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Effect of Static Synchronous Compensators (STATCOM) Device on Distance Protection Setting

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Abstract: The flexible AC transmission systems (FACTS), are high current power electronic devices used to control the voltage, power flow and stability of a transmission system. Distance protection is always used for transmission lines protection. The use of these FACTS devices creates certain problems for distance relays because of the rapid changes introduced by the associated control actions in primary system parameters, such as line impedances. This paper discusses the effect STATCOM device on distance protection relays setting. Transmission line between Merowe station to Markheyat substation, is taken as case study. The study is carried-out using short circuit calculation and simulation before and after adding STATCOM device using NEPLAN software The results show that that the distance relay cannot trip the faults in the real zones operating area after addition of STATCOM device to the case study.

Key words: STATCOM, Distance relay, Protection, NEPLAN

I. INTRODUCTION

With the rapid development of power electronics, FACTS devices have been proposed and implemented in power systems. FACTS devices can be utilized to control power flow and enhance system stability. Particularly with the deregulation of the electricity market, there is an increasing interest in using FACTS devices in the operation and control of power systems with new loading and power flow conditions. Due to the present situation, there are two main aspects that should be considered in using FACTS devices: The first aspect is the flexible power system operation according to the power flow control capability of FACTS devices. The other aspect is the improvement of transient and steady state stability of power systems. STATCOM devices are widely used in power systems as one of FACTS devices type.

Power System protection is the art and science of detecting problems with power system components and isolating these components [1].

A distance relay, as its name implies, has the ability to detect a fault within a pre-set distance along a transmission line from its location. Every power line has a resistance and reactive per kilometer related to its design and construction so its total impedance will be a function of its distance.

Adding STATCOM device to a transmission line causes a problem to the distance relays, which will be presented in this work.

II. CLASSIFICATION OF FACTS

The term 'dynamic' is used to express the fast controllability of FACTS-devices provided by the power electronics. This is one of the main differentiation factors from the conventional devices. The term 'static' means that the devices have no rotating components [6].

The left column of FACTS-devices in figure (1) uses Thyristor valves or converters. They have low losses because of their low switching frequency of once a cycle in the converters or the usage of the Thyristor to simply bridge impedances in the valves. The right column of FACTS-devices contains more advanced technology of voltage source converters based today mainly on Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated Thyristor (IGCT)[4].

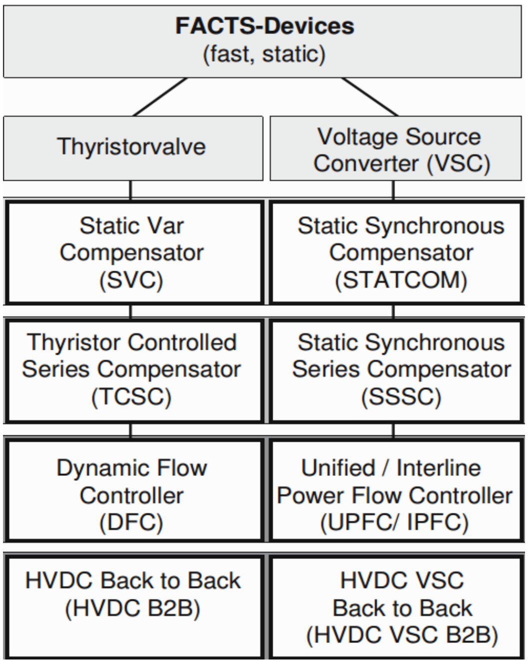


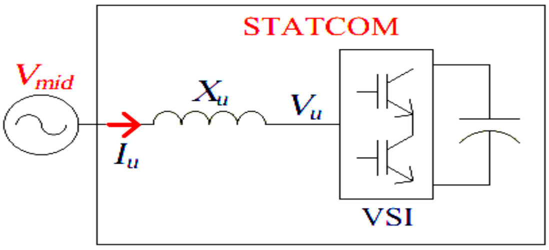
Figure (1) Classification of FACTS device

