MODIFIED DISTANCE PROTECTION IN PRESENCE OF UPFC ON A TRANSMISSION LINE

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Abstract

This paper presents a modified distance protection scheme in the presence of Unified Power Flow Controller (UPFC), one of the Flexible Alternating Current Transmission System (FACTS) devices. The presence of UPFC on a transmission line has a great influence on the measured impedance at the relaying point. The measured impedance itself depends on the power system structural conditions, pre-fault loading, and especially the fault resistance. In the presence of UPFC, its controlling and structural parameters as well as its installation point affects the measured impedance. Therefore, the conventional distance schemes might not fulfil the protective duties satisfactorily and new approaches are required.

1 Introduction

The measured impedance at the relaying point is the basis of distance protection operation. There are several factors affecting the measured impedance at the relaying point. Some of these factors are related to the power system parameters prior to the fault instance [1]-[3], which can be categorized into two groups: structural and operational conditions. In addition to the power system parameters and independent of the absence or presence of FACTS devices, the fault resistance could greatly influence the measured impedance, in such a way that in the case of zero fault resistance, the power system parameters do not affect the measured impedance. In other words, in the absence of FACTS devices, power system parameters affect the measured impedance only in the presence of the fault resistance, and as the fault resistance increases, the impact of the power system parameters on the measured impedance becomes more severe.

In the recent years, FACTS devices are introduced to power systems to increase the transmitting capacity of lines and provide the optimum utilization of power systems capability. This is done by pushing the power systems to their thermal limits. It is well documented in the literature that the introduction of FACTS devices into a power system has a great influence on its dynamics. As power system dynamics changes, many sub-systems are affected, including the protective systems. Therefore, it is essential to study the effects of FACTS devices on the protective systems.

Unlike the power system parameters, the structural and controlling parameters of FACTS devices, as well as their installation position could affect the measured impedance in the case of zero fault resistance. In the presence of FACTS devices, the conventional distance characteristics are greatly subjected to mal-operation in the both forms of over-reaching or under-reaching the fault point. Therefore, the conventional characteristics might not perform satisfactorily in the presence of FACTS devices.

Impact of UPFC on distance protection is investigated in [4] by means of simulation, and in the case of UPFC installation at the near end, the effect of instrument transformers connection point is studied. Impacts of instrument transformers connection point are studied in [5] for UPFC insulation at the near end by means of schematic equations. The analytical and simulation results of the application of distance relays for the protection of transmission systems employing UPFC are presented in [6]. The impact of UPFC operating characteristics on the transmission line protective relay behaviour is studied in [7] for series and shunt compensating parts individually and collectively. A refined Differential Current Protection Method (DCRM) for solving problems associated with presences of STATCOM, SSSC, and UPFC is presented in [8]. The impact of UPFC on distance relay is investigated in [9] and a new adaptive relaying technique is presented based on synchronized phasor measurements from Phasor Measurement Units (PMU) installed at line terminals. Furthermore, the effects of series connected FACTS devices, or FACTS devices with the series branch including TCSC, TCPST, and UPFC, on the measured impedance have been presented in [10] and more detailed studies for UPFC have been presented in [11].

The presented solutions in [8]-[9] are based on unit protection or the data exchange between the relays at line ends. The other potential solution for problems caused by introduction of UPFC on a transmission line could be adaptive based modified distance protection, where the distance relay reach-point is adapted or modified due to the power system conditions and UPFC parameters.

This paper investigates the measured impedance at the relaying point in the presence of UPFC, and a modified distance protection is presented for distance relays at the ends of the compensated line by UPFC, based on the power system conditions and UPFC structural and controlling parameters.

2 Measured Impedance at Relaying Point

In the Absence of UPFC, the measured impedance at the relaying point could be expressed by the following equation, more detailed calculations can be found in [2].

$$Z_A = p\,Z_{1L} + \frac{3R_f}{C_{ld} + 2C_1 + C_0(1 + 3K_{0L})} \tag{1}$$

Once UPFC is installed on the transmission line and depending on its absence or presence in the fault loop, the measured impedance at the relaying point is affected. The detailed equations due to the presented model for UPFC could be found in [12]. In the case of UPFC out of the fault loop, the measured impedance will be the same as (1), but its elements are changed.

