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Analysis of Impact of STATCOM on Distance Relay Using MATLAB

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Abstract

In order to study the performance of an impedance protection relay in a transmission system with a Flexible Alternating Current Transmission (FACTS) controller, such as a Static Synchronous Compensator (STATCOM), this research offers modelling of an impedance relay with STATCOM and simulation findings. A power frequency sequence circuit-based apparent impedance calculation method for transmission lines integrating STATCOM has been investigated. The outcomes of the simulation demonstrate how STATCOM affects distance relay protection in several zones during a line to ground fault event. The tripping characteristic in the presence of STATCOM is also influenced by its installation position and management parameters. Here, the effective parameters described above allow for the calculation at the relaying point, of the measured impedance. The findings are discussed with reference to a typical 400KV, 300KM STATCOM transmission line.

Major Findings: *The STATCOM's reactive power injection lever affects the apparent impedance, which can cause the distance relay to either reach or exceed its maximum capacity. The effect is contingent upon the STATCOM's position. Distance Relay performance is negatively impacted when STATCOM is present in a fault loop.*

Keywords: *Distance Relay, Facts, Modelling, STATCOM, Transmission Protection*

1.0 Introduction

The most widely utilized kind of transmission line protection has been the distance relays scheme, which have been employed over long era[1,2]. Among the many relays, distance relay is one of the most helpful types of relays for transmission lines. Nonetheless, a number of things could go wrong with the relay in the transmission line[3,4]. These variables fall into three groups. The first one is dependent on the kind of lines, such as a teed-feeder system's infeed currents[5,6]. Numerous techniques have been employed to get rid of this problem[7,8]. Fail resistance is the second is the component that leads to the distance relay and relay under-reach measuring higher measured impedance values[9,10]. Various techniques have been suggested in to lessen the impact of value of fault resistance[11-14]. The tertiary classification involves the existence of compensators on the line, encompassing basic compensators like FACTS controllers or fixed series capacitors Several techniques have been investigated

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in[15-19] to avoid the effect of series compensators on relay operation. In[20,21] the impact of FACTS controllers in distance protecting scheme is studied. It has been demonstrated in[22-24] that the relay misidentifies the problem when shunt-FACTS is present[25]. The literature also demonstrates how FACTS devices have a greater influence on phase-to-ground problems. Techniques for removing FACTS device effects in distance protection have been presented in recent studies. The negative effect of static VAR compensator on distance protection is the exclusive focus of[20], where it is demonstrated that SVC has a more notable effect on protection distance in phase-to-ground faults. Although the algorithm in[20] is based on a fuzzy system, fault resistance is not taken into account, and the impact of STATCOM on the protection distance is lessened. Adaptive tripping strategy for single line-to-ground fault have been studied for this purpose, and in[22] a flexible distance protection strategy for shunt FACTS compensate line linking with wind farm is described.

Although tripping features can lessen the impact of fault resistance, the relay's measured impedance remains uncorrected. Put another way, this approach modifies the shape of the relay protection zone while maintaining the fault resistance effect in the relay's measured impedance. The location of the fault is then not identified. Since the line impedance from the relay to the fault location determines the fault location, at this instance, the impedance increases as increase in the fault resistance. As a result, the fault site is not identified. Utilizing differential protection in transmission lines is an additional method. Fault location cannot be recognized using current differential protection techniques[23].

One significant element may be the advancement of solid state and electromechanical relays with mho properties. A sizable section of the transmission line is protected from high-speed threats by zone 1 distance relays. The remaining protected line is covered by Zone 2, which also offers some protection power for the remote end bus. Zone 3 serves as the remote end bus's protection for whole of the associated lines[24,25]. Comprehending the working principles of distance relays and the variables influencing their performance in various abnormal scenarios are essential for their effective implementation. In most cases, we can use simulation software to analyse and test faults and select the best protective relay based on system requirements; nevertheless, large-scale simulation tests are typically conducted for security and reliability reasons. Due to the large number and diversity of jobs involved, it's critical to have an excellent simulation environment[26].

