main benefits of the modular Multi-level Converter (MMC) based HVDC system over a customary two-level VSC system are

- robustness through the use of redundant submodules;
- scalability;
- high ac-side current quality; and
- smaller converter footprint – important to reduce the platform mechanical requirements;

The improvement of AC side force quality that a MMC converter brings is huge over what a traditional two-level VSC gives. Waveform shows voltage profile that a two-level VSC creates and waveform shows voltage profile that a 25-level MMC produces. Obviously the voltage waveform that a MMC produces is fundamentally improved than that of a 2-level VSC. The 2-level VSC creates square waveform which contains high symphonious mutilations. Accordingly consonant channels are needed in a customary 2-level VSC system. While the MMC produces more sinusoidal like voltage waveform, which means better nature of AC supply and no necessity of symphonious channel. Figure 4.2 shows the geography of a modular multilevel converter. A three stage modular multilevel converter contains six arms. Each arm has different, frequently a couple hundred, submodules (SM). An individual submodule of the most well known construction, the half bridge (HB) variation. A solitary submodule comprises of two IGBTs and a capacitor. In each sub-module the capacitor can be either associated or avoided by exchanging the two IGBTs on or off. Subsequently, each sub-module can be considered as an autonomous two-level two quadrant voltage converter that produces a voltage of either Vsm or 0 yet can uphold current stream in the two ways.

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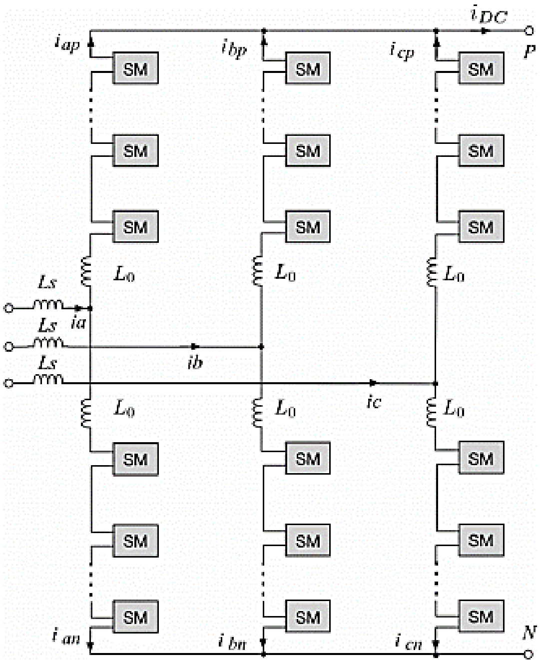

Figure 4.2. MMC topology where Ls is the phase input reactance, L0 is the arm reactance and SM is a submodule.

4.3 Fault Analysis of DFIG-Based Wind Farm

Figure 4.3 shows a regular DFIG with a rotor crowbar insurance circuit. It essentially comprises of a wind turbine, gearbox, asynchronous generator, RSC, grid side converter (GSC), rotor crowbar protection circuit, and control system. The DFIG stator is straightforwardly associated with the grid, while the rotor is associated with the grid by a consecutive converter. The converter system empowers variable speed activity of the wind turbine by decoupling the force system electrical recurrence and the rotor mechanical frequency.