III. STATIC SYNCHRONOUS COMPENSATORS (STATCOM)

STATCOM is a type of variable source type static VAR generators for FACTS. STATCOM operates as a voltage source in series with a reactor. The voltage of the STATCOM is synchronised with the voltage of the line to which the STATCOM system is connected. Figure (2) shows a simplified diagram of a STATCOM. Basically a STATCOM consists of a voltage source inverter (VSI), with an output voltage Vu, a DC capacitor as the DC link voltage of the inverter, and a buffer reactor with a reactance Xu. The output of the STATCOM acts as a voltage source at the midpoint, Vmid [11].
Figure (2): Simplified diagram of SATCOM

3-1 STATCOM Mode of Operation:-

Referring to fig (2), general expression for the apparent power between the AC mains and the STATCOM is given by:



$$S_{mid} = \frac{V_{mid}V_u}{X_u}\sin(\alpha) - j\left[\frac{V_{mid}V_u}{X_u}\cos(\alpha) - \frac{V_u^2}{X_u}\right] \qquad (1)$$

where S_{mid} is the apparent power flowing between the AC mains and the STATCOM and α is the power angle between the AC mains and the STATCOM. The resistance of the buffer reactor in the STATCOM is assumed to be zero. STATCOM absorbs real power flow from V_{mid} for lagging power angle, α and injects it to the AC mains for leading power angle. Thus, it can be used to control the DC link voltage of the inverter.

3-2 Principle of Operation of STATCOM

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous Condenser (SC) is shown in figure (3), which shows a variable AC voltage source (E) whose magnitude is controlled by adjusting the field current. Neglecting losses, the phase angle (δ) difference between the generated voltage (E) and the bus voltage (V) can be assumed to be zero. By varying the magnitude of E, the reactive current supplied by SC can be varied. When E = V, the reactive current output is zero. When E > V, the SC acts as a capacitor

when E < V , the SC acts as an inductor.
When δ = 0, the reactive current drawn (Ir) is given by:[13]

$$I_r = \frac{V-E}{X'} \qquad (2)$$

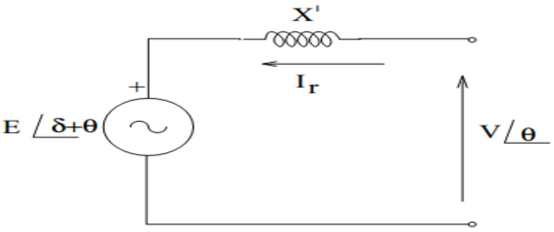


Figure (3): Synchronous Condenser

3-4 Basic Control Scheme of STATCOM

Figure (4) shows a simplified block diagram of the internal control for a converter of a STATCOM with internal voltage control capability, such as a three-level converter. The reactive power output is controlled by the internal voltage magnitude in the form of(PWM) and angle. The feedback signals are the system voltage, VS, the converter output current, Iu, and the DC bus voltage, Vdc. The control input signals are the reactive current reference (I_{qRef})and the DC bus voltage reference, (V_{dcRef}). The DC voltage reference determines the real power of the converter which must be absorbed from the AC system in order to supply its internal losses. As the block diagram illustrates, the converter output current is decomposed into real and reactive components. These components are compared to the real current reference which is derived from the DC bus voltage and the reactive current reference. The real and reactive current error signal is converted into the magnitude and angle of the desired output voltage by appropriate gate signals of the switching devices.