It is challenging to modernize a transmission system by constructing additional transmission lines due to environmental and financial constraints. In order to maximize efficiency and make better use of the currently installed transmission lines without hampering reliability and quality of the applied electrical power, many approaches must be investigated. As options to deal with this problem, Flexible Ac Transmission System (FACTS) and high-power semiconductor technologies have also been developed. But due to the additional complexity brought about by the interplay between the transmission system and FACTS devices, the power frequency, voltage, and current waveform with the transients superimposed on its, especially when a fault occurs, may differ significantly from those of systems without FACTS device connections. As a result, system parameters like power angle and line impedance will change quickly. The effects of FACTS devices on conventional protection relay schemes, including distance protection relay, must thus be thoroughly studied. The STATCOM is among the most significant and extensively utilized flexible AC transmission system devices. It is related to voltage source converter and has the ability to inject a current that is nearly sinusoidal, varying in amplitude and quadrature with the voltage of the connecting line. In the region, injecting or absorbing systems are frequently employed to maintain VAR power in the power connection.

Both steady and transient situations will affect the volt and ampere signals at the relay point due to the presence of STATCOM devices the fault loop. This will have an impact on the distance relay's behaviour[27,28].

2.0 Static Synchronous Compensator (STATCOM)

Among the important FACTS Controllers is STATCOM. Either a (VSC) voltage-sourced converter or a (CSC) Current-Sourced Converter could serve as its foundation. When comparing total cost, voltage-sourced converters are the more desirable device compared to current-sourced converters, and this is the foundation for most converter FACTS controller presentations. In order

to absorb system harmonics, STATCOM may be made to function as active filter as well. Reactive power can be produced, absorbed, or both by STATCOM, and its output can be adjusted to maintain control over electrical power system parameters. Systems are generally balanced at the transmission level, but they get upset when there is a failure.

This study uses a 3 level, 3 phase IGBT of the STATCOM type. A signal error derived from the reference voltage and the observed terminal voltage's root mean square value is the controller input. An angle **δ**, the result of processing such an error, is given to the PWM signal generator by means of a PI controller[29].

3.0 Distance Relay

The basis for the working of a distance relay is impedance measured at the relaying location. A distance relay measures the true impedance of the line segment between the relaying locations and the fault when the fault resistance is zero. As seen in Figure 1, this impedance equals pZ1l, where line positive sequence impedance is ZIL, and it expressed in ohms and p is the section of line length between the relaying locations and the fault[30-33].

When a distance relay measures impedance, it does not equal the specified magnitude for a given fault resistance value. In this instant, the counted impedance at the relay point is influenced by the physical and working characteristics of the power transmission system. The load angle for line is, or ð, the ratio of the line end voltages' magnitude, or h, can be used to depict the actual conditions before the fault instance. In general, this equals EB/EA = h$e^{-j\delta}$. The SSA and SSB short circuit values at the line ends are used to assess the structural problems. At the starting position point, the measured impedance, as shown in Figures 1 and 2, can be represented using the following formulas.

$$Z_{1A} = Z_{1SA} + pZ_{1L} \quad (1)$$

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

$$Z_{0A} = Z_{0SB1sA} + pZ_{0L} \quad (3)$$

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

$$Z_{\Sigma} = 2\frac{Z_{1A}Z_{1B}}{Z_{1A}+Z_{1B}} + \frac{Z_{0A}Z_{0B}}{Z_{0A}+Z_{0B}} \quad (5)$$

$$C_1 = \frac{Z_{1B}}{Z_{1A}+Z_{1B}} \quad (6)$$

$$C_0 = \frac{Z_{0B}}{Z_{0A}+Z_{0B}} \quad (7)$$

$$K_{OL} = \frac{Z_{OL}-Z_{1L}}{3Z_{L1}} \quad (8)$$

$$K_{\delta} = \frac{1-he^{-j\delta}}{Z_{1A}he^{-j\delta}+Z_{1B}} \quad (9)$$

$$Z_{AG} = pZ_{1L} + \frac{3R_f}{\left(Z_{\Sigma} + 3R_f\right)K_{\delta} + 2C_1 + C_0 + (1+3K_{0L})} Z_{1SA} + pZ_{1L} \quad (10)$$

