

## ANALYSIS OF COMMUTATION FAILURE IN MULTI-INFEED HVDC SYSTEM

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### ABSTRACT

The characterization of the commutation failure behavior of the converter in a multi-infeed system must consider some parameters in addition to the single infeed systems. Multi-infeed Short Circuit Ratio (MSCR) and Multi-infeed Effective Short Circuit Ratio (MESCR) are two parameters which characterize the network in Multi infeed HVDC systems. Simulation of CIGRE HVDC Benchmark System & Analysis of commutation Failure in Multi-Infeed HVDC Systems is carried out in MATLAB/SIMULINK. The HVDC controls are modeled in detail in MATLAB to test the performance of HVDC Benchmark system. Multi-infeed Short Circuit Ratio (MSCR) and Multi-infeed Effective Short Circuit Ratio (MESCR) are determined for Multi-infeed HVDC system. Multi-infeed Interaction Factor (MIIF) is obtained for Multi-Infeed HVDC System for various lengths of transmission lines between the inverters.

**Key words:** SCR, ESCR, AC, DC, MSCR, MESCR, MIIF, CCC, GTO, IGBT,  $\alpha$ ,  $\mu$ ,  $\gamma$ , CIGRE.

### I. INTRODUCTION

High Voltage Direct Current (HVDC) Technology is a most attractive transmission technology when power has to be transmitted over long distances. A total of around 70000MW of transmission capacity is transmitted around the world through 95 HVDC projects [1]. With the concentration of load in one region, the HVDC links are sometimes terminated in close proximity to each other. A benchmark system provides a good common base for testing of simulators and digital programs and to make comparisons between simulation sources to obtain confidence in and revise existing or new simulation models. The main purpose of this benchmark model proposed by CIGRE is to encourage comparison of performance of different DC control equipment and strategies of various manufacturers and institutes by means of HVDC simulator or digital computer studies made on this model. This benchmark system has a rather simple, but operationally difficult configuration. It is a two terminal DC scheme where the main circuit values proposed are arbitrary and do not represent any particular HVDC scheme [9]. The performance of various components in a power system depends on the characteristic of the

power system usually referred as the strength of the system [5]. The strength of the system reflects the sensitivity of the system variables to various disturbances in the operation of components connected in the system. Therefore, the short circuit level or the equivalent impedance at a bus is often a good measure of the strength of the system at that particular point. Traditionally, an index, which is used to assess the performance of a converter at the bus are Short Circuit Ratio (SCR) and Effective Short Circuit Ratio (ESCR). SCR is basically defined as the ratio between the short circuit capacity of the AC network at the commutation bus and the nominal DC power level. A system is called weak AC system if its SCR value is in between 2 to 3 [6].

In the Multi-infeed HVDC system, both converters connect into the same AC network and the commutation failure behavior of each could be affected by the other converter's presence. Hence characterization of the Commutation failure behavior of the converters in a Multi-infeed HVDC system must consider parameters such as SCR and ESCR to Single-infeed HVDC system. The definitions of SCR and ESCR to Multi-infeed of the HVDC converter are called as Multi-infeed Short Circuit Ratio (MSCR) and Multi-infeed Effective Short Circuit Ratio (MESCR). Another factor (MIIF) is proposed as a parameter for estimating the degree of voltage interaction between two converters [7].

“Multi-infeed Interaction Factor” (MIIF) which proposed by prof A.M.Gole is an accurate indicator of the immunity of an HVDC system to commutation failure [8]. Initially Single-infeed HVDC is obtained by modeling the CIGRE HVDC Benchmark system [9] in MATLAB. Multi-infeed HVDC system is modeled by two single-infeed CIGRE HVDC systems connected by a transmission line at their inverter bus.

## II. MULTI -INFEED HVDC SYSTEM

### 2.1 Introduction

Single-infeed HVDC is one in which there will be one rectifier station and inverter station. The rapid growth of DC transmission in many countries is resulting in multi-infeed configurations. The Multi in feed HVDC systems are the one where two or more HVDC links terminate in to the same AC network.

