Performance Evaluation of a Distance Relay as Applied to a Transmission System With UPFC

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***Abstract*—This paper presents analytical and simulation results of the application of distance relays for the protection of transmission systems employing flexible alternating current transmission controllers such as the unified power flow controller (UPFC). Firstly a detailed model of the UPFC and its control is proposed and then it is integrated into the transmission system for the purposes of accurately simulating the fault transients. An apparent impedance calculation procedure for a transmission line with UPFC based on the power frequency sequence component is then investigated. The simulation results show the impact of UPFC on the performance of a distance protection relay for different fault conditions; the studies also include the influence of the setting of UPFC control parameters and the operational mode of UPFC.**

***Index Terms*—Distance relay, flexible alternating current transmission (FACTS) controllers, power system protection, UPFC.**

I. Introduction

CONTINUING pressure to minimize capital expenditure and the increasing difficulties involved in obtaining transmission rights of way have focused the attention of the utility community on the flexible alternating current transmission (FACTS) concept [1], [2] resulting in the initiation of studies and implementation programmes which are now well underway. Power transfer in most integrated transmission systems is constrained by transient stability, voltage stability, and/or power stability. These constrains limit the full utilization of available transmission corridors. FACTS is a technology that provides the requisite corrections of transmission functionality in order to fully utilize existing transmission systems and, therefore, minimize the gap between the stability and thermal limits.

FACTS technology is based on the use of reliable high-speed power electronics, advanced control technology, high-power microcomputers and powerful analytical tools. The key feature is the availability of power electronic switching devices that can switch electricity at megawatt levels (kV and kA levels). The impact of FACTS controllers on transmission systems is thus likely to have a significant impact on power system networks worldwide.

Amongst the different types of FACTS controllers, UPFC is considered to be one of the most effective in the control of power flow. It comprises two back-to-back gate-turn-off thyristor (GTO) based voltage source converters (VSCs) connected by a dc -link capacitor. An exciting transformer connecting one VSC is arranged in shunt and a boosting transformer linking the second VSC is inserted into the transmission line. By virtue of its ability to control freely and independently three major parameters in power transmission *viz.* the line impedance and the magnitude and phase of the voltage, it provides both voltage regulation and improvement in stability.

Because of the presence of FACTS controllers in a fault loop, the voltage and current signals at the relay point will be affected in both the steady state and the transient state. This in turn will affect the performance of existing protection schemes, such as the distance relay which is one of the very widely used methods in transmission line protection [3], [4]. The main principle of this technique is to calculate the impedance between the relay and fault points; the apparent impedance is then compared with the relay trip characteristic to ascertain whether it is an internal or external fault. A common method of calculating this impedance is to use symmetrical component transformation using power frequency components of voltage and current signals measured at the relay point.

Some research has been done to evaluate the performance of a distance relay for transmission systems with FACTS controllers. The work in [5] has presented some analytical results based on steady-state model of STATCOM, and the authors have studied the impact of STATCOM on a distance relay at different load levels. In [6], the voltage-source model of FACTS controllers has been employed to study the impact of FACTS on the tripping boundaries of distance relay. The work in [7] shows that thyristor-controlled series capacitor (TCSC) has a major influence on the mho characteristic, in particular the reactance and directional characteristic, making the protected region unstable. The study in [8] also shows that the presence of FACTS controllers in a transmission line will affect the trip boundary of a distance relay, and both the parameters of FACTS controllers and their location in the line have an impact on the trip boundary. All the studies clearly show that when FACTS controllers are in a fault loop, their voltage and current injections will affect both the steady state and transient components in voltage and current signals, and hence the apparent impedance seen by a conventional distance relay is different from that for a system without FACTS. Although the work presented in the [6] and [8] show the adverse impact of FACTS controllers on the performance of distance relay, the models employed for the various