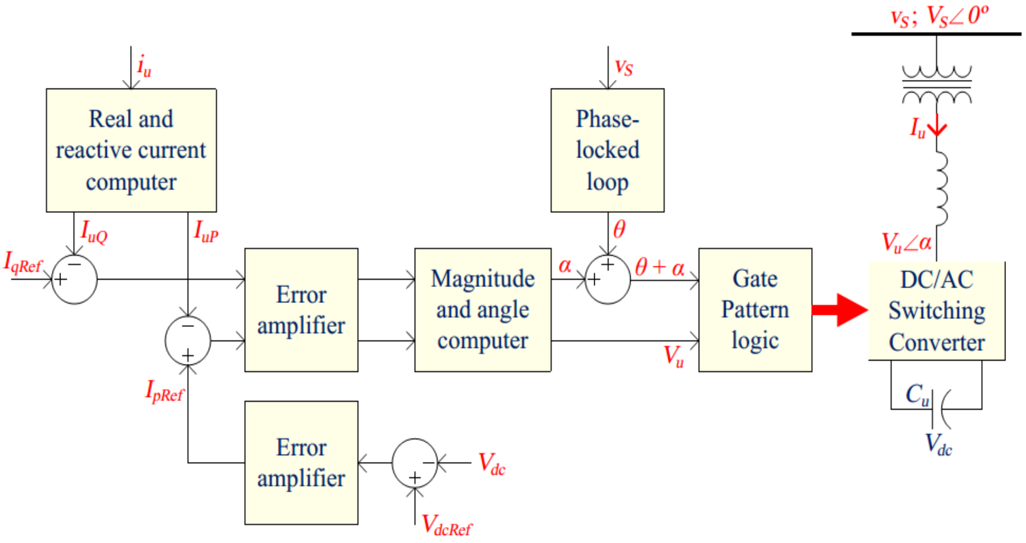


Figure (4): A simplified block diagram of the internal control for a converter of a STATCOM

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IV. DISTANCE RELAY

Distance protection, in its basic form, is a non-unit system of protection offering considerable economic and technical advantages. Unlike phase and neutral over-current protection, the key advantage of distance protection is that its fault coverage of the protected circuit is virtually independent of source impedance variations.

Distance relays are normally used to protect transmission lines. They respond to the impedance between the relay location and the fault location, As the impedance per kilometer of a transmission line is fairly constant, these relays respond to the distance to a fault on the transmission line, by measuring the voltage applied to the relay and the current applied to the relay [10].

When a fault occurs on a line, the current rises significantly and the voltage collapses significantly, the distance relay (also known as impedance relay) determines the impedance by $Z = V/I$. If the impedance is within the reach setting of the relay, it will operate [10].

4-1 Relay Performance:

Distance relay performance is defined in terms of reach accuracy and operating time. Reach accuracy is a comparison of the actual ohmic reach of the relay under practical conditions with the relay setting value in ohms.

Reach accuracy particularly depends on the level of voltage presented to the relay under fault conditions. The impedance measuring techniques employed in particular relay designs also have an impact. Operating times can vary with fault current, with fault[10].

4-2 Types of Distance Relay:

The limit of each region within the device range (distance relay) is drawn according to the type of the device and its manufacturing method. These drawings may be circular, parallel gram or just winding (curves) depending upon the operating requirements.

The digital protection devices are character bed by their ability to modify the drawing shapes of the zones into different shapes, in these devices the drawings of the zones are represented by many circles having fixed shapes. There are many kinds of distance protection devices which differ basically in the way the devices operating limits are drawn[12].

Distance relays may be classified according to the shape of their zones of operation. Traditionally, all zone shapes have been circular, because an electromechanical relay, produces a circular boundary for the zones of operation.

Some of the terminology used in describing the zones (e.g., “the line of maximum torque”) dates back to the electromechanical origins of distance relays. However, far more complex zone shapes can be achieved with modern solid-state and computer relays, although some of the older terminology continues to be used in describing the latter relays. Four general relay types are recognized according to the shapes of their operating zones:

a- impedance relays.
b- admittance or mho relays.
c- reactance relays.
d- quadrilateral relays.

These four relay characteristic shapes are illustrated in Figure (5):

The impedance relay has a circular shape centered at the origin of the R–X diagram. The admittance (or mho) relay has a circular shape that passes through the origin. The reactance relay has a zone boundary defined by a line parallel to the R axis. The zone extends to infinity in three directions as shown in Figure (5).

The quadrilateral characteristic, as the name implies, is defined by four straight lines. This last characteristic is only available in solid-state or computer relays. More complex shapes can be obtained using one or more of the above relay types, in a logical combination to provide a composite tripping zone [14].

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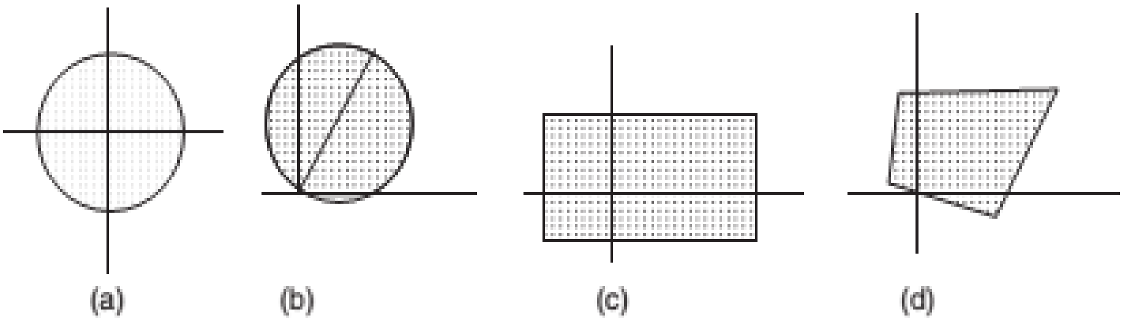

