Performance of Distance Relay Estimation in Transmission Line with UPFC

T. Manokaran and v.karpagam

Abstract—**This paper presents 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. The simulation results show the impact of UPFC on the performance of a distance protection relay for different fault conditions and for different fault location.**

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

I. INTRODUCTION

Power transfer in most integrated transmission systems is constrained by transient stability, voltage stability, and 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 [4], [5]. 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 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 [6] has presented some analytical results based on steady-state model of STATCOM, and 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. 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.

II. UNIFIED POWER FLOW CONTROLLER (UPFC)

The UPFC is a device which can control simultaneously all three parameters of line power flow(line impedance, voltage and phase angle). Such "new" FACTS device combines together the features of two "old" FACTS devices: The Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). In practice, these two devices are two Voltage Source Inverters (VSI's) connected respectively in shunt with the transmission line through a shunt transformer and in series with the transmission line through a series transformer, connected to each other by a common dc link including storagecapacitor.

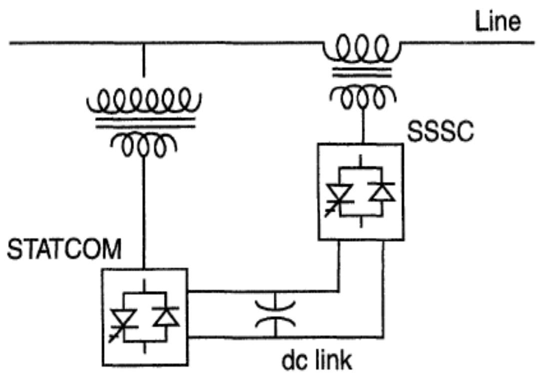

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Fig 2.1: UPFC model diagram

The shunt inverter is used for voltage regulation at the point of connection injecting an opportune reactive power flow into the line and to balance the real power flow exchanged between the series inverter and the transmission line. The series inverter can be used to control the real and reactive line power flow inserting an opportune voltage with controllable magnitude and phase in series with the transmission line. Thereby, the UPFC can fulfill functions of reactive shunt compensation, active and reactive series compensation and phase shifting. Besides, the UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system. As the need for flexible and fast power flow controllers, such as the UPFC, is expected to grow in the future due to the changes in the electricity markets.

A combination of Static Synchronous Compensator (STATCOM) and a Static Synchronous Series Compensator (SSSC) which are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation. The UPFC model for transmission line shown in Figure (2.1).

III. Distance Protection For Transmission Line

The operation of the relays discussed so far depended upon the magnitude of current or power in the protected circuit. However, there is another group of relays in which the operation is governed by the ratio of applied voltage to current in the protected circuit. Such relays are called distance or impedance relays. In an impedance relay, the torque produced by a current element is opposed by the torque produced by a voltage element. The relay will operate when the ratio V/I are less than a predetermined value.

A system with instantaneous impedance relays, set to act on impedances less than or equal to the impedances, of a section as shown in Figure (2.3) would be difficult to adjust, a fault near the junction of two sections is likely to cause the operation of two relays.

The voltage element of the relay is excited through a potential transformer from the line to be protected. The current element of the relay is excited from current transformer in series with line. The line is the protected zone. Under normal operating conditions, the impedance of the protected zone is Z_L. The relay is so designed that it closes its contacts whenever impedance of the protected section falls below the predetermined value.

A distance or impedance relay is essentially an ohmmeter and operates whenever the impedance of the protected zone falls below a predetermined value. There are two types of distance relay in use for protection of power supply, namely;

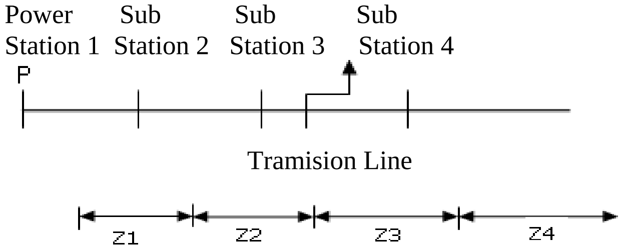


Figure 3.1: Distance protection of line

(i)Definite-distance relay which operates instantaneously for fault up to a predetermined distance from the relay.

(ii)Time –distance relay in which the time of operation is proportional to the distance of fault from the relay point. A fault nearer to the relay will operate it earlier than a fault farther away from the relay.

IV. Transmission Line With UPFC

A. *INTRODUCTION*

In ac power systems, given the insignificant electrical storage, the electrical generation and load must balance at all times. To some extent, the electrical system is self-regulating. If generation is less than load, the voltage and frequency drop, and thereby the load, goes down to equal the generation minus the transmission losses.

However, there are only a few percent margins for such a self-regulation. If voltage is propped up with reactive power support, then the load will go up, and consequently frequency will keep dropping, and the system will collapse. Alternately, if there is inadequate reactive power, the system can have voltage collapse. When adequate generation is available, active power flows from the surplus generation areas to the deficit areas, and it flows through all parallel paths available which frequently involve extra high-voltage and medium-voltage lines. Often, long distances are involved with loads and generators along the way. Presence of a large number of powerful low impedance lines along that loop. There are in fact some major and a large number of minor loop flows and uneven power flows in any power transmission system.