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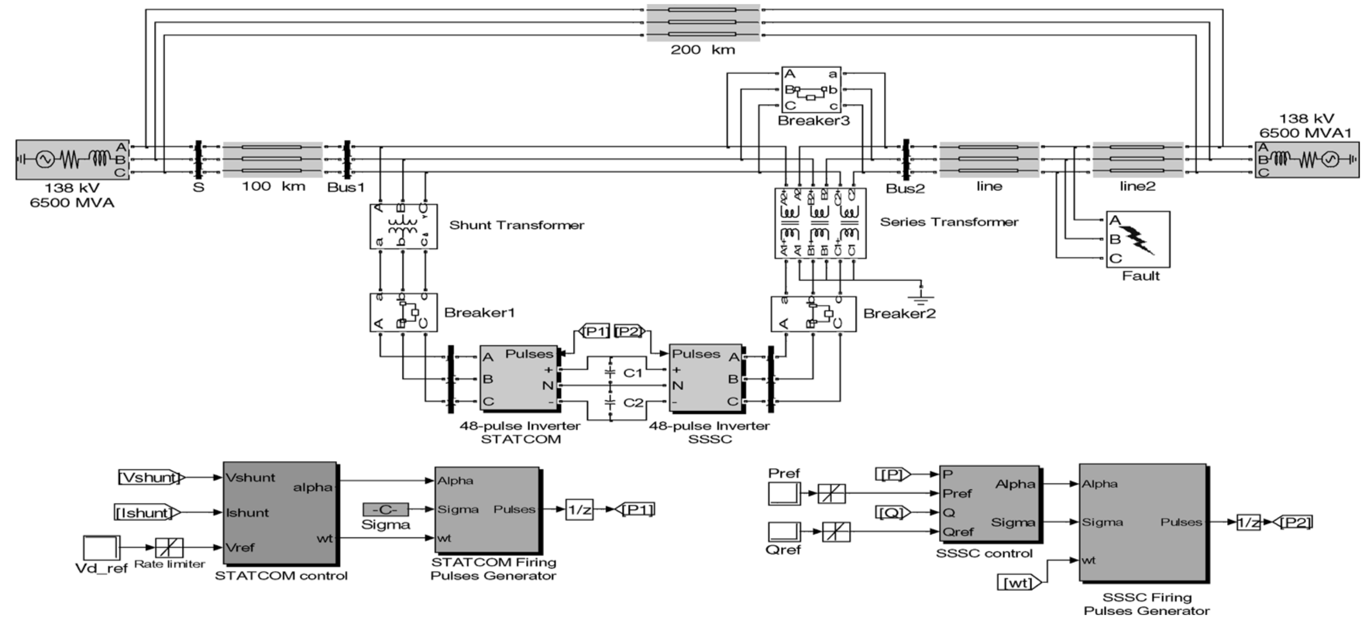

Fig. 1. Transmission system with UPFC.

FACTS controllers are rather simple and approximate and hence the studies are not an accurate reflection of the behavior of the distance relay in the FACTS environment.

The first part of this paper is to set up a very accurate model of a UPFC system including its complex control strategies, which is then embedded into a transmission system model; the simulated voltage and current signals at the relay point are then employed to make a comprehensive assessment of the performance of a typical distance relay protection under a vast majority of different system and fault conditions. The 138-kV transmission system employed herein is a typical system as encountered in the U.S. power system network.

II. UPFC and Transmission System Model

A. Transmission System Employing a UPFC Model

In this study, SimPowerSystem 3.1 toolbox in Matlab 7 is used to model the 138-kV parallel transmission system with UPFC installed in the middle of one transmission line [9]. The system built with this tool is shown in Fig. 1. Two 200-km parallel 138-kV transmission lines terminated in two 6500-MVA short-circuit levels (SCLs) sources and the angle difference is 20°. The 160-MVA UPFC is installed in the middle of the second transmission line. The simulation time step length is 0.02 ms.

The UPFC consists of two 48-pulse voltage source inverters which are connected through two 2000 μF common dc capacitors. The first inverter known as STATCOM connects into the transmission system through a 15 kV/138 kV Δ/Y shunt transformer, and injects or consumes reactive power to the transmission system to regulate the voltage at the connecting point; another inverter known as static synchronous series compensator (SSSC) connects into the system through a 15 kV/22 kV Y/Y series transformer to inject an almost sinusoidal voltage of variable magnitude and angle, in series with the transmission line to regulate the power flow through the transmission line.

The transmission line is based on the distributed parameter line model. The positive and negative sequence line impedance is $0.195+\mathrm{j}3.3425\ \mathrm{ohm/km}$, and the zero sequence transmission line impedance is $2.638+\mathrm{j}11.27\ \mathrm{ohm/km}$.

B. Voltage Source Inverter Model

The voltage source inverter employed herein is based on the 48-pulse quasiharmonic neutralized GTO inverter [10] and the structure is shown in Fig. 2. It consists of four 3-phase, 3-level GTO inverters and four phase-shifting transformers. Each inverter uses a 3-level GTO bridge block to generate three square-wave voltages. These voltage are fed to the secondary windings of four phase-shifting transformers whose primary windings are connected in series to produce an almost sinusoidal voltage output. A dc capacitor is connected to the four 3-level inverters, the magnitude of square-wave voltage can be $+\mathrm{V}_{\mathrm{dc}}$, 0, $-\mathrm{V}_{\mathrm{dc}}$. The duration of zero voltage in each quarter cycle is defined as "dead angle" γ, and it can be adjusted from 0°–90°. The fundamental component of voltage source inverter has the amplitude of

$$V_{X,n} = \frac{2}{\pi} V_{\mathrm{dc}} \cos\left(\frac{\pi}{24}\right) \cos\gamma. \tag{1}$$

As seen from above, the magnitude of the output voltage can be adjusted through changing the value of dead angle γ and/or the dc voltage of the capacitor. The phase angle α of the output voltage can be adjusted by using the input signal from the pulse generator. When the dead angle $\gamma = \pi/48$, the first significant harmonics of the voltage source inverter on the ac output are 47th and 49th and it is operated as a 48-pulse inverter. In this study, the STATCOM inverter is operated as 48-pulse inverter, that is to say, the dead angle kept constant during the operation, and the SSSC inverter is operated with a variable dead angle to control the amplitude of the injection voltage.