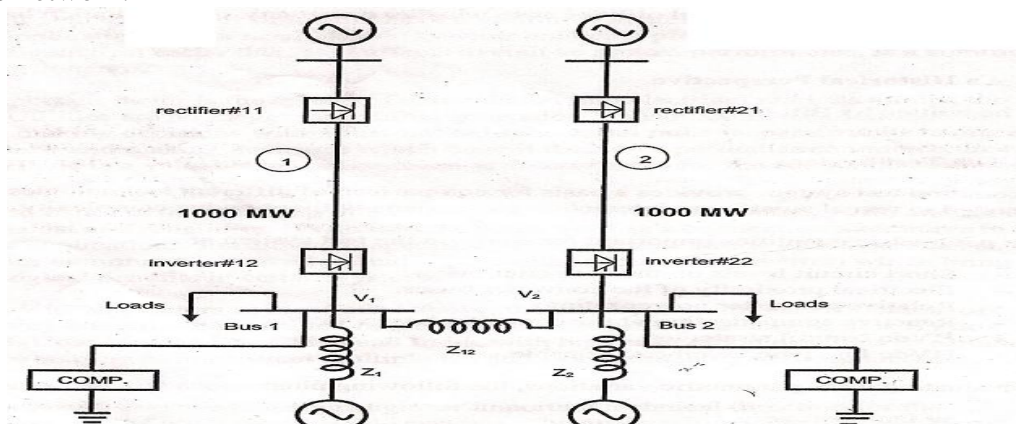


Fig 2.1 Multi in feed HVDC System

## **2.2 Short Circuit Ratio (S.C.R)**

The Short Circuit Ratio (SCR) is one of the most important parameters for characterizing the degree of expected operational problems. It is the ratio between the AC system short circuit power and the rated DC power.

$$SCR = \frac{S}{P_{d1}} \quad (3.2)$$

Where S is short circuit capacity  
P<sub>d1</sub> is nominal power.

## **2.3 Effective Short Circuit Ratio (E.S.C.R)**

Shunt capacitors including ac filters connected at the ac terminal of a dc link can significantly increase the effective ac system impedance. In allow for this, the effective short-circuit ratio (ESCR) is defined as follows:

$$ESCR = \frac{S - Q_c}{P_{d1}} \quad (3.3)$$

Where, S is short circuit capacity.  
P<sub>d1</sub> is nominal power  
Q<sub>c</sub> is reactive shunt compensation.

Traditionally these indices SCR & ESCR are used to access the Commutation Failure in single-feed HVDC systems.

# **III. COMMUTATION FAILURE IN MULTI - INFEEED HVDC SYSTEMS**

## **3.1 Introduction**

In the Multi in feed HVDC systems both converters connect in to same ac network and the CF behavior of each converter could be affected by the other converter's presence. Hence characterization of the CF behavior of the converters in a multi-in feed system must consider parameters in addition to the simple ESCR that is commonly used for single in feed systems. As the Short Circuit Ratio (SCR) and Effective Short Circuit Ratio (ESCR) which represent the strength of the ac system are generally used to analyze the commutation failure in single infeed HVDC systems. Same concept is extended to Multi-infeed HVDC system, the parameters Multi-Infeed Short Circuit Ratio (MSCR) and Multi-Infeed Effective Short Circuit Ratio (MESCR) are formulated and developed. The MSCR & MESCR gives only indication of strength of the systems, a new factor Multi infeed interaction factor (MIIF) is also proposed to determine the interaction between two HVDC systems in Multi-infeed HVDC systems.

