



Effects of VSC based HVDC system on distance protection of transmission lines



Mohammad Meraj Alam^{a,*}, Helder Leite^a, Jun Liang^b, Adriano da Silva Carvalho^a

^a Department of Electrical and Computer Engineering, Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

^b School of Engineering, Cardiff University, The Parade, Cardiff CF24 3AA, Wales, United Kingdom

ARTICLE INFO

Article history:

Received 26 September 2016

Received in revised form 27 March 2017

Accepted 29 April 2017

Keywords:

Distance relay

HVDC

Transmission line

Voltage Source Converter

ABSTRACT

The priority to reactive power contribution from the Voltage Source Converter (VSC) based High Voltage Direct Current (HVDC) connection to support the grid during faults as suggested by the modern Network Code (NC) for HVDC affects the distance protection of transmission lines. Moreover, suppressing the negative sequence current during an unbalanced condition also interferes with the proper operation of the distance relays. This is because the current contribution from the converter is limited in magnitude and modified in the waveform in order to protect the power electronic devices during the fault in comparison to the synchronous generator fault current characteristics. This paper discusses the cause as well as the severity of the problems faced by the distance protection of transmission lines connected to the VSC based HVDC system by analyzing the apparent impedance analytically and in the simulation. The response of the relay to balanced and unbalanced faults lying on transmission lines is investigated. It is shown that the VSC limited reactive support and suppressed negative sequence current affect fault detection, forcing the relay to malfunction. The results of this paper can be used as a reference for understanding the effects of VSC-HVDC system on the operation of the distance protection during faults.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Transmission lines are often exposed to major as well as minor disturbances. The fault current associated with major disturbances can jeopardize the power system unless protected by the relays and circuit breakers [1]. These protective relays are responsible for the correct detection and isolation of faults to minimize the damage [2]. Therefore, transmission lines are always protected by the relays, for instance, line differential protection, directional overcurrent protection, directional earth fault and distance protection (pilot and non-pilot), which are selective, robust and sensitive in nature [3]. Of these, the distance relays are more common for line protection, which provides high-speed primary protection and slow speed backup protection [4]. However, the distance protection comes with major drawbacks of overreach and tripping during overload and power swing, which consequently led to major blackouts, such as USA 2003 and Europe 2006 [5]. Furthermore, the present day power system is evolving from what it was a decade ago by the replacement of conventional Synchronous Generator (SG) with the renewable energy sources and Voltage Source Converter (VSC) based High Voltage Direct Current (HVDC)

connection. This change in the power system is leading to a low or very low Short Circuit Ratio (SCR) because of increase in the network impedance as the point of connection between the ac system and VSC is remotely located [6]. In addition to this, the system inertia is also reducing when a considerable amount of power is supplied by the VSC station [7–9], and any load-generation imbalance causes frequency excursion and line overloading leading to the malfunction of the distance relay. Hence, it is highly relevant to look into the performance of the distance relays in the presence of VSC-HVDC system.

Nowadays, VSC-HVDC is utilized for the grid integration of far offshore Wind Power Plant (WPP) and interconnection of WPPs to each other or to multiple infeed points leading to Multi-Terminal HVDC (MTDC) by the efficient use of multilevel converter technologies [10,11]. Furthermore, one of the important benefits of VSC based HVDC or MTDC is that the onshore VSC's can provide limited reactive current during faults as per the Network Code (NC) decided by the Transmission System Operator (TSO) to support the network voltage [12–14]. Since this reactive current injection is the positive sequence current and the presence of negative sequence current in addition to the positive sequence current limits the amount of available positive sequence reactive current during an unbalanced fault [15,16]. Moreover, the negative sequence current causes an extra stress on the Power Electronic Switches

* Corresponding author.

E-mail address: merajalam@fe.up.pt (M.M. Alam).

(PES) due to large unbalanced ac fault currents [17]. Consequently, the negative sequence current can be suppressed to zero to give room to the positive sequence reactive current support from the VSC and to de-stress the PES by keeping the ac currents balanced under unbalanced grid conditions. Additionally, the grid code does not stipulate any specific requirement regarding the negative sequence current supplied by the VSC during the fault [15,18]. This eventually modifies the overall fault behaviour of VSC's compared to SG in terms of both magnitude and waveform [19]. Therefore, the network operator is facing challenges in handling the grid protection systems due to these exclusive behaviours of VSC, which affect the current and voltage measured by the protective relays during the fault leading to an inaccurate computation of the apparent impedance and malfunction of the distance relay [19–21].