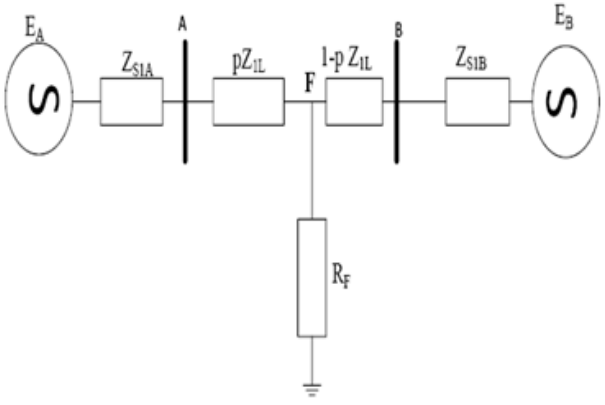


Figure 1. Single phase equivalent circuit to earth fault[24].

If the fault resistance is zero, the measured impedance at the relay point equals the impedance of the line section connecting the relaying and fault sites. When fault resistance is present in the power system, it has an impact on the measured impedance. The formulas may alter as a STATCOM is injected to a power transmission system. This variance is dependent on the installation location in addition to the STATCOM parameters. As a result, the three installation points are the near point, the midpoint, and the distant end are given the updated equations. STATCOM is represented in the ensuing sub-section by its natural coupling reactance (ZST) and source voltage (E).

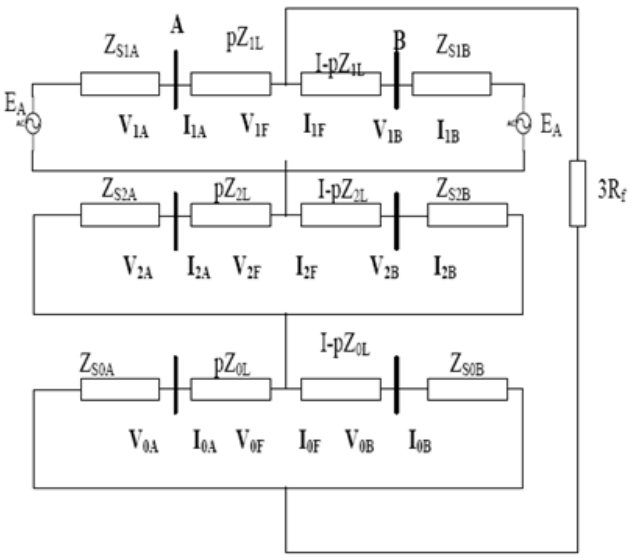


Figure 2. Equivalent circuit Line to earth fault[24].

3.1 Near End Location of STATCOM

In this instance, the fault mesh lacks STATCOM. Several of the equations above are changed in this case as follows:

$$Z_{1A} = pZ_{1L} + \frac{Z_{S1A}Z_{ST}}{Z_{S1A}+Z_{ST}} \quad (11)$$

$$Z_{0A} = pZ_{0L} + \frac{Z_{S0A}Z_{ST}}{Z_{S0A}+Z_{ST}} \quad (12)$$

$$K_\delta = \frac{-A(B-E_{ST})+Z_{ST}(1-B)}{A(PZ_{1L}B+Z_{1B}E_{ST})+Z_{ST}(Z_{1B}+(A+pZ_{1L})B)} \quad (13)$$

Where $A = Z_{1sA}$ $B = he^{-j\delta}$

Is obvious that the measured impedance of fault location is the same as the same line impedance in the absence of fault resistance.

3.2 Central Point Location of STATCOM

In this instance, the occurrence of fault in the transmission line section, in between the relay location point and the mid-point without STATCOM present in the line. On the other hand, STATCOM is a part of the fault loop as fault happens at the transmission segment that connects the midpoint and the remote location. In this instance,

$$Z_{1B} = (0.5-p)\,pZ_{1L} + \frac{DZ_{ST}}{D+Z_{ST}} \quad (14)$$

$$Z_{0B} = (0.5-p)\,pZ_{0L} + \frac{CZ_{ST}}{C+Z_{ST}} \quad (15)$$

$$K_\delta = \frac{D(1-E_{ST})+Z_{ST}(1-E)}{D((0.5-p)Z_{1L}+Z_{A1}E_{ST})+FZ_{1L}+Z_{SB}+Z_{1A}E} \quad (16)$$