### **3.1.1 Multi in feed Short circuit Ratio (MSCR)**

The definition of SCR and ESCR to multi-infeed of the HVDC system can be obtained by extracting the elements of the bus impedance matrix. The MSCR equation suggests an approximate indication of short circuit ratio at a converter bus taking into consideration the

influence of operation of remote converters electrically connected to the converter bus that is under consideration. From the fig 3.1 below MSCR is given by

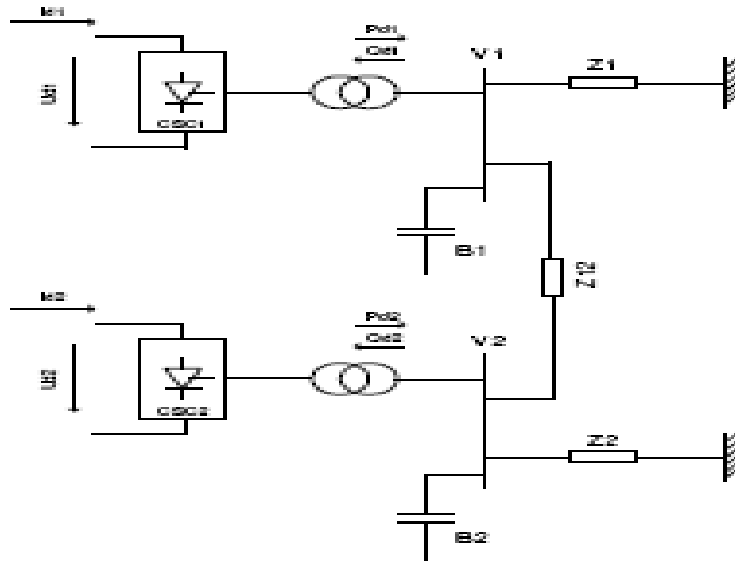


Fig 3.1 Two HVDC converter station

$$MSCR_n = \frac{1}{\sum_{m=1}^k P_{dcm} * Z_{n,m}} \quad (3.5)$$

Where K corresponds to number of HVDC terminal stations.

$P_{dcm}$  is the nominal power of the HVDC station

$Z_{n,m}$  is the  $n^{th}$ ,  $m^{th}$  element in the  $Z_{bus}$  matrix in p.u.

### 3.1.2 Multi-Infeed Effective Short Circuit Ratio (MESCR)

While calculating the  $Z_{bus}$  matrix the impact of shunt elements are also considered by including these elements in the formation of the matrix. Using the elements from the new  $Z_{e BUS}$  the Multi-Infeed Effective short circuit ratio is defined by

$$MESCR_n = \frac{1}{\sum_{m=1}^k P_{dcm} * Z_{e n,m}} \quad (3.6)$$

Where k is number of HVDC terminal stations.

$Z_{e,n,m}$  is the  $n^{th}$ ,  $m^{th}$  element included in the effective  $Z_{e BUS}$  matrix.

### 3.2 Multi-Infeed Interaction Factor (MIIF)

As it is explained in above sections, the multi-infeed inverter situation is considered the most problematic configuration because of the commutation performance. In a Multi-infeed scheme with two or more HVDC inverters supplying into a common ac system, the ability of each inverter to influence its own bus is important as is the ability of one inverter to influence another inverter's bus. A new factor called multi-infeed interaction factor (MIIF) is defined in [1] relates

AC bus voltages at the two inverters. These voltages reflect the interaction between the two inverters.

The Multi-Infeed Interaction Factor (MIIF) is proposed as a parameter for estimating the degree of voltage interaction between two systems. Since the performance of HVDC converter is largely affected by the ac voltage and as the MIIF shows the level of voltage interactions between two buses, the MIIF is also expected to be a good measure of the interaction between converters in multi-infeed dc systems.

$$\text{MIIF} = \frac{\Delta V_{2\%}}{1\% \text{ change in } V_1} \quad (3.7)$$

Where  $\Delta V_2 \%$  is percentage bus voltage change at converter 2 for a inductive fault at  $V_1$  is the bus voltage at inverter 1.

A schematic diagram of the multi-infeed is shown in Fig 3.2. Which shows two HVDC converters (Converter 1 and Converter 2) feeding an ac network. The ac network consists of two thevenin equivalents with an interconnecting tie line. For systems with several HVDC links in close proximity, there will be multiple MIIFs calculated forming a matrix. The MIIFs from the existing buses to the new bus may also be relevant.