Numerous research has been performed on the performance of the distance relay in the presence of VSC based Flexible AC Transmission System (FACTS) devices. The effects of the shunt and series VSC based multiline FACTS controllers [22] and Unified Power Flow Controller (UPFC) [23] on the distance relay have been studied analytically and in simulation for a different arrangement of FACTS and different fault conditions. The work in [24] highlights the impact of UPFC on power swing characteristics and the operation of the distance protection due to the change in line constants (ABCD) parameters. The authors in [25,26] published the adverse impacts of shunt-FACTS controllers, Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) on the performance of both standalone and channel aided distance protection. The research in [27] presents an adaptive distance protection scheme in order to prevent the malfunction of the relay with shunt compensated lines. Although many publications are available regarding the behaviour of the distance relay with VSC-based FACTS controllers for different fault types and fault locations, very few researchers have studied the adverse impact of VSC based HVDC on the distance protection during a major disturbance, which unfortunately has been left undiscussed. The authors in [20,21] present that the distance relay fails because of interference from the fast reactive power control strategy of the VSC-HVDC station when a fault on a transmission line lies in zone 1 and zone 2 reach of the distance relay. However, the impact of the converter dynamics due to the suppression of the negative sequence current during an unbalanced condition and reactive current support based on NC along with converter current limitation strategy on the distance relay have not been explained so far.

This paper aims to investigate the impacts of VSC-HVDC system on the distance protection of transmission lines when following the NC guidelines for HVDC connections of reactive current support during faults. Furthermore, the effect of the negative sequence current suppression during an unbalanced fault along with the VSC current limitation strategy is also assessed using analytical and simulation methods. The main contributions of this paper are as follows.

- An analytical estimation and comparative analysis of apparent impedance seen by the distance relay is presented for a single line to ground and phase-to-phase fault on a transmission line connecting VSC-HVDC in a power system using sequence networks, as given in Appendix Table 1.
- The locus observed by the distance relay during a fault with the detailed model of VSC as Modular Multilevel Converter (MMC) is simulated in PSCAD. Moreover, the effect of the transient response of VSC due to the reactive current injection, suppressed negative sequence fault current, converter current limitation strategy on the dynamic positive sequence impedance trajectory on RX plane are studied.

2. Apparent impedance analysis during fault

Fig. 1(a) presents a simplified arrangement of a power system consisting of a VSC connected to the grid through a delta-star winding transformer and a transmission line. The distance relay $R1$ and $R2$ located at both the ends of the transmission line protects the line. Figs. 1(b) and 1(c) illustrate the sequence networks of the power system arrangement for a single line to ground and phase-to-phase faults. Figs. 2(a) and 2(b) also present the sequence network of the power system during phase-to-phase-to-ground and three-phase faults. The VSC is represented as a controlled current source both in the positive and negative sequence networks because the inner current control is the main control that tracks the current references coming from the outer control [28]. From the sequence networks, the sequence component of the voltage, V_{R1}^x at the relay location $R1$ can be derived for the different fault types. Henceforth, (1) gives the positive sequence component of the voltage at the fault location, V_F^1 , from the relay $R1$ as follows.

Where

Z_L^x	sequence impedance of the line	Z_g^x	sequence Thevenin equiv. grid impedance
X_{tr}^x	sequence reactance of the transformer	X_{con}^x	sequence reactance of the converter reactor
I_{con}^x	sequence component of converter fault current	I^x	sequence fault current
I_g^x	sequence component of grid fault current	I_{tr}^0	transformer zero sequence current
V_g^1	positive seq. Thevenin equiv. grid voltage	V_F^x	fault point voltage on the line
V_{R1}^x	sequence voltage at the relay $R1$	m	length of the transmission line
R_f	fault resistance	x	0, 1, 2
I_{R1}^{abc}	phase currents through relay $R1$	V_{R1}^{abc}	phase voltages at the relay $R1$
I_{R1}^x	sequence currents through relay $R1$	I_g^{abc}	phase currents through relay $R2$

$$V_F^1 = V_{R1}^1 - I_{con}^1 (mZ_L^1) \quad (1)$$

With reference to the negative sequence network of the simplified power system for any unbalanced faults, as depicted in Figs. 1(b), 1(c), and 2(a), the negative sequence voltage V_F^2 at the fault location is given by (2), which is similar to (1) except the superscript. Therefore,

$$V_F^2 = V_{R1}^2 - I_{con}^2 (mZ_L^2) \quad (2)$$

Apart from this, the ground faults such as the single line to ground and phase-to-phase-to-ground faults involve the zero sequence component of the fault current and zero sequence network of the system as unveiled in Figs. 1(b) and 2(a). It is evident from the Figs. 1(b) and 2(a) that the converter does not supply the zero sequence component of the fault current due to the delta-star winding of the transformer. Thus, the converter controller is independent of the zero sequence current regulation and the grounded neutral of the transformer is the only path for its flow through the line (I_{tr}^0). The zero sequence voltage at the fault V_F^0 is given by (3):

$$V_F^0 = V_{R1}^0 - I_{tr}^0 (mZ_L^0) \quad (3)$$

Download English Version:

<https://daneshyari.com/en/article/4945565>

Download Persian Version:

<https://daneshyari.com/article/4945565>

[Daneshyari.com](https://daneshyari.com)