Comparing Effects of SVC and STATCOM on Distance Relay Tripping Characteristic

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***Abstract*-This paper presents and compares the measured impedance at the relaying point in the presence of shunt connected Flexible Alternating Current Transmission System (FACTS) devices, i.e. Static Var Compensator (SVC) and STATic synchronous COMpensator (STATCOM). The presence of the shunt connected FACTS devices on a transmission line greatly affects the measured impedance at the relaying point. The Measured impedance itself depends on the power system structural conditions, pre-fault loading, and especially the ground fault resistance. In the presence of shunt connected FACTS devices, their structural and controlling parameters as well as their installation position, affects the measured impedance. Here, the measured impedance at the relaying point is calculated due to the mentioned affecting parameters, and compared in the two cases of SVC and STATCOM.**

I. INTRODUCTION

The measured impedance at the relaying point is the basis of the 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. First group is the structural conditions, while the second group is the operational conditions. In addition to the power system parameters, the fault resistance could greatly influence the measured impedance, in such a way that when the fault resistance is zero, the power system parameters do not affect the measured impedance. In other words, 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 becomes more severe.

In the recent years, FACTS devices are introduced into the power systems to increase the transmitting capacity of the lines and provide the optimum utilization of power systems capability. This is done by pushing the power systems to their thermal limits [4]. 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, especially the distance protection, which is the main protective device at HV, EHV and UHV levels.

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 characteristic are greatly subjected to mal-operation in the both form of over-reaching or under-reaching the fault point. Therefore, the conventional characteristics might not be usable in the presence of FACTS devices.

The impact of STATCOM on the measured impedance has been discussed in [4], by assuming the instantaneous operation of its controlling system. The effect of shunt connected FACTS devices has been studied in [5], but not with the comparing goal. The effects of series connected FACTS devices, or FACTS devices with the series branch, on the measured impedance at the relaying point have been presented in [6] and more detailed studies for Unified Power Flow Controller (UPFC) have been presented in [7], where it has been assumed that the protective system operate before the FACTS devices control system. In [6]-[7], the protective system operates before the control system of FACTS devices.

This paper presents and compares the measured impedance at the relaying point in the presence of shunt connected FACTS devices, i.e. SVC and STATCOM. In addition to the structural and controlling parameters of these devices, the measured impedance depends on their installation position. Therefore, the measured impedance is presented for the cases of device exclusion and inclusion in the fault loop, and its presence at the near end of the line. The measured impedances and the tripping characteristics resulted for SVC and STATCOM are compared, so it can be seen that how much the provided device for the shunt compensation, via a variable impedance or variable voltage source, could affect the measured impedance and the tripping characteristic.

II. MODELING SVC AND STATCOM

Shunt connected FACTS devices, including SVC and STATCOM, are usually utilized to regulate the voltage at their connection point. The model of each of these devices and the general model for them are presented in this section.

A. SVC and its Modeling

Static Var Compensator (SVC) is an early type of the shunt connected FACTS devices, which controls its connecting point voltage by adjusting its susceptance in order to supply or absorb the reactive power. SVC consists of a Thyristor Controlled Reactor (TCR) and a set of Thyristor Switched

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Capacitors (TSC) in parallel, and an associated controlling system. The controlling system operates to regulate the voltage at its connecting point, according to its controlling strategy within its operational limits [5], [8].

SVC can be modeled as a variable shunt reactance depending on the conduction duration of TCR thyristor and the connection status of the set of capacitors. The shunt reactance is shown by Z_{SVC}.

B. STATCOM and its Modeling

Advancement in the power electronic devices, such as Gate Turn Off (GTO) devices, introduced the so-called advanced Static Var Systems (SVS). STATCOM is an example of the advanced SVS, consisting of three-phase sets of several GTO based valve and a dc link capacitor and the associated control system. The control system operates in such a way that its connection point voltage is being regulated according to its controlling strategy within its operational limits. STATCOM consists of a converter which is connected to the line via a shunt coupling transformer [5], [8].

STATCOM can be modeled as a shunt branch consisting of an impedance, due to the coupling transformer, $Z_{STATCOM}$, and a voltage source [5]-[6], $E_{STATCOM}$, which is in phase with the voltage of its connection point, so it can only inject or absorb reactive power according to the amplitude of voltage source.

C. General Model

The proposed model for STATCOM could be utilized as the general model of the shunt connected FACTS devices, a shunt branch with the impedance of Z_{Sh} and the voltage source of E_{Sh}. In the case of SVC, there is no voltage source, so E_{Sh} is zero and Z_{Sh} is equal to Z_{SVC}. On the other hand and in the case of STATCOM, E_{Sh} is $E_{STATCOM}$ and Z_{Sh} is equal to $Z_{STATCOM}$.