Figure (5): Types of Distance Relays

V. CASE STUDY

The transmission line between Merowe damp and Markheyat (Merowe damp - Markheyat) is selected as case study. The Length of this line is 346km, with 1793 towers. The distance between each tower and the other is 500 m. This transmission line is double circuit. The parameters of this transmission line are presented in table (1) below.

Table (1): parameters of transmission line under study

NO	Parameter	Parameter Value
1	V	500 **kV**
2	(ACSR)	4*325**mm²**
3	NO Towers	1793**Tower**
4	L	346 **km**
5	R_1	0.028 **Ω/km**
6	X_1	0.276 **Ω/km**
7	R_0	0.3445 **Ω/km**
8	X_0	0.9810 **Ω/km**
9	C_1	$13.083*10^{-9}$ **f/km**
10	C_0	$9.99*10^{-9}$ **f/km**
11	CT Ratio	2000/1
12	VT Ratio	500000/110
13	K_{imp}Ratio	0.44

VI. SIMULATION RESULTS AND DISCUSSION

6-1 Simulation Results:

Simulation is done using NEPLAN program, three settings of the distance relay are adjusted. Distance relay diagram is displayed before and after addition of the STATCOM device.

6-1-1 1Distance relay Diagram before adding (STATCOM)

The diagram is displayed for different fault conditions, assuming that the faults are located at a distance of 70% on the transmission line.

- Three phase fault:

Figure (6) below shows the operation area of distance relay in the case of three phase fault. Without the