In the case of UPFC in the fault loop, the measured impedance will be as following:

$$Z_A = (p + C_{1S})Z_{1L} + \frac{C_{Sh} + C_{Z_{Se}} + C_{V_{Se}} + 3R_f}{C_{ld} + 2C_1 C_{1A} + C_0 C_{0A}(1 + 3K_{0L})} \tag{2}$$

It can be seen that in the absence of the fault resistance, the measured impedance at the relaying point is not equal to the actual impedance of the line section between the relaying and fault points, and it deviates from its actual value due to four additional deviating terms.

3 Effects of UPFC on Distance Relay Ideal Tripping Characteristic

Impacts of the presence of UPFC on a transmission line have been tested for a practical system. A 400 kV Iranian transmission line with the length of 300 km has been used for this study. By utilizing the Electro-Magnetic Transient Program (EMTP) [13] various sequence impedances of the line are evaluated according to its physical dimensions. The calculated impedances and the other parameters of the system are:

$Z_{1L} = 0.01133 + j\,0.3037$ Ω/km
$Z_{0L} = 0.1535 + j\,1.1478$ Ω/km
$Z_{1SA} = 1.3945 + j\,15.9391$ Ω
$Z_{0SA} = 7.4540 + j\,27.8187$ Ω
$Z_{1SB} = 0.6972 + j\,7.9696$ Ω
$Z_{0SB} = 3.7270 + j\,13.9093$ Ω
$h = 0.96$
$\delta = 16°$

In the absence of UPFC, Figure 1 shows the ideal tripping characteristic of the distance relay, which is the measured impedance at the relaying point as the fault resistance varies from 0 to 200 ohms, while the fault location moves from the near end up to the far end of the line. The quadrilateral characteristic covering 80% of the line and the impedance of the transmission line, Z_{1L}, are shown in Figure 1. In addition, the dotted line is the measured impedance for the faults at the reach-point while the fault resistance varies from 0 to 200 ohms.
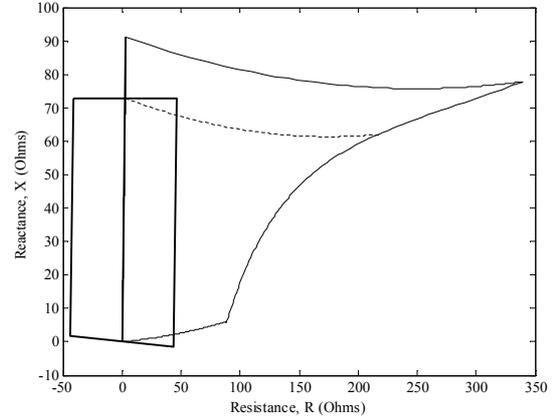

Figure 1: Distance relay ideal tripping characteristic, without UPFC

It can be seen that in the absence of the fault resistance, the measured impedance at the relaying point is the actual value. In other words, the left side of the ideal tripping characteristic is the impedance of the transmission line.

Usually UPFC controls its connecting point voltage and its flowing current according to its controlling strategy. Therefore, UPFC controlling parameters vary by the variation of the loading conditions of the power system. But in this study the operational conditions of the power system are assumed to be constant and it is assumed these conditions are achieved by different UPFC controlling parameters.

The ideal tripping characteristic for UPFC installation on near end, mid-point, and far end of the line are investigated in [14]. In the case of UPFC out of fault loop, it does not affect the measured impedance for zero fault resistance. In [14] and the other papers describing about UPFC, UPFC is simulated in three cases of phase shifting (phase angle of 90° or – 90°), tap changer (phase angle of 0° or 180°), and shunt compensation modes. Among these three operational modes, the tap changer mode is more effective on the reach point of the distance relay. Therefore, two cases of UPFC at the near end and mid-point in the tap changer mode are investigated.

Figure 2 shows the effect of UPFC installation at the near end of the transmission line in the tap changer mode. Here, the amplitude of the injected voltage takes the magnitudes of 0.00, 0.05, and 0.10 for both phase angles of 0° and 180°. In Figure 2 the tripping characteristic without UPFC is also shown in the dashed form for comparison.

It can be seen that an inactive UPFC would affect the measured impedance at the relaying point. This is due to the presence of the coupling transformers. The tripping characteristic transfers upward. The measured resistance increases while the measured reactance increases for low fault resistances and decreases for high fault resistances.

In the case of UPFC in the positive tap changer mode, phase angle of 0°, as the amplitude of the injected voltage increases, the measured resistance decreases for high fault resistances