In the case of SVC, Z_{Sh} is the controlling parameter and the amount of the injected or absorbed reactive power is controlled by adjusting this parameter. On the other hand and in the case of STATCOM, Z_{Sh} is fixed and it is a structural parameter, while E_{Sh} is the controlling parameter and the amount of the injected or absorbed reactive power is controlled by adjusting this parameter.

III. Measured Impedance at Relaying Point

Distance relays operate based on the measured impedance at the relaying point. In the absence of FACTS devices and for zero fault resistance, the measured impedance by a distance relay only depends on the length of the line section between the fault and the relaying points. In Fig. 1 this impedance is equal to pZ_{1L}, where p is per unit length of the line section between the fault and the relaying points, and Z_{1L} is the line positive sequence impedance in ohms.

In the case of a non-zero fault resistance, the measured impedance is not equal to the impedance of the line section located between the relaying and the fault points. In this case, the structural and operational conditions of the power system affect the measured impedance. The structural conditions are

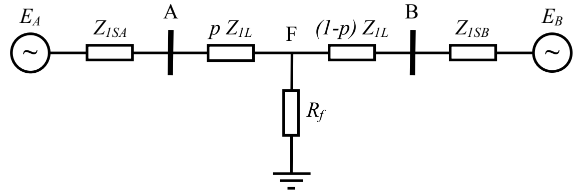

Fig. 1. Equivalent circuit for single phase to ground fault

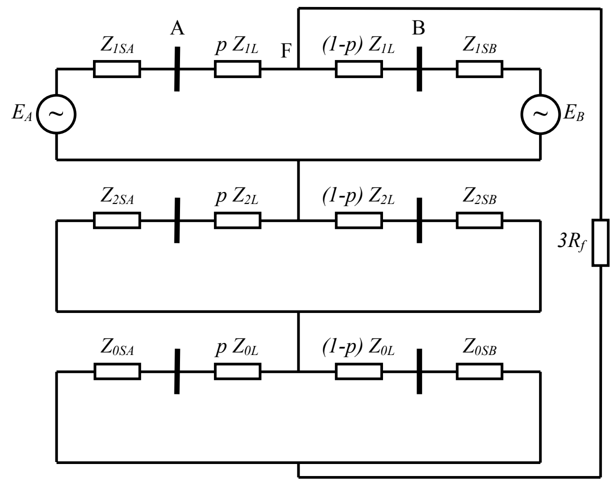

Fig. 2. Equivalent circuit of phase A to ground fault

evaluated by short circuit levels at the line ends, S_{SA} and S_{SB}. The operational conditions prior to the fault instance can be represented by the load angle of the line, δ, and the ratio of the voltage magnitude at the line ends, h, or totally $E_B / E_A = he^{-j\delta}$. In the absence of FACTS devices and with respect to Fig. 1 and Fig. 2, the measured impedance at the relaying point can be expressed by the following equations. More detailed calculations can be found in [2].

$$Z_{1A} = Z_{1SA} + p\,Z_{1L} \tag{1}$$

$$Z_{1B} = Z_{1SB} + (1-p)Z_{1L} \tag{2}$$

$$Z_{0A} = Z_{0SA} + p\,Z_{0L} \tag{3}$$

$$Z_{0B} = Z_{0SB} + (1-p)Z_{0L} \tag{4}$$

$$Z_{\Sigma} = 2\frac{Z_{1A}Z_{1B}}{Z_{1A}+Z_{1B}} + \frac{Z_{0A}Z_{0B}}{Z_{0A}+Z_{0B}} \tag{5}$$

$$C_1 = \frac{Z_{1B}}{Z_{1A}+Z_{1B}} \tag{6}$$

$$C_0 = \frac{Z_{0B}}{Z_{0A}+Z_{0B}} \tag{7}$$

$$K_{0L} = \frac{Z_{0L}-Z_{1L}}{3Z_{1L}} \tag{8}$$

$$K_{ld} = \frac{1-h\,e^{-j\delta}}{Z_{1A}h\,e^{-j\delta}+Z_{1B}} \tag{9}$$

$$C_{ld} = (Z_{\Sigma}+3R_f)K_{ld} \tag{10}$$

$$Z_A = p\,Z_{1L} + \frac{3R_f}{C_{ld}+2C_1+C_0(1+3K_{0L})} \tag{11}$$