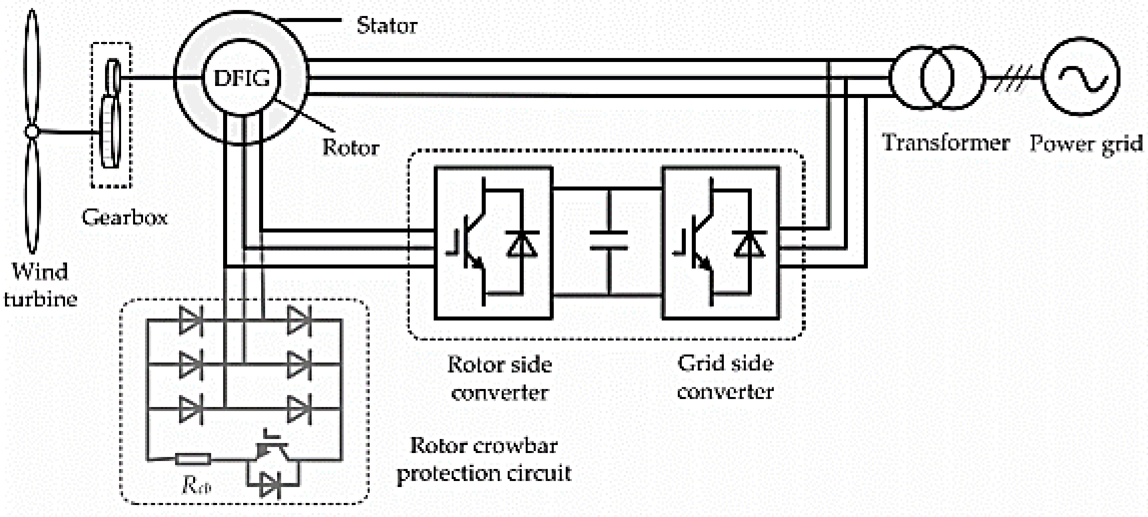

Figure 4.3. A typical DFIG with a rotor crowbar protection circuit

The DC faults can be classified as follows:

1. Pole to pole fault (Positive cable to negative cable fault).
2. Positive cable ground fault.
3. Negative cable ground fault.
4. Unbalancing of positive pole capacitor bank.
5. Unbalancing of negative pole capacitor bank.

The submarine DC links are practically safe to the shaft to post faults as protection and channel set the positive and negative links apart. Then again, the link ground faults are more normal. This sort of the DC faults is because of the protection disappointment (insulation breakdown). Link maturing and openness to wet

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climate can be the reasons of the protection disappointment. For this situation, deficiency current will circle through establishing points of the system. To moderate unevenness between the positive and negative shafts and give a reference voltage in bipolar HVDC designs, the midpoint of the DC capacitor is normally grounded. Additionally, the sheath of the link is generally grounded at the two closures at substations. Consequently, flaw flows can return through the sheath of the link that is associated with the ground and other establishing focuses that can be including the midpoint of the DC capacitor and the impartial ground connection of the converter transformer. The protection disappointment can likewise happen with the DC capacitors in the capacitor bank of each shaft. Moreover, an inappropriate establishment is another justification losing a few pieces of the capacitor bank that will prompt the capacitor unbalancing.

4.3.1Single Pole-to-Pole Fault Analysis

In the MMC-HVDC system the DC side transport is grounded by cinching opposition. Since the DC side is grounded by two huge resistors, the DC voltage at the two shafts is cinched to give potential reference focuses to the DC system. As the DC valve sides at the two finishes are three-sided wiring, when a solitary shaft to-ground deficiency happens in the MMC-HVDC system, there is no association highlight the ground. Moreover, the clipping obstruction on the DC side has an enormous opposition esteem, which can be around viewed as open circuit when single shaft to-ground flaw happens. For the AC side, just the potential reference point of the DC system is changed hypothetically, while the DC system can in any case communicate power. For DC transmission lines, after consistent express, the issue shaft voltage is diminished to 0, the other post voltage is cinched to the twofold, and the interpole voltage Udc stays unaltered. Along these lines, the protection level of non-shortcoming post is needed to be higher, and the transmission system ought to analyze the single shaft to-ground issue on schedule. The fundamental harm of shaft to-ground deficiency is that the sound post voltage would ascend to double the appraised esteem. Meanwhile, the AC side voltage has a huge DC inclination and the transformer will most likely be unable to withstand. This addresses an incredible test for line protection and transformer activity. Because of the selection of little current establishing techniques, the issue current of the pole to-ground issue is more modest than that of the shaft to-post short out issue. The essential benefit is that any overcurrent wouldn't harm power gadgets and unprecedented security isn't needed on connect arms, notwithstanding, it additionally causes trouble for identifying the deficiency. Truth be told, as long as there is no stumbling of the converter stations, the control activity can be kept up and dynamic force can be traded as planned.

