

A Generalized N Terminal Current Order Control Scheme for LCC MTDC

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Abstract— This research work proposes a current order sharing technique for LCC MTDC power system. LCC MTDC architecture has great advantages over other HVDC transmission technologies because of its huge power handling capability, simple design and less initial and maintenance cost. Simple two terminal HVDC technology have evolved so much but the MTDC technology still have some outstanding problems which need to be addressed. Current order sharing between MTDC terminals plays an important role in stable DC transmission and lack of suitable current order sharing causes DC voltage collapse or current saturation problems for terminals. A dynamic current order sharing technique is developed for LCC MTDC system in which terminal current order is being calculated based on current ratio of respective terminal to total current. The technique has ability to readjust current order for each terminal in case of any disturbance. A generalized $n_{rec} \times n_{inv}$ terminals current order calculation method is also proposed for MTDC system. The method is investigated under fault conditions in PSCAD to check its feasibility. The results prove that the proposed technique self-adjusts current order as the fault is cleared or any terminal has lost operation.

Index Terms – Line Commutated Converter, HVDC, MTDC, Current Order, PSCAD/EMTDC

I. INTRODUCTION

Mostly power generating stations are located far away from load which needs a system capable of transferring bulk amount of power to load. In China, it has been estimated that wind power resources reach to 30GW by 2020 and an approximate value of installed wind power in China and over the world is 42 287 MW and 194 390 MW respectively [1] [2]. Generally, wind farms are installed in huge windy area away from metropolitan cities to get maximum available power.

Since last few decades, High Voltage Direct Current (HVDC) technology has been deployed in several power transmission projects and working with high reliability and less maintenance [3]. World's first Commercial DC transmission was started in 1954 by ABB to link island of Gotland to the Swedish mainland [4]. Rapid evolution of power system techniques and integration of renewable energy resources have proved that HVDC is a suitable and economic technique having ability to transfer huge

power irrespective of power resources; either its hydropower, wind or from fossil fuels [5].

The major two HVDC power conversion technologies are i) Line Commutated Converter (LCC) and ii) Voltage Source Converter (VSC) [6]. Each technology has its own pros and cons but the major problem associated with both is i) LCC converter absorbs huge reactive power in order to operate and ii) VSC converter has low power rating than LCC so it is not viable for bulk power transmission [7] [8]. During normal operation, LCC converter requires reactive power almost 40% of transferred active power which is being provided by static capacitors and synchronous condensers [9]. Unlike LCC, VSC has inherit property to handle real and reactive power but has high power losses because of fast switching and conduction of IGBTs [10]. Modular Multilevel Converters (MMC) is extended version of VSC which increases power handling capacity of VSC but with high cost and complex design [6]. In fact, simple construction, less power loss and high power transfer capability with high voltages make LCC HVDC system still superior on other technologies [11].

With the increasing demand of electric power for industrial as well as domestic load, the simple two terminal HVDC power system design has been modified to multi terminal HVDC transmission system. Since past few years, impressive research has been done to improve performance of Multi terminal Direct Current (MTDC) transmission [12] [13].

Based on converter technology used, MTDC system can also categorized as LCC MTDC, VSC MTDC and Hybrid MTDC consisting of both LCC and VSC [14]. To integrate bulk power, LCC MTDC remains at top priority [15]. The reactive power problem related to LCC converters have dealt to some extent with latest Capacitor Commutated Converter based technique [16].

The control system plays a vital role in any power system design problem. The control system of LCC MTDC is not that much easy because of current order coordination between terminals.

Conventionally, a current controller is implemented at rectifier end to control main current of system while an auxiliary current controller with main voltage controller is implemented at inverter side for normal operation of

two terminal HVDC system [19]. Rectifier controls current or reactive power based on inverter current order sharing; however, current order sharing and calculation technique between terminals in case of MTDC is still an outstanding problem. Thus, the main purpose of this work is to propose a dynamic current order computing technique for $n_S \times n_R$ LCC MTDC power system with n_S sending and n_R receiving ends.