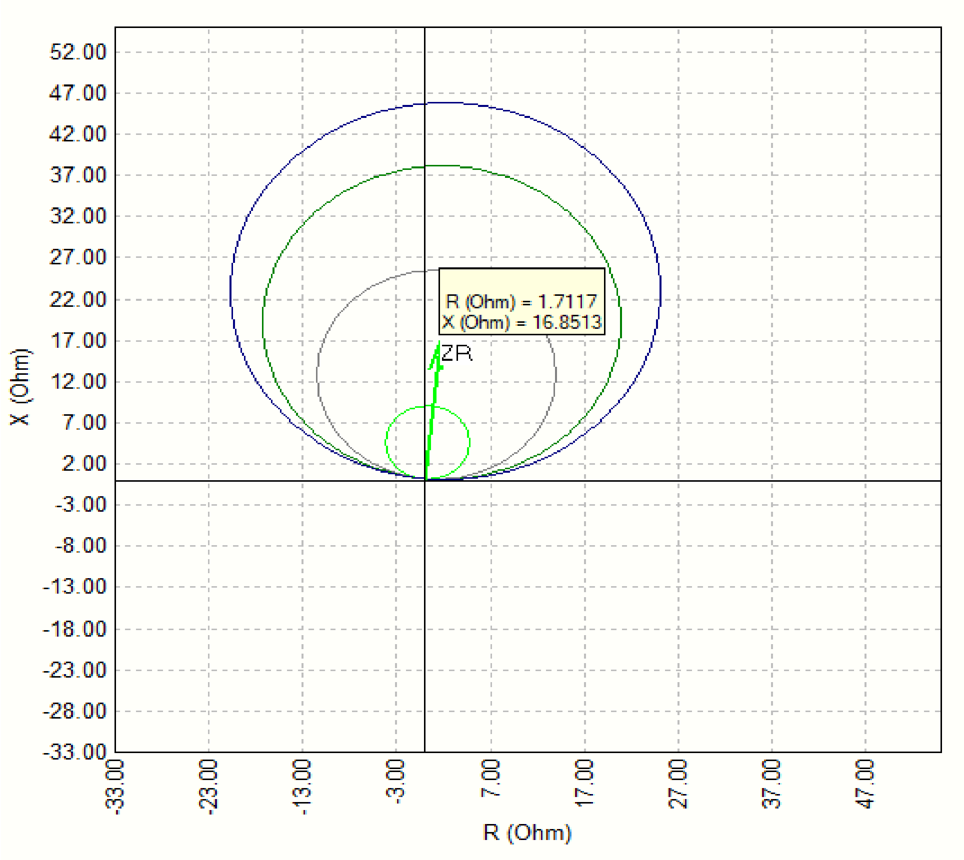

Figure (6): Operation area of distance relay in the case of three phase fault before adding the STATCOM.

- Line to Ground Fault:

Figure (7) below shows the operation area of distance relay in the case of line to ground fault without the STATCOM.

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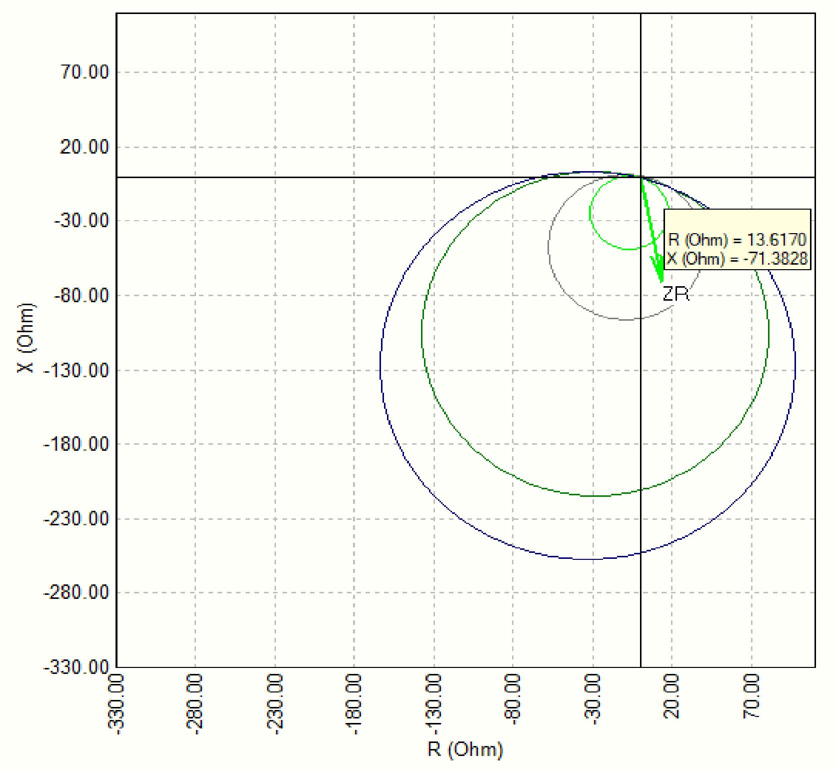

Figure (7): operation area of distance relay in the case of line to ground fault before adding the STATCOM.

6-1-2 Distance relay Diagram after adding (STATCOM)

The diagram is displayed after adding the new calculated impedance of STATCOM to the original impedance of transmission line for different fault conditions, assuming that the faults are located at a distance of 70% on the transmission line.

- Three phase fault:

Figure (8) below shows the operation area of distance relay in the case of three phase fault with the STATCOM.

