Adaptive Relay Setting for Flexible AC Transmission Systems (FACTS)

P. K. Dash, A. K. Pradhan, Ganapati Panda, and A. C. Liew

***Abstract*—The paper presents an apparent impedance calculation procedure for distance relaying of transmission line involving FACTS devices, particularly the UPFC (unified power flow controller). The presence of UPFC significantly affects the trip boundaries which are also adversely affected by fault resistance combined with remote end infeed. Depending on the UPFC location, the trip boundary is influenced by the fault location, prefault condition, the arc fault resistance and the parameters of the UPFC itself (series voltage magnitude and phase angle). The adaptive nature of this protection scheme necessitates the use of a neural network for generation of trip boundaries.**

***Index Terms*—Adaptive protection, distance relaying, FACTS, protection setting.**

I. Introduction

THE USE OF power electronics devices to improve the power transfer capability of long transmission lines forms the basis of the concept of FACTS. By the development of thyristors with current extinguishing capability, all solid state implementation of power flow controllers could be realized. The unified power flow controller (UPFC) is a new device within the FACTS [1]–[4] family which consists of shunt and series converters. The series converter injects a series voltage of variable magnitude and phase. On the other hand the shunt branch is required to compensate for any real power drawn or supplied by the series branch and losses. While the use of UPFC improves the power transfer capability and stability of a power system, certain other problems emerge in the field of power system protection, in particular the transmission line protection. The implementation of control strategies for FACTS devices introduces new power system dynamic problems that must be considered while selecting the zones of protection. The basic concerns include the change in impedance, the phase angle, voltage magnitude, load currents and transient induced by the fault and the consequent control actions.

The presence of a FACTS device like UPFC in the fault loop affects both the steady state and transient components in the voltage and current. Therefore, the apparent impedance calculations should take into account the variable series voltage source and its angle and shunt current and admittance presented by the shunt converter of the UPFC. However, if the UPFC is not present in the fault loop, the apparent impedance calculations are similar to the ordinary transmission lines. Thus a decision concerning the relative position of the UPFC must be considered before the calculation of apparent impedance seen by the distance relay. Further, depending on the severity and the type of fault and its duration, the magnitude and phase angle of the variable series voltage source are adjusted. This gives rise to different distance relay impedance settings for different control characteristics of the UPFC and its location vis-a-vis the transmission fine. In addition the relay characteristics are influenced to a great extent by the presence of a resistance in the path of an Earth fault [5]–[8]. Due to the presence of UPFC in a transmission system and its presence or absence in fault loop, the distance relay either over-reaches or under-reaches under different system operating conditions. The presence of another source as in the case of two terminal system influence the apparent impedance characteristics of the relay. Thus there is a strong motivation to calculate impedance seen by the distance relay when there is an UPFC present in the line and to obtain adaptive settings, when the control of UPFC changes.

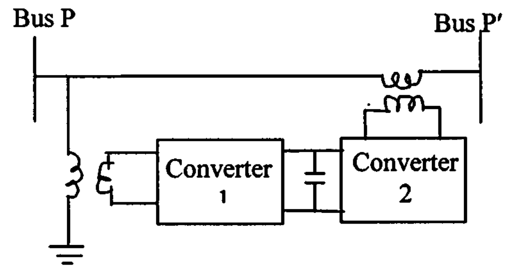

Fig. 1. Basic circuit arrangement of UPFC.

This paper, therefore presents the apparent impedance calculations and the distance relay setting characteristics for faults involving the UPFC and the ones that exclude the UPFC. However, if the UPFC is located at the sending end of the line, the UPFC will be always present in the fault loop and will influence the relay-setting characteristic. The effects of the presence of the earth fault resistance, the UPFC control parameters, and the infeed from both the ends on the distance relay apparent impedance characteristics are also highlighted in this paper. It is envisaged that these characteristics will be required to adapt the relay settings in the presence of UPFC for different made transmission line operating conditions.

II. UPFC Model

The unified power flow controller consists of two switching converters that are operated from a common dc link provided by dc storage capacitor. Converter 2 provides the main function of UPFC by injecting an ac voltage of controllable magnitude

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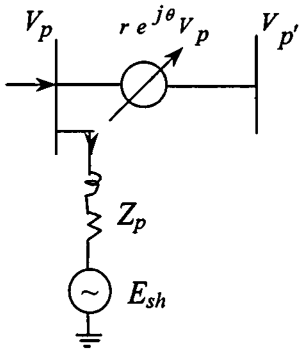

Fig. 2. Equivalent voltage representation of UPFC.

and phase angle in series with the transmission line via a series transformer 1. The basic function of converterl is to supply or absorb the real power demand by converter 2 at the common dc link. The active current component of converter 1 is obtained from power balance between the series and the shunt converters and the reactive component can be independently controlled to provide necessary voltage support at the bus. Fig. 1 shows the schematic representation. In Fig. 2, the source models are shown from which we obtain

$$V_{p'} = V_p(1 + re^{j\theta}) \quad \text{where } r = |V_c|/|V_p|,\ 0 < r < r_{\max}.$$

The magnitude $|V|$ is controllable by UPFC and the angle θ is controllable from 0 to 2π. The shunt current I_p is obtained as

$$I_p = \frac{V_p - E_{sh}}{Z_p}$$

where E_{sh} is the shunt converter voltage controlled by the UPFC and Z_p being its impedance. The next section will outline apparent impedance calculation procedure for a two-terminal transmission system.