II. MTDC ARCHITECTURE

A multi terminal HVDC has several configurations since its introduction in 1980 [19]. A three terminal MTDC (one rectifier and two inverters) schematic diagram is shown in figure 1. The system parameters are given in table 1 as per CIGRE Benchmark model. MTDC model consists of 12 pulse converters (two six pulse bridge in series) on each terminal with significant short circuit ratio (SCR) of 2.5 and 50Hz frequency [20]. The bus voltage magnitude of AC1 to AC3 is 345kV.

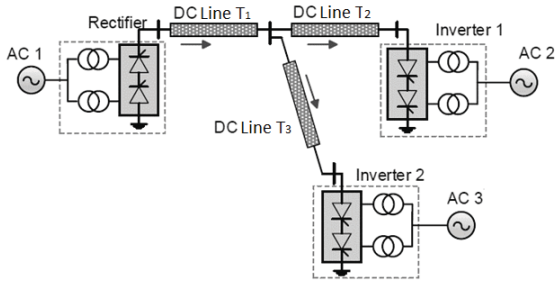


Figure 1: Three Terminal LCC MTDC System

TABLE 1: SYSTEM PARAMETERS

Converter	Rectifier	Inverter1	Inverter2
Control Mode	CC/CIA	CC/CEA	CC
Rated power [p.u.]	1	0.6	0.4
Rated current [p.u.]	1	0.6	0.4
Operating Angles	$\approx 20^\circ$	$\approx 140^\circ$	$\approx 140^\circ$

The AC side of each terminal comprises of supply network, high pass filters and transformers to provide converter rated voltages. Supply network side is developed by connecting voltage source in series with Thevenin equivalent impedance of AC system [20]. High pass filters are installed to absorb harmonics produced by converter and to provide reactive power for converter. The 3ϕ transformers connected to each bridge at all terminals have star and delta connections to provide

phase difference of 30° which eradicate the 5th and 7th harmonics of ac side current while 6th harmonic of dc voltage is also eliminated because of this configuration [9]. DC side is equipped with smoothing reactors at each of three terminals and dc transmission line is modeled as lumped T network. The major portion of reactive power required is supplied by capacitor banks while AC filters supply some proportion of required power [21].

III. LCC MTDC CONTROL SCHEMES

Several LCC MTDC control schemes have been discussed in [3], [17], [19] and [22]; among all the current margin control scheme is most popular and practical. However, the coordination between MTDC terminals is essential because i) when any of inverter is lost and current order is not readjusted then rectifier continues to supply same current and remaining inverters will be overloaded ii) when rectifier is shutdown then DC voltage will collapse due to negative inverter current margin.

Therefore, a controller should be able to maintain current balance by coordinating and distributing new current order between rectifier(s) and inverter(s) in case of any disturbances.

$$\sum_{i=1}^n I_{ord R_i} = \sum_{i=1}^n I_{ord I_i} + I_{margin} \quad (1)$$

The current margin control is simple and requires DC current, voltage and firing angles as an input.

Three main control modes of LCC MTDC converters are Constant Current (CC), Constant Extinction Angel (CEA) and Constant Ignition Angle (CIA) [6]. The control system of simple two terminal model is well evolved and matured enough to deal with voltage and current disturbances.

For normal 3 terminal LCC MTDC system, whenever a terminal quit then system could not find a new operating point easily due to lack of current order sharing. In other case, when a terminal resumes its operation, a new different operating point need to be calculated immediately.

This paper tries to establish a current order coordination between all terminals of MTDC in order to operate under all field conditions such as i) when any terminal lost its operation ii) malfunction of any power system apparatus iii) AC/DC faults and etc.