4.3.2 Multi-Terminal MMC Fault Current Circuit

The fault current circulation of multi-terminal MMC system is more intricate than that of single-terminal MMC. For a two-terminal MMC appeared in Figure 4.4, there exists another current i'fsm after a faults appeared as the red dabbed line. The capacitance of lower arms in the two converters is associated with the shortcoming release circuit, however because of the balance of the two converter stations, there is likewise a comparable flaw circuit that streams from the left converter establishing electrode to the issue point. Albeit the greatness of i'fsm is diverse in each stage and changes with time, the amount of three stages can be viewed as a fixed worth. At the point when the converter station boundaries are indistinguishable, the i'fsm produced by the two converters can be counteracted by one another. Hence, when all is said in done, i'fsm has little impact on transmission lines.

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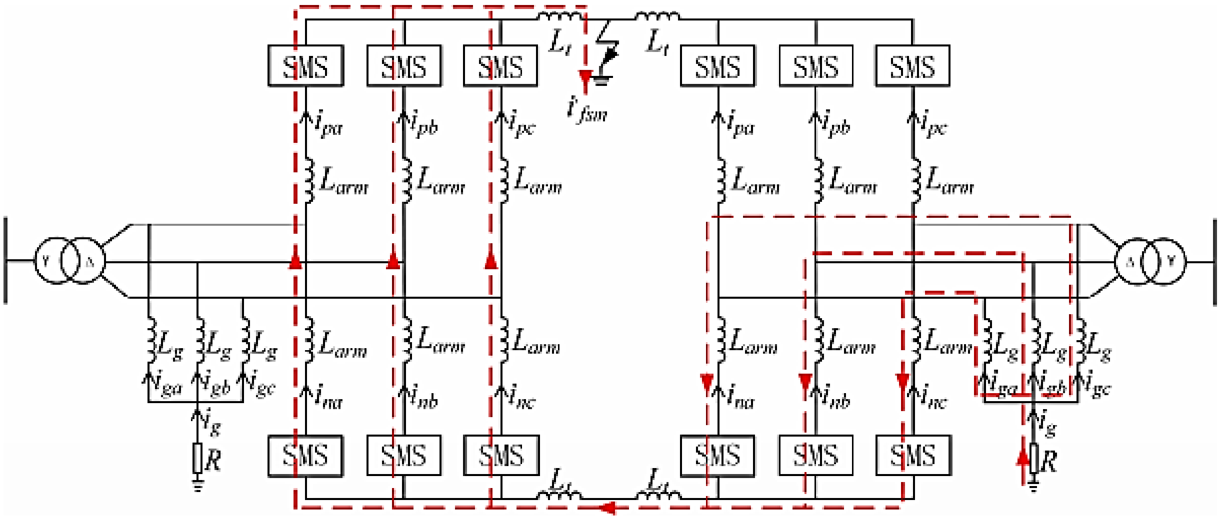

Figure 4.4. Fault current circuit in double-terminal MMC during positive pole-to-ground fault

Expecting that the periods of the two DC systems are close, the lower arm voltage in each period of the two converters is counterbalanced, so it tends to be gathered that lone the sub-modules in the upper arm are released after a shaft to-ground shortcoming. With the advancement of a shortcoming, the upper arm sub-module capacitor voltage drops clearly. The control system will undoubtedly build the DC current to make up for the energy misfortune. On the off chance that no extra arm energy balance control technique is embraced, this will prompt a voltage ascend in the lower arm capacitance. At long last, the energy lopsidedness of upper and lower arms brings about system breakdown. In the upper arm sub-modules are released in converters during a positive post to-ground shortcoming, and the release current incorporates two sections: ifsm through the establishing cathode in nearby converter and i'fsm through establishing anodes in different converters. What's more, the two pieces of the current are in equal. The ifgc created by the capacitance to earth would arrive at the main top in around 2 ms and wavers in several milliseconds. The deficiency consistent state current is dictated by ifsm.