III. Apparent Impedance Calculations

System conditions external to the protected line influence the relay performance and to demonstrate the adaptive nature of the protection scheme a two-terminal model with the external systems represented by a single equivalent source potential and source impedance is shown in Fig. 3(a). In the following analysis a single-line to ground fault is considered at F through a fault resistance R_f and the digital distance relay placed at M is considered.

For the example, E_{am} and E_{an} represent equivalent voltage sources at the two ends, $E_{an}/E_{am} = he^{-j\delta}$, h is the amplitude ratio, and δ is power transfer angle, I_{ld} and I'_{Id} are the prefault currents in the fine assuming the UPFC is placed between the points P and P' and shunt voltage source is receiving a current I_p. As the fault point F is beyond the UPFC, the following relations hold good:

$$V_{ap'} = V_{ap}(1 + re^{j\theta}) = C_p V_{ap},\ C_p = 1 + re^{j\theta} \tag{1}$$

$$I'_{ld} = I_{ld} - I_p = (V_{ap'} - E_{an})/Z_{1snp}$$

$$I_{ld} = E_{am}(1 - h_1 e^{-j\delta_1})/Z_{1smp} \tag{2}$$

Also

$$\begin{aligned} I'_{ld} &= (V_{ap}/C_p - V_{afd})/Z_{1pf}, \\ I_p &= (V_{ap} - E_{sh})/Z_p \\ E_{sh} &= V_{ap}/C_{sh}, \\ E_{an} &= he^{-j\delta}E_{am} \end{aligned} \tag{3}$$

where V_{afd} is the a-phase voltage at the fault point, E_{sh} is the voltage of the shunt source, Z_p its impedance, C_{sh} is the ratio between the a-phase voltage magnitude $|V_{ap}|$ and the magnitude of shunt voltage $|E_{sh}|$. The impedances Z_{1smp}, Z_{1snp} are net positive-sequence impedances from M and N sides to point P, respectively. Z_{1pf} is the positive-sequence impedance of the line between the bus P and the fault point F.

Proceeding as outlined in the Appendix, the apparent impedance measured at M is obtained as

$$Z_A = Z_{1mf} + \Delta Z \tag{4}$$

where as shown in (5), at the bottom of the next page, where C_1, C_0 are positive and zero-sequence distribution factors, K_{0l} is the zero-sequence compensation factor and C_p, C_{ld}, C_{ldd} are factors dependent on the UPFC series voltage, angle and shunt voltage phasor and impedance values. All these factors are defined in the Appendix.

However, if the fault occurs at a point F_1, which does not include the UPFC as shown in Fig. 3(b), the apparent impedance seen by the relay at M is obtained as

$$Z_A = Z_{1mf} + \Delta Z_1 \tag{6}$$

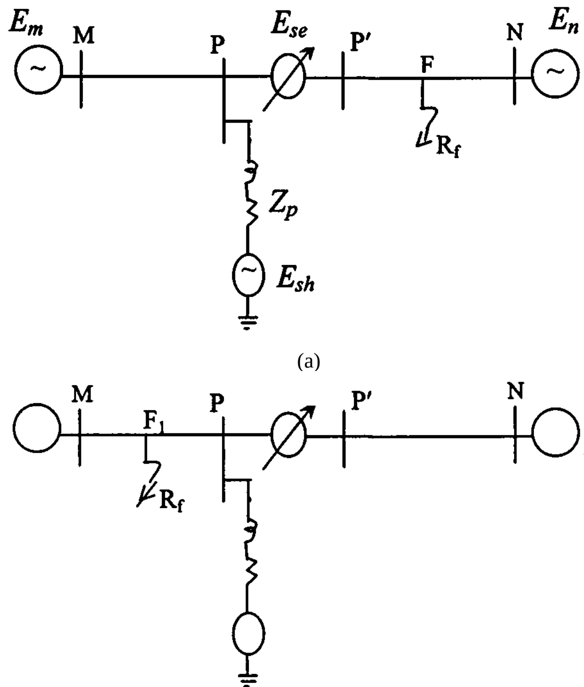

Fig. 3. (a) System under study for fault at F and (b) system under study for fault at F_1.