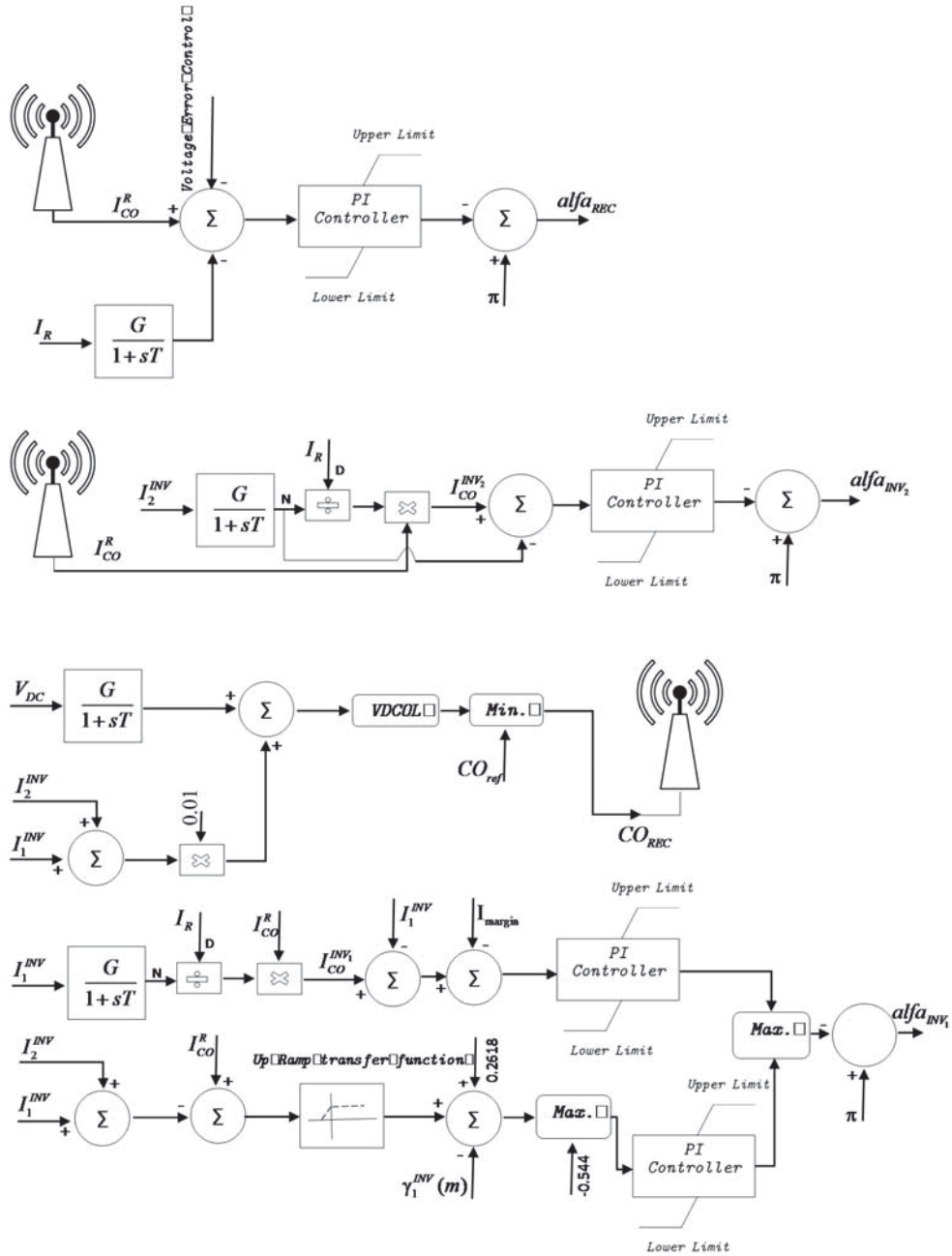


Figure 2: Current Order computing technique

IV. CURRENT ORDER DISTRIBUTION TECHNIQUE

A practically simple current order computing technique is presented in figure 2 for parallel LCC MTDC system. The technique presented is i) master control will calculate the current order of rectifier based on total current of inverters and ii) current order of inverter is rectifier current order multiply by ratio of inverter current to total current. This technique has advantage of automatically adjusting current order of

each inverter in case of any inverter lost, increase or decrease in power demand or any other malfunction.