5. RESULTS

A DC cut off is the most genuine condition for the VSI. The IGBTs can be hindered for self-insurance during faults, leaving reverse diodes presented to overcurrent. For the shortcoming paying little heed to where the dc impede happens, it very well may be addressed by a comparable circuit.

5.1 Operation with activated MMC protections

In this thyristor assurances are initiated after the shortcoming recognition. Inverter insurances are set off when branch current arrives at 1.4 pu (2.1 kA), which happens 1.5 ms after the issue beginning. The 1.4 pu current trigger point is chosen in such a worth to forestall the current moving through the IGBT diodes to transcend their predefined top forward current. Current setting off of the seaward rectifier station would prompt an any longer deferral, as seaward arm flows take in excess of 11 ms to arrive at 1.4 pu. At this stage, the rectifier station would trigger on negative shaft overvoltage, as it arrives at 1.7 pu in around 3 ms. Again a 1.7 pu overvoltage set point addresses a satisfactory compromise to stay away from link overvoltage without requiring expanded flood arrester rating. Figure 5.1 show the conduct of the on-shore and seaward converters when the converter thyristors are set off and the wind farm is conveying its evaluated power. On-shore ac-grid flows relate to the notable flows of a half-connect rectifier. The seaward MMC ac-terminal flows additionally display the conduct of a half-connect uncontrolled rectifier, regardless of no grid-shaping converter being operational in the seaward ac-grid. The seaward grid DC-voltage motions are brought about by reverberation between the seaward ac-grid transformers inductance and capacitors and supported by the wind farm dynamic force age. The wavering recurrence is around 160 Hz and is a component of the transformer immersion qualities. By and by, the motions would make the wind turbines stumble on over-recurrence or potentially over-voltage. Nonetheless, this impact is pertinent, as the wind farm is equipped for infusing dynamic capacity to the seaward ac-grid in any event, when the MMC substation insurances have been triggered.

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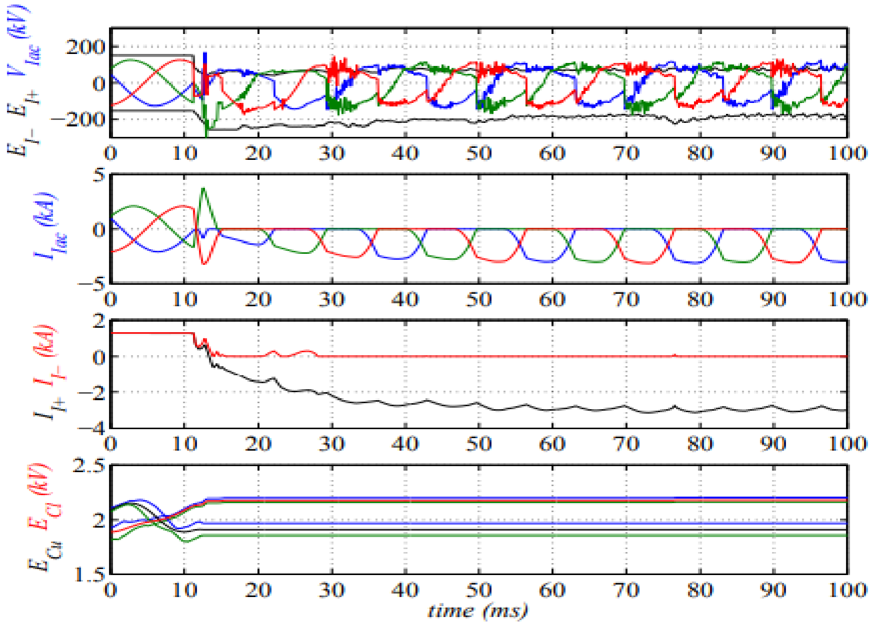