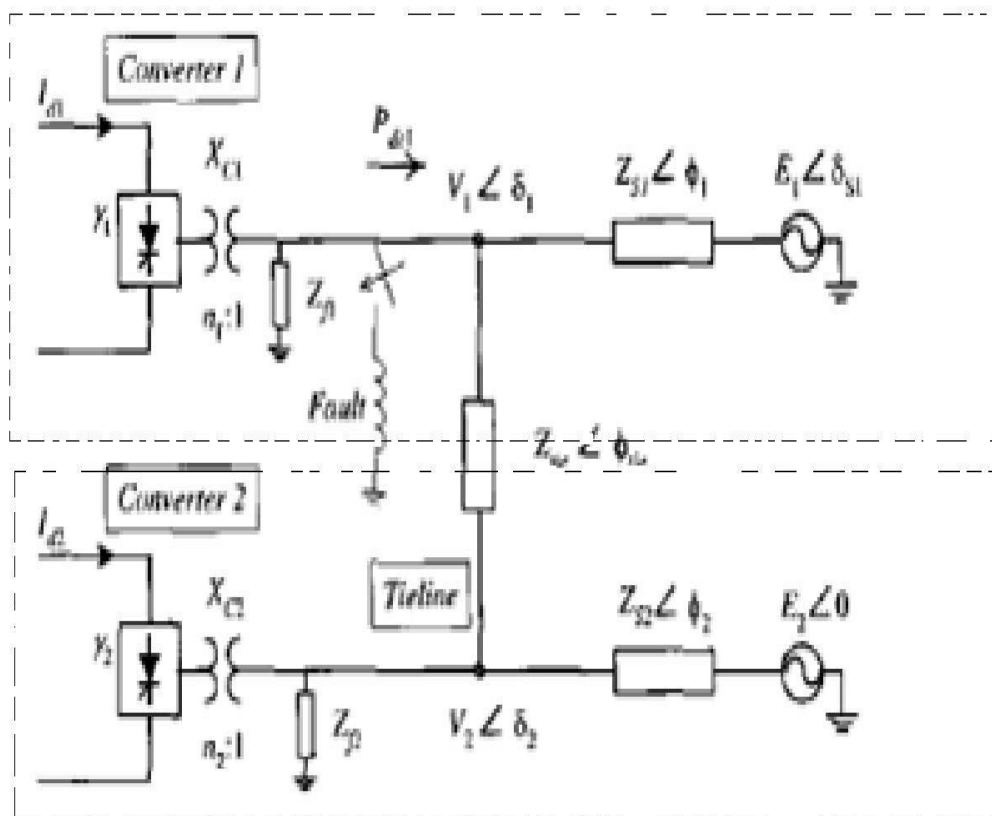


Fig 3.2 Multi-infeed HVDC system

The typical MIIF matrix for three inverter Multi-infeed HVDC system is given in table 3.1

Table 3.1: Typical MIIF Matrix

MIIF Table		Relative Inverter AC Voltage Change		
		Inverter 1	Inverter 2	Inverter 3
Bus at which fixed reduction is applied	Inv. 1	$MIIF_{1,1} = \frac{\Delta V_1}{\Delta V_1}$	$MIIF_{2,1} = \frac{\Delta V_2}{\Delta V_1}$	$MIIF_{3,1} = \frac{\Delta V_3}{\Delta V_1}$
	Inv. 2	$MIIF_{1,2} = \frac{\Delta V_1}{\Delta V_2}$	$MIIF_{2,2} = \frac{\Delta V_2}{\Delta V_2}$	$MIIF_{3,2} = \frac{\Delta V_3}{\Delta V_2}$
	Inv. 3	$MIIF_{1,3} = \frac{\Delta V_1}{\Delta V_3}$	$MIIF_{2,3} = \frac{\Delta V_2}{\Delta V_3}$	$MIIF_{3,3} = \frac{\Delta V_3}{\Delta V_3}$

MIIF values range from zero to one with zero implying infinite electrical separation and one implying the same bus. Hence diagonal elements of the MIIF matrix are unity indicating that interaction of the bus with respect to the same bus.