Suppose inverter 2 has lost operation then inverter 1 and rectifier will automatically adjust their current orders, because the total current reduces which will reflect in current orders of remaining terminals when inverter 2 current becomes zero. Moreover, the technique has ability to operate any terminal at different power ratings than others which makes it feasible for implementation in MTDC supplying different load areas.

The generalized $n_{REC} \times n_{INV}$ technique can be written as follows, where CO_{ref} is reference current order.

$$I_{ord}^{REC} = \min \left(VDCOL \left(0.01 \times \sum_{i=1}^n I_i^{INV} + V_{dc} \right), CO_{ref} \right) \quad (2)$$

$$\left(I_{ord}^{INV} \right)_k = I_{ord}^{REC} \times \frac{I_k^{INV}}{\sum_{i=1}^n I_i^{INV}} \quad (3)$$

$$\left(I_{ord}^{REC} \right)_k = I_{ord}^{REC} \times \frac{I_k^{REC}}{\sum_{i=1}^n I_i^{REC}} \quad (4)$$

V. SIMULATIONS RESULTS & DISCUSSION

A simulation model is developed in PSCAD/EMTDC to verify the feasibility of proposed technique. Rectifier and inverter 2 are kept in current control mode while inverter 1 is working in constant extinction angle control mode.

The rectifier, inverter 1 and inverter 2 DC voltage and current are shown in Figure 3(a)-(c). Due to parallel connected MTDC, voltages established by inverter 1. The rectifier current is being divided at inverters terminals as per prescribed current orders. The α orders are shown in figure 3(d) for proposed current order sharing scheme. The operating values of α orders are in range which clearly explains the validity of proposed scheme. The real and reactive power transferred are shown in figure 4.

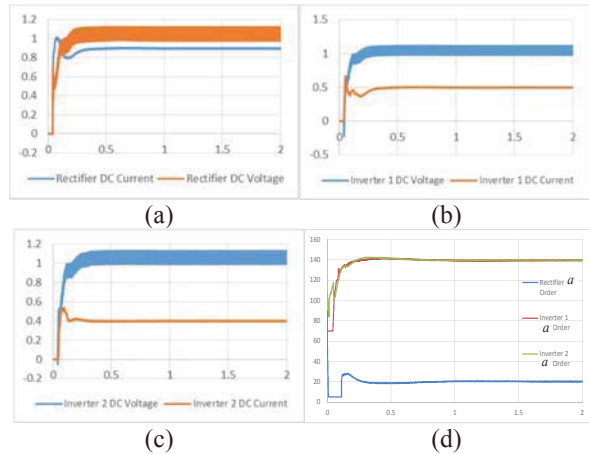


Figure 3: The DC voltage and current and α orders of converters. (a) Rectifier DC voltage and current (b) Inverter 1 DC voltage and current (c) Inverter 2 DC voltage and current (d) α Orders of all converters (in Degree)

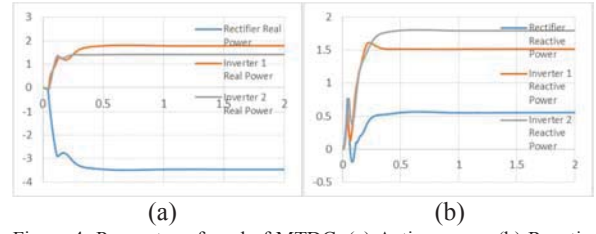


Figure 4: Power transferred of MTDC. (a) Active power (b) Reactive power.

The current order of each terminal is shown in figure 5. The steady state error between current orders and direct current of rectifier, inverter 1 and inverter 2 are 0.0557, 0.0351 and 0.0282 respectively.