Figure 5.1 MMC station behavior when thyristor protections trigger 1.5 ms after the fault

5.2 Wind Power Plant power reduction during faults

The outcomes in the past area call attention to that a decrease on top issue current is conceivable if the WPP can diminish its produced power in under 40 ms after the shortcoming beginning. Wind turbines ought to be distantly set off by the seaward converter station, as voltages and flows on wind turbine terminals don't fundamentally withdraw from their appraised values inside 40 ms. Figure 5.2 show the conduct of the on-shore and seaward converter stations when a force decrease order is given to the WPP.

It is accepted that the correspondence delay between the seaward converter station and the wind turbines is 5 ms. Thus, the force decrease is enacted 8 ms after the beginning of the deficiency. At the point when a 5 ms correspondence delay is thought of, the greatest rectifier and absolute flaw flows decline by 33% and 31%, separately. For a 20 ms delay, the qualities are 14% and 15%, individually. In all cases, the consistent state rectifier current is decreased to nothing and the complete issue current settles to 5.2 kA, which relates to a decrease of 31%. When the force decrease order is gotten, the seaward converter flows in Figure 5.3 are diminished to focus in around 20 ms following the wind turbine momentum elements. The wind farm power decrease causes the air conditioner grid motions to cease to exist in around 22 ms. In consistent express the flows through both converter posts is zero, while cell capacitor voltages are kept inside sensible cutoff points.

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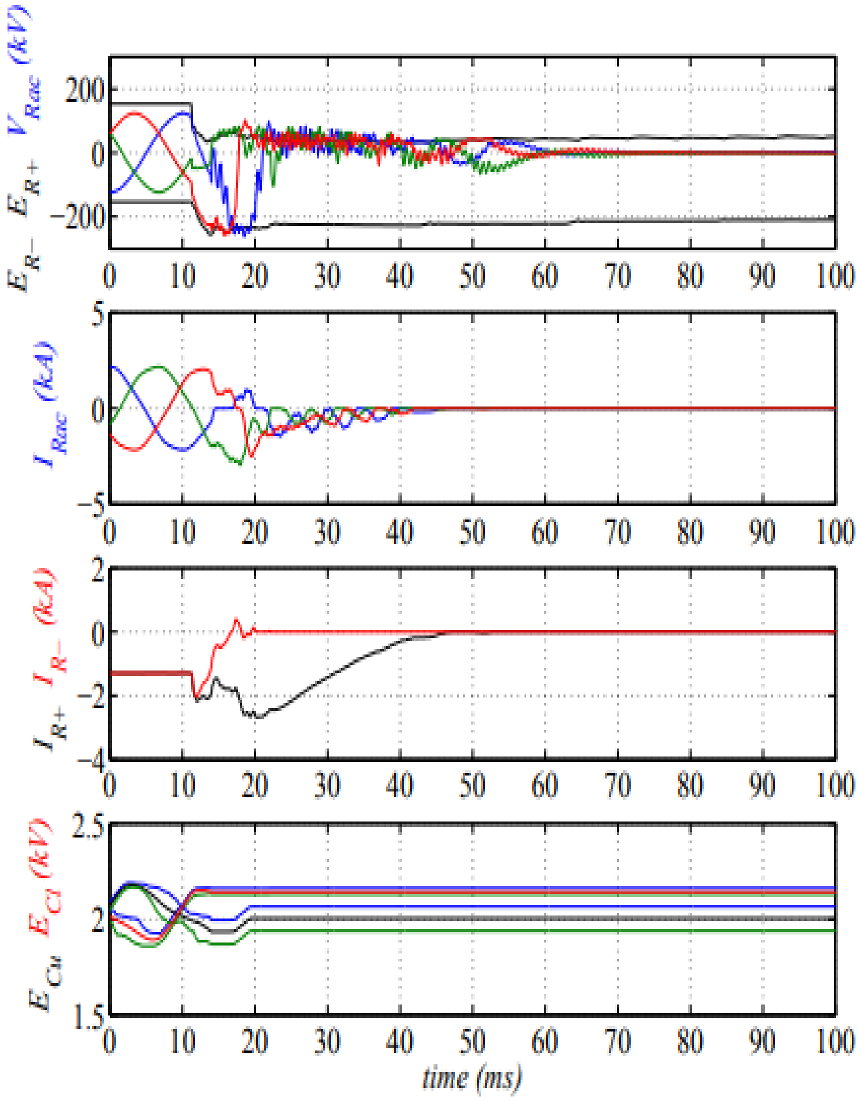