Fig 3.3 MIIF range

MIIF values below at 0.15 would indicate a very low potential for multi in feed interaction. MIIF values between 0.15 and 0.40 indicate links with a moderate potential and values above 0.4 indicate a high potential for inverter interaction.

The analysis of commutation failure for single and Multi in feed HVDC systems is carried out as a part of this project for CIGRE HVDC Benchmark System. In MATLAB/SIMLINK software CIGRE HVDC Benchmark System is simulated as single in feed HVDC system then Multi in feed HVDC system is simulated with two CIGRE HVDC Benchmark Systems connected through a transmission line and MIIF is found and results are presented in chapter 4.

## IV. RESULTS

### 4.1 Commutation Failure Analysis in Multi-Infeed HVDC System Using Matlab

The Multi infeed HVDC system has two HVDC links each of is 1000MW HVDC link and a tie line. 230KV transmission line is used as tie line. The HVDC links in Multi- infeed HVDC system are modeled in MATLAB in similar way as single-infeed HVDC system.

The simulation of Multi-infeed HVDC system is carried out in MATLAB/ SIMULINK to carry out commutation failure analysis. The modeled Multi in feed HVDC systems is shown in Fig 4.1.

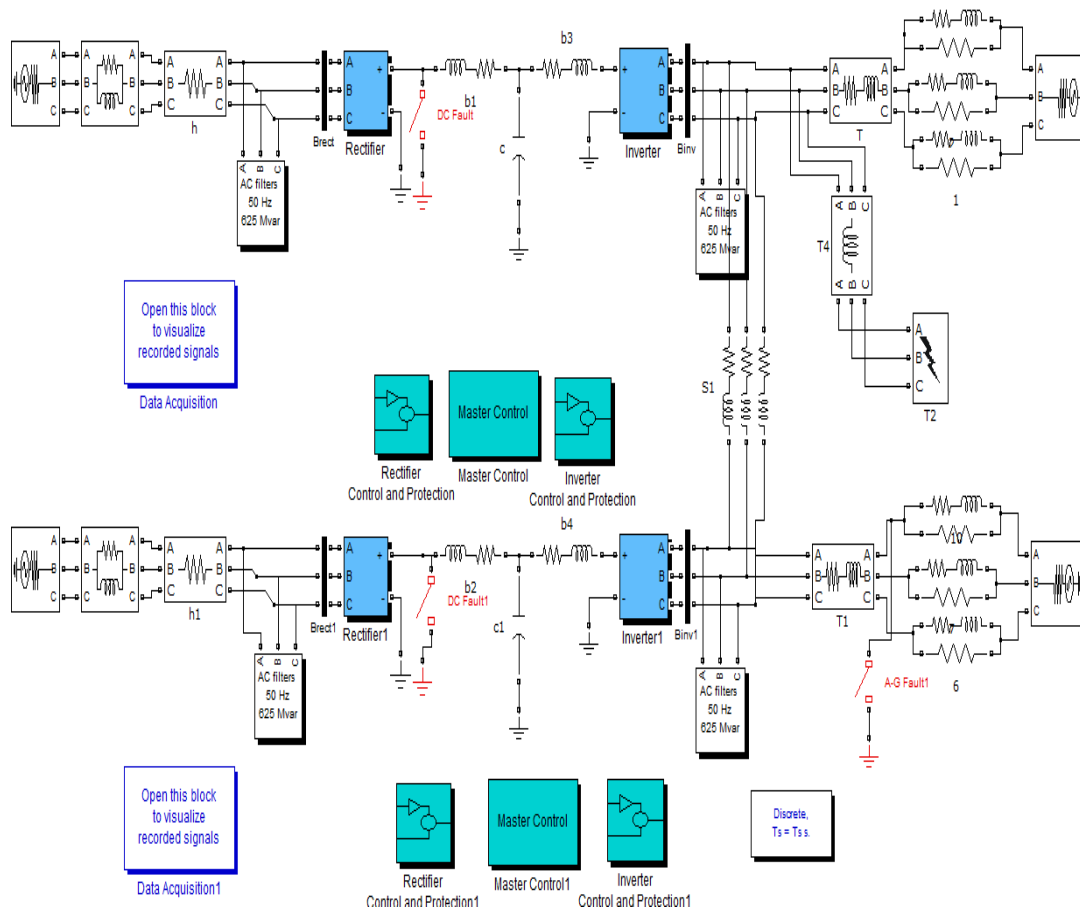


Fig4.1. Multi- infeed HVDC system

Table 4.1: 230 KV Transmission line details

Positive Sequence Series Resistance	0.0687 Ω/KM
Positive sequence series inductive Reactance	0.20442 Ω/KM
Positive sequence shunt capacitive reactance	0.17428Megaohms/KM
Zero sequence series resistance	0.17175 Ω/KM
Zero sequence series inductive reactance	0.51105 Ω/KM
Zero sequence shunt capacitive reactance	0.4359Megaohms/KM
Line Length	250km

### 4.2 Multi Infeed Interaction Factor (MIIF)

The MIIF is obtained by creating a three phase inductive fault at inverter 1 and measuring the voltage dip at inverter 2 with respect to voltage dip at inverter1. Fault impedance is varied in such way that, 1% voltage dip at inverter1 is created and correspondingly the voltage dip at inverter 2 is measured. The interaction between the inverters basically depends upon the electrical distance between the inverters. Thus, the value of MIIF varies if the length of transmission line is varied. The MIIF is obtained for different line lengths to find out the interactions between the two HVDC systems.

#### Case1: Tie line length=50km.

For a tie line length of 50km, a three phase fault is applied at inverter 1, the fault inductance value is varied and every time the dip in voltage is measured until there is 1% dip in voltage at inverter 1. At 5.3H there is 1% dip in voltage at inverter1. Correspondingly the dip in voltage at the 2<sup>nd</sup> inverter bus is noted. Then MIIF is calculated from the equation 3.7 given in