B. *SIMULATION MODELS*

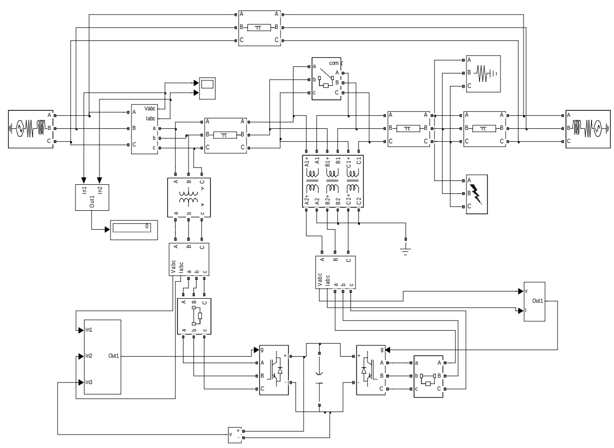


Figure 4.1: Simulink diagram of transmission line with UPFC model

1) SINGLE PHASE TO GROUND FAULT

Comparing the impedance trajectory for a system with UPFC and without UPFC, it is apparent that the degradation in relay performance is far worse in the case of a system employing the full UPFC and as mentioned before, this can be directly attributed to the generation of a large zero-sequence voltage component in the injected voltage. Here single phase to ground is considered. If this zero sequence voltage component of the injected voltage (V_{opq}) were to known and the relaying point voltage V_s was then modified as ($V_s' = V_s - V_{opq}$) , then the impedance trajectory shifts quite close to the relay Mho boundary.

2) EFFECT OF FAULT LOCATION

When both the shunt and series parts work together, the UPFC works as a complete device and its function is to both regulate the power flow in the transmission line and maintain the voltage at the STATCOM connecting point. When there is an phase-to-ground fault at say 150 km, the simulation results show that the zero sequence component voltage of the UPFC is much higher than the positive and negative sequence components and this will dominate the relay point voltage and thus has a big impact on the apparent impedance.

When an single phase to ground fault is on the right side of UPFC, i.e., at a fault distance of 150 km from the relay point, and the desired voltage, the apparent impedance trajectory seen by the A-ground element of the system with UPFC. From the above, it can be seen that both the resistance and reactance components of the transmission system apparent impedance with UPFC are larger than for the system without UPFC,

It is apparent that when the fault is on the left side of UPFC (i.e., <100km), the apparent impedance seen by the distance relay is almost the same as that for the system without UPFC; however, when the fault is on the right side of UPFC, both the apparent resistance and reactance of the system with UPFC are larger than for the system without UPFC.

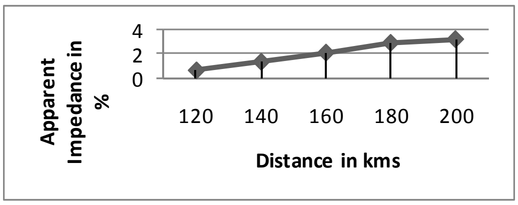
C. RESULTS

1) With and Without UPFC

Condition	**Apparent Impedance (p.u)**	**Fault type**
Without UPFC	0.0003729	Single line to ground fault
With UPFC	0.02007	Single line to ground fault

Table 4.1: Comparison of impedance value with and without UPFC

2) EFFECT OF FAULT LOCATION IN SINGLE PHASE TO GROUND FAULT

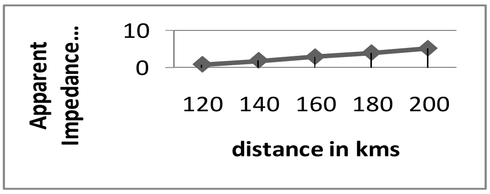


Graph 4.1: Single phase to ground fault

3) Effect of fault location in phase to phase fault

Fault location from UPFC (kms)	120	140	160	180	200
Change in impedance value %	0.8	1.9	2.9	4.0	5.2

Table 4.2: Comparison of impedance value changes in phase to phase fault



Graph 4.2: Phase to Phase fault

V. CONCLUSION AND FUTURESCOPE

This project firstly presents a detailed model of a transmission system employing UPFC. This is to illustrate the adverse effect the presence of a UPFC has on the performance of a distance relay. The simulation results show the impact of UPFC when it is operated with UPFC and without UPFC, respectively, on the distance relay. Importantly, the impact on the performance of a distance relay is significantly higher when the full UPFC is in operation compared to a system employing only without UPFC; this is by virtue of the fact that in the case of the former, there is active and reactive power injected by both STATCOM and the SSSC. When comparing the results at different fault locations from UPFC there is a tendency for the distance relay to under-reach more in the case of full UPFC. The results presented in this project clearly highlight the fundamental problems of protecting a transmission system employing a UPFC using distance protection.

Work may be extended for other types of system and other types of fault, including inter circuit faults. Moreover to investigate the zero sequence component compensation in the voltage signal at the relay point in order to improve the performance of a distance relay as applied to a system employing UPFC.

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