Where

$C = 0.5Z_{0L} + Z_{S0B}$
$D = 0.5Z_{1L} + Z_{S1B}$
$E = he^{-j\delta}$
$F = Z_{ST}(1-p)$

the following changes need be made to several of the equations mentioned:

There is no difference between the measured and actual impedance levels when the fault resistance is absent. As STATCOM is working in the faulty section it affects the measured impedance, and when the fault observes on the line segment between the midpoint and the remote end. The aforementioned equations should be modified to look like this:

$$Z_{1A} = G_PZ_{1L} + \frac{HZ_{ST}}{H+Z_{ST}} \quad (17)$$

$$Z_{0A} = G_PZ_{0L} + \frac{IZ_{ST}}{I+Z_{ST}} \quad (18)$$

$$K_\delta = \frac{J+HK+M}{H(GZ_{1L}K+Z_{1B}E_{ST})+L} \quad (19)$$

$$K'_\delta = \frac{-J+HK+M}{H(GZ_{1L}K+Z_{1B}E_{ST})+L} \quad (20)$$

Where

$G = p - 0.5$
$H = 0.5Z_{1L} + Z_{S1A}$
$I = 0.5Z_{0L} + Z_{S0A}$
$J = 0.5Z_{1L} + Z_{S1B}$
$K = he^{-j\delta}$
$L = (Z_{1B} + (Z_{1SA} + pZ_{1L})K)$
$M = E_{ST}(Z_{1SB} + (Z_{1SA} + Z_{1L}))$

It is clear that in this situation, STATCOM parameters affect the relaying location point impedance even when zero fault resistance.

3.3 Remote Location of STATCOM

STATCOM is mounted at the transmission line's remote bus for this case. Consequently, the fault loop does not contain STATCOM. The equations in this case need to be changed to:

$$Z_{1B} = N + \frac{Z_{S1B}Z_{ST}}{Z_{S1B}+Z_{ST}} \quad (21)$$

$$Z_{0B} = N + \frac{Z_{S0B}Z_{ST}}{Z_{S0B}+Z_{ST}} \quad (22)$$

$$K_{\delta} = \frac{P(1-E_{ST})+Z_{ST}(1-O)}{P(N-Z_{1A}E_{ST})+Z_{ST}(N+P+Z_{1A}O)} \quad (23)$$

Where

$N = (1-p)Z_{L1}$

$O = he^{-j\delta}$

$P = Z_{1SB}$

When the resistance of fault is zero, it is evident that, for this case, measured impedance equals the line segment impedance that is located in the relaying location and fault sites.

4.0 Simulation Scheme

An example simulation of the 300 km long and 400 kV transmission line is shown in Figure 3. Furthermore, there is significant distortion in the voltage and current signals when a fault arises on transmission lines. Subsystem frequency transients, high frequency oscillation amounts, decaying dc components, and other things could be present in these signals. Anti-aliasing low pass filters with the appropriate cut-off frequency can remove the higher frequency components; nevertheless, they are unable to reject low frequency components and eliminate decaying dc components. This impacts the efficiency of digital relaying and makes it extremely difficult to predict the phasor quickly. As a result, we often eliminate the dc-offset components using the mimic filter[29].

The following procedures are taken into account when modelling the relay:

1. Retrieve the discrete V and I signal data from the system simulation that is being studied.
2. To eliminate dc-offset components, give the V and I signals the filtering treatment. Employ the identical filtering process for the three-phase ampere and volt signals.
3. Phase estimation with DFT is the third step.
4. Determine the impedance values under fault situations for every phase.
5. Sketch the trajectory of the impedance. As can be seen from the explanation above, MATLAB can easily complete all protective relay algorithms. The benefit of using SIMULINK for power system fault simulation is that protective relay design and testing can be completed quickly and easily. Its primary feature, which involves incorporating protection relay algorithms and system fault simulation into a simulation system, can increase the effectiveness of protective relay tests.

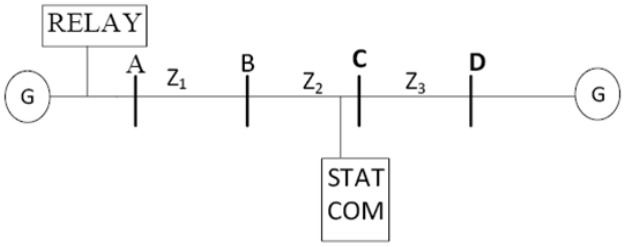


Figure 3. A single line diagram utilizing STATCOM for distance relay[24].