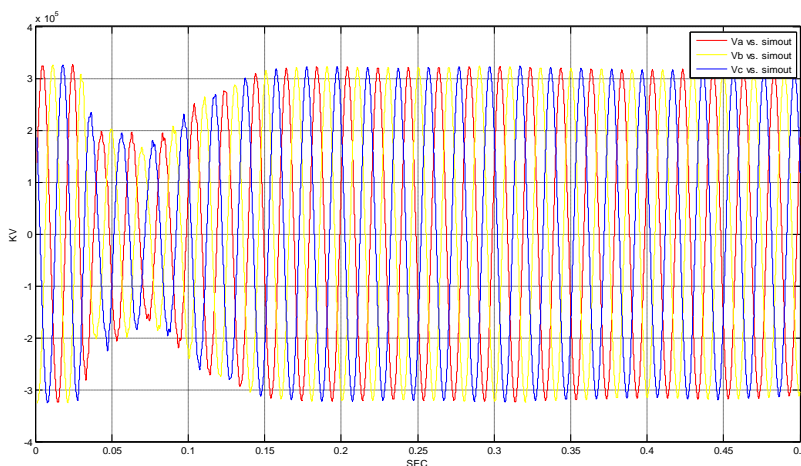


Fig4.2. AC bus Voltage Waveform at inverter1

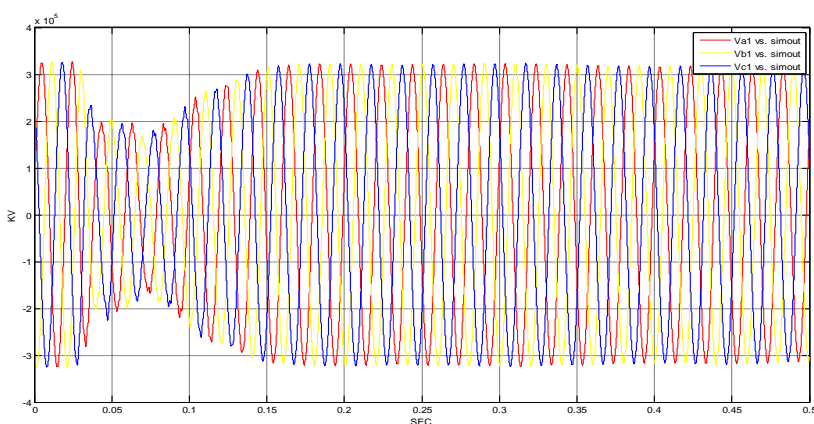


Fig4.3. AC bus Voltage Waveform at inverter2  
From the above waveforms

Converter	Pre-fault voltage (V) in (kv)	Voltage during fault $V_f$ in (kv)	% change in voltage $(V-V_f)/V*100$
Inverter1	228.338	226.055	1
Inverter2	228.338	226.70	0.717

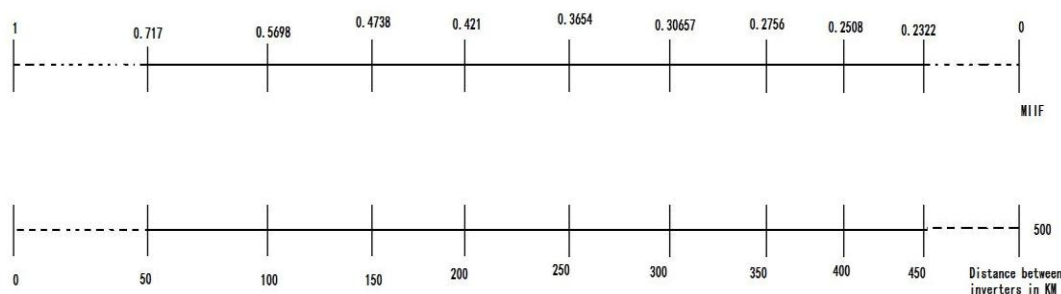
$$\Delta V_2 \% = 0.717$$

$$MIIF = (\Delta V_2 \%)/(1\% \text{ change in } V_1) = 0.717$$

Table 4.2: MIIF values for different transmission lengths

Tie line length	MIIF	Fault Inductance(H)	Impedance of transmission line (Z)
50 KM	0.715	5.30	3.435+j10.221
100 KM	0.5698	5.79	6.870+j20.410
150KM	0.4738	6.19	10.305+j32.972
200KM	0.421	6.43	13.740+j40.821
250KM	0.3654	6.68	17.175+j51.025
300KM	0.30657	6.97	20.612+j61.233
350KM	0.2756	7.13	24.045+j71.435
400KM	0.2508	7.29	27.484+j81.643
450KM	0.2322	7.40	30.915+j91.845