Figure 5.2 MMC station behavior when thyristors are triggered and wind power plant delivered power is reduced

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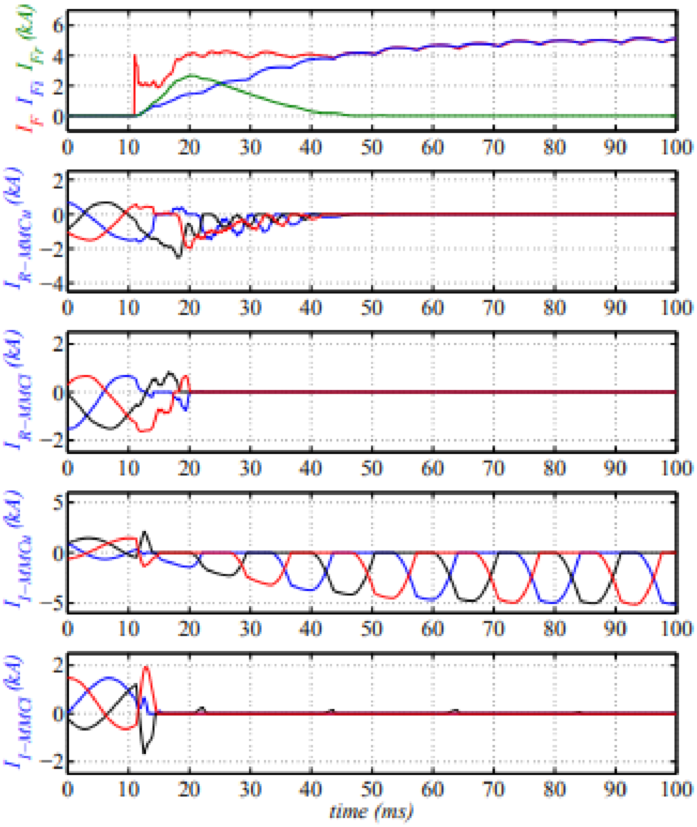

Figure 5.3 Fault and MMC branch currents when thyristors are triggered and WPP delivered power is reduced.

6. CONCLUSION

This paper presents the attributes of a different kinds of faults in MMC-HVDC transmission lines of wind power plant. After the single post to-ground shortcoming of the MMC-HVDC transmission line happens, the relationship coefficient between the voltage change rate and the current of the deficiency shaft is chiefly negative, while the connection coefficient of the non-flaw post is principally sure. Moreover, the supreme estimation of the relationship coefficient of the non-shortcoming shaft is marginally bigger than that of the issue post. Nonetheless, different sorts of disappointments have no such qualities. A deficiency transient current primarily incorporates the shortcoming shaft side arm sub-module release and transmission line capacitance to earth release. As per the shortcoming attributes, another fast post to-ground deficiency assurance conspire dependent on nearby data is proposed. The insurance information window is short and the activity speed is quick. Force misfortune in transmission lines firmly affects the running expense of a multi terminal DC system. Since the geography decides the length and the limit of the transmission lines, thus it decides the obstruction of the sub-ocean links, which further influences the absolute force misfortune in the system.

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