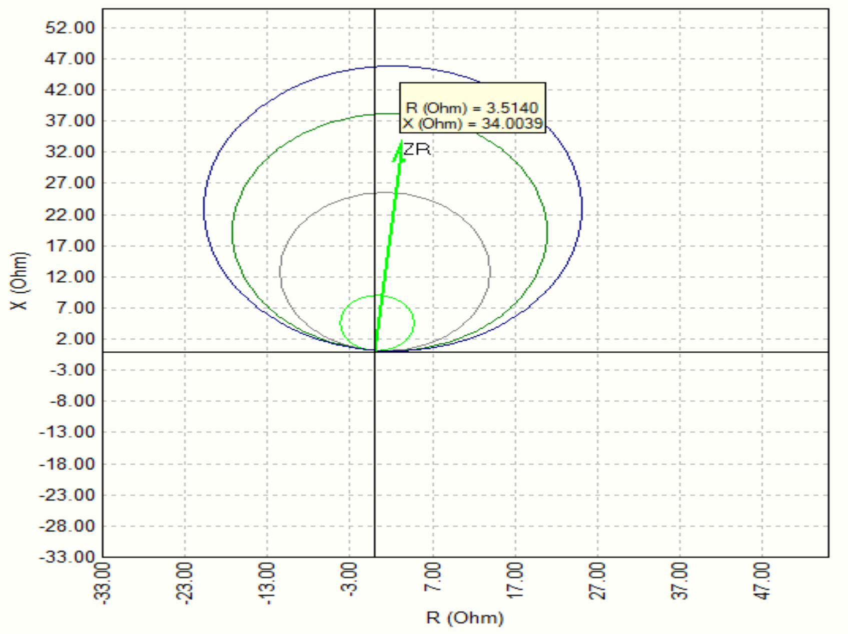

Figure (8): operation area of distance relay in the case of three phase fault after adding the STATCOM.

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- Line to Ground Fault:

Figure (9) below shows the operation area of distance relay in the case of line to ground fault with the STACOM.

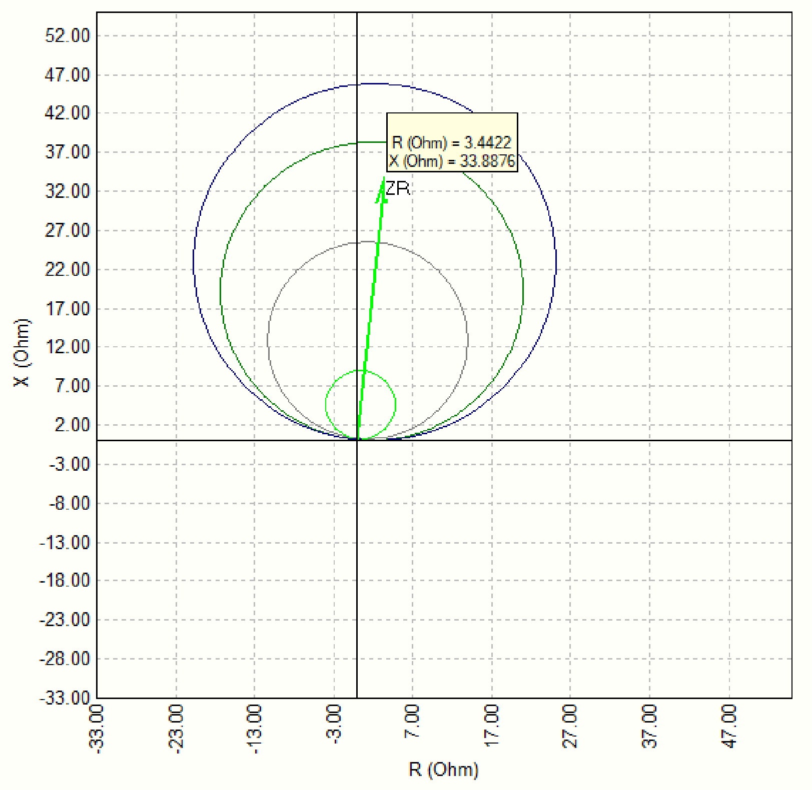

Figure (9): operation area of distance relay in the case of line to ground fault with the STACOM.

6-2 Discussion:-

Figures (5), (6) show that, adding STATCOM to the transmission line has an effect on distance relay setting. which is that the distance relay cannot tripp the faults in the real zones operating area. The relay is said to be in (under -Reach) state, because the impedance is apparently greater than the impedance to the fault.

VII. CONCLUSION

STATCOM devices have been proposed and implemented in power systems, to control power flow and enhance system stability.

When a fault occurs on a transmission line, distance relay protection would trip according to its measured impedance. In the absence of fault resistance, measured impedance for the system without STATCOM equals the actual impedance from relaying location and the fault. However, with the existence of STATCOM, the apparent impedance seen by the distance relay needs to be observed to clarify the performance of distance relay. The installation of STATCOM would have varying effects on apparent impedance. Therefore calculations that make the distance relay adjust the operating zones areas after adding the STATCOM to solve the problem of (**under**-reach) are strongly recommended.

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