MIIF value varies between 0 and 1. MIIF value below 0.15 indicates a very low potential for multi in feed interaction. MIIF value between 0.15 and 0.40 indicate HVDC links with a moderate potential and values above 0.4 indicate a high potential for inverter interaction. The obtained MIIF values can be interpreted in a following way with respect to the distance between the two inverter.



$$MSCR_1 = \frac{1}{P_{dc1} * Z_{11} + P_{dc2} * Z_{12}}$$

$$\begin{aligned} &= \frac{1}{(1 * (0.1039 + j0.387)) + (1 * (0.3247 + j0.9601))} \\ &= 0.2128 - j0.6717 \\ MSCR_2 &= \frac{1}{P_{dc2} * Z_{21} + P_{dc} * Z_{22}} \\ &= \frac{1}{(1 * (0.3247 + j0.9661)) + (1 * (0.1039 + j0.387))} \\ &= 0.2128 - j0.6717 \end{aligned}$$

## CONCLUSION

In this paper, implementation of a matlab-simulink model for MIIF has been introduced. If the length of the transmission line between two inverters is 450km, the MIIF is 0.232 indicating very low potential for inverter interactions. If the length of transmission line is between 200km to 400km then there is moderate potential for inverter interactions. If the length of transmission line is less than 200km then there is high potential for inverter interactions.

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