5.0 Results and Discussion

Figure 4 depicts the behaviour of impedance trajectory when STATCOM is not connected in transmission

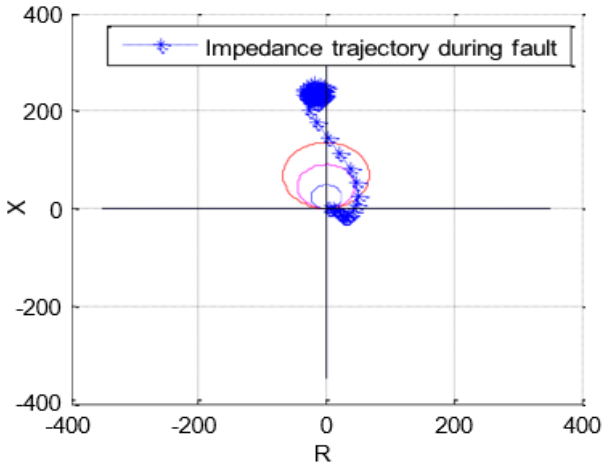


Figure 4. STATCOM-enabled impedance trajectory.

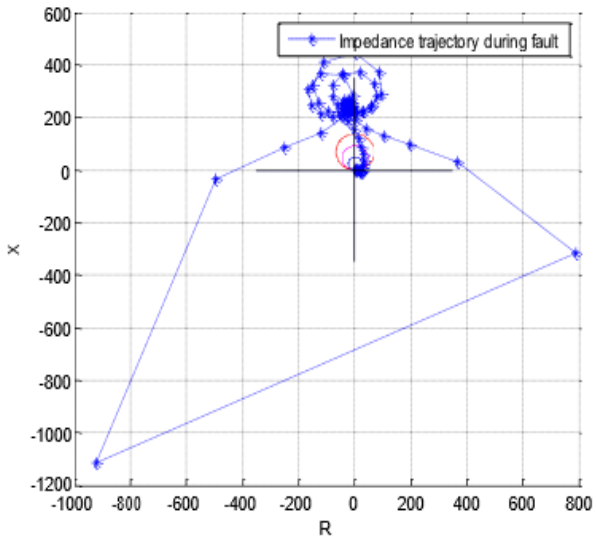


Figure 5. STATCOM-enabled impedance trajectory.

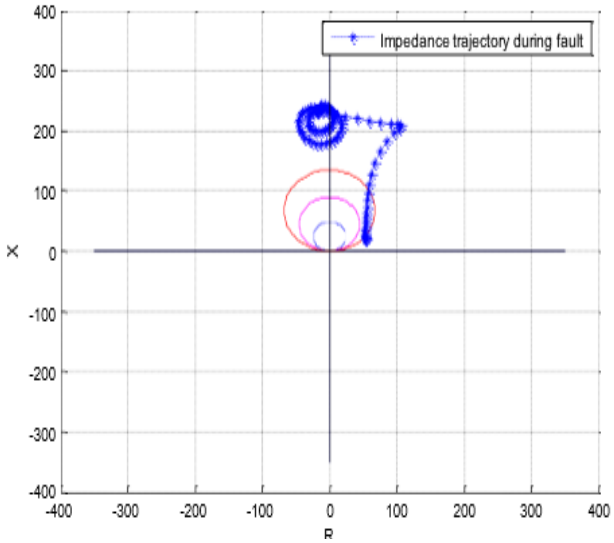


Figure 7. STATCOM-enabled impedance trajectory.

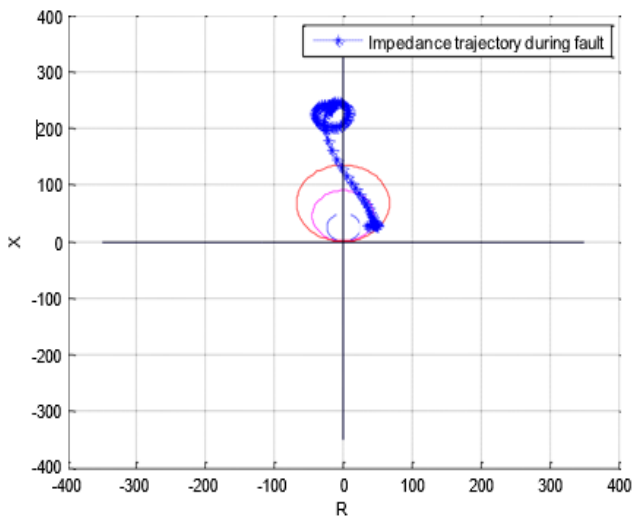


Figure 6. Trajectories of impedance without STATCOM.