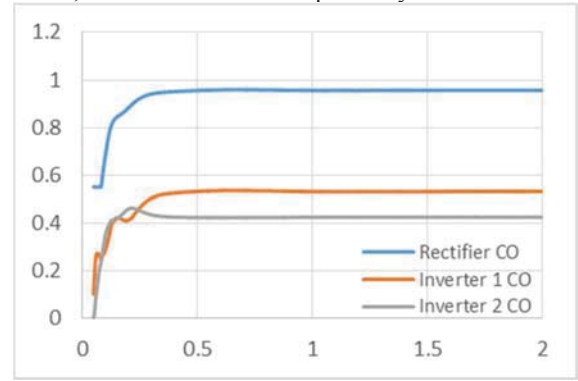
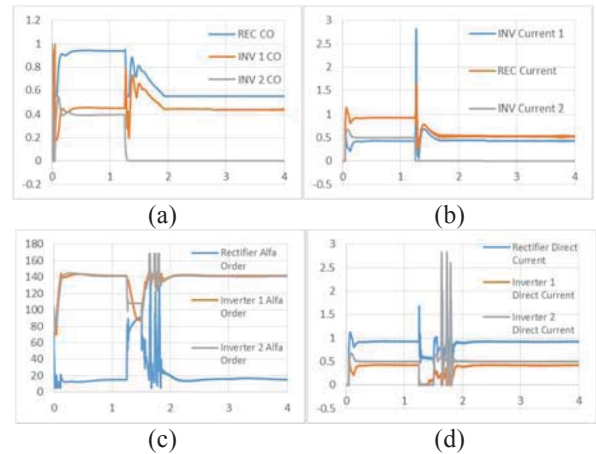


Figure 5: Current orders of 3 Terminal MTDC

To check validity of proposed current order calculation technique, MTDC model is experienced under faults. 3-terminal model is switched to 2-terminal to see the behavior of system in case when inverter 2 lost operation due to any disturbance. Inverter 2 is switched off at 1.25s and system observes current order recalculations. The current orders, direct currents, firing angle (for rectifier and inverters), direct voltages, and RMS AC voltages are shown in figure 6.



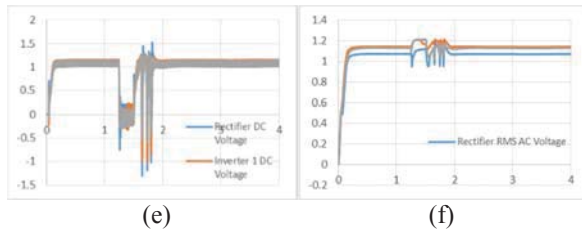


Figure 6: When inverter 2 switched off at $t=1.25s$. (a) Current order recalculations (b) Direct current under permanent fault (c) Firing angle (d) Direct current under temporary fault (e) Direct voltage (f) RMS AC voltages

Figure 6 shows that system continues its operation with remaining terminals even when one terminal is permanently off. After transition period of 0.5s, model behaves like 2-terminal HVDC with current margin of 0.1. To see temporary fault, Inverter 1 and Inverter 2 transmission lines are grounded at $t=1.25s$ for 0.25s.

Figure 6 shows that the readjustment of system parameters to original position soon after the fault is cleared. Rectifier and inverter 2 keep their constant current control operation while inverter 1 retain in constant extension angle control mode and regulate system voltages. It has been observed that MTDC system with proposed current order sharing takes nearly 0.5s to become stable again after temporary fault.

VI. CONCLUSION

A simple self-adjustable current order sharing technique is designed for multi terminal direct current (MTDC) transmission system. In proposed scheme, current order of k^{th} terminal is rectifier current order multiply by ratio of current at k terminal to total current. Change in total current reflects the disturbance at any terminal which ultimately affects the current order. Due to this arrangement the scheme automatically adjusts the current order of each working terminal in order to avoid negative current margin which collapse dc voltages and over current burden at inverters. A generalized scheme for $n_{rec} \times n_{inv}$ is also presented for LCC MTDC power system. The model is investigated in PSCAD to check performance in both normal and abnormal conditions. The simulation results show that the scheme has efficiently recalculated the current orders during faults and recover back to original steady state values with in 0.5s as soon the fault is cleared. Hence it is substantiated that the method has capability to distribute accurate current orders for all field conditions.

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