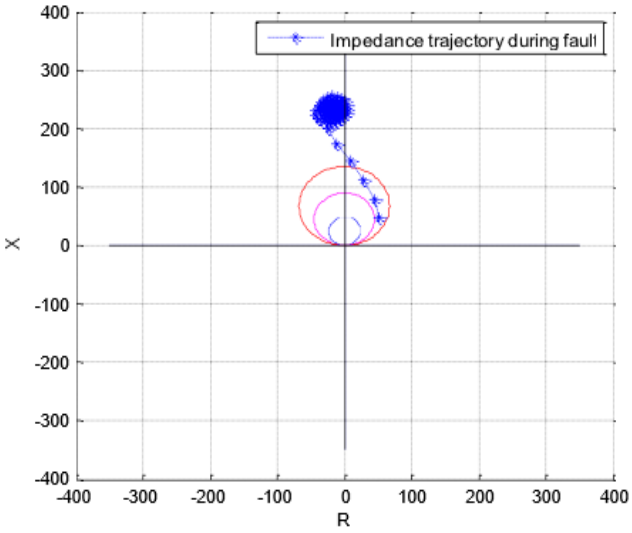


Figure 8. Impedance path in the absence of STATCOM.

line, while it can be clearly seen in Figure 5 the fault appears to be under zone 1, but its behaviour indicate that it is external of zone 1. This is due to the influence of STATCOM. If a defect arises in zone 2, the following characteristics will manifest:

Figure 6 describes STATCOM not exists in the line the characteristics under zone 2, In Figure 7 STATCOM is connected to the line, the characteristics of fault's show that it is outside of zone 2, even though it appears to be in zone 2.

When fault occurs in zone 3 impedance path was under Zone 3 is where the fault is located, and its features are in Figure 8. In Figure 9 STATCOM is injected in the line, the impedance path due to fault's show that it is outside of the zone, even though it appears to be in zone 3.

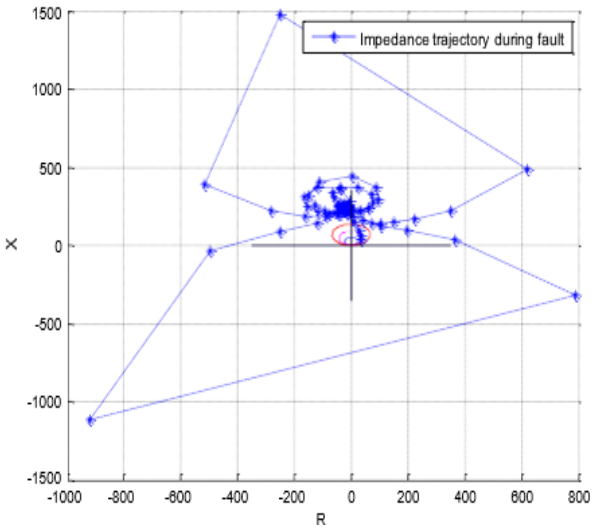


Figure 9. Trajectory of impedance using STATCOM.

6.0 Conclusion

This simulation presents a comprehensive model of a power transmission system using STATCOM. It also shows how to use STATCOM to determine the system's apparent impedance in the occurrence of a single line to ground fault. When STATCOM introduces reactive current into the system, the measured impedance will increase and the impedance relay will be under-reaching; on the other hand, when STATCOM employs zone-wise, the measured impedance will decrease, and the impedance relay will be over-reaching.

From above results it is clearly visible that when STATCOM in present in the transmission line it affects the trajectory path of impedance in zone 1, zone 2, zone 3. If STATCOM not connected to power transmission line impedance trajectory was under the same zone as for located

7.0 References

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