Journal of Mines, Metals and Fuels, *73(11): 3379-3385; 2025. DOI: 10.18311/jmmf/2025/50007*

Online ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Enhancing Generator Loss of Excitation Protection with Offset Distance Relay in the Presence of STATCOM

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Abstract

In the realm of synchronous generators, safeguarding against the Loss of Excitation (LOE) stands as a pivotal safety measure. The repercussions of LOE extend beyond the generator itself, affecting both the generator and the interconnected electricity grid. This study delves into the use of impedance-based positive and negative offset mho relays for prompt identification of LOE phenomena. Notably, challenges arise when implementing these protection measures in the presence of Flexible AC Transmission Systems (FACTS) components, necessitating precise adjustment of relay parameters for optimal functionality. Fluctuations in the system's total impedance can lead to overreach or underreach by the relays, potentially compromising the protection mechanism. This article provides a comprehensive exploration of both types of mho relays, elucidating their configurations and drawing comparisons. The impact of STATCOM on the LOE protection of POMR and NOMR is simulated using Simulink/MATLAB. In conclusion, the essay discusses the merits and demerits of each relay strategy, shedding light on their respective advantages and limitations in the context of LOE protection

Major Findings: *STATCOM presence affects generator LOE protection. Positive offset mho relays perform better. Accurate relay settings with STATCOM ratings are vital. P-Q and R-X directional methods outperform traditional G-B or U-I schemes..*

Keywords: *Generator Protection, Loss of Excitation (LOE), Negative Offset Mho Relay, Positive Offset Mho Relay, Static Synchronous Compensator (Statcom)*

1.0 Introduction

In 1949, the first single-zone impedance-based protection system was developed. This relay is used to quickly detect a LOE, and it can be programmed to do so regardless of the load on the machine. However, its power swing operation judgment is unparalleled[1]. A change needs to be made in this relay to get rid of this drawback. Consequently, the two-zone relay was created. This relay is employed in situations where power swing and voltage control performance are of interest[4], and it can tell the difference between an LOE and a loss of synchronisation. Improved reliability in a stable power swing scenario is achieved through optimised settings for excitation limiters and an LOE prevention mechanism[2,3]. The R-X scheme, the R-X with directed elements system, the P-Q scheme, the G-B scheme, and the U-I scheme are the five schemes available for

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safeguarding against excitation loss. The R-X method is commonly utilised. The relay's performance in the face of an external fault and a LOE is demonstrated in PSCAD software[4]. When excitation is lost, the field current, active Power (P), and Reactive Power (Q) all drop. To identify a LOE, the impedance attributes must enter the relay zone. The scenario has been included in PSCAD[5], although it does not enter the zone when an external fault occurs. Researchers have proposed a new way of excitation protection that uses measurements of S to address the limitations of the standard approach[6]. The influence of UPFC on the excitation protection relay's time delay is studied; this is because UPFC causes the relay to take longer to respond to a lack of excitation. The mitigating strategy was introduced to reduce this lag time[7]. Previous literature[8] introduces the influence of TCSC on the protection of line networks. LOE performance due to a fixed series capacitor, synchronous buck converters SSSC, and GIPFC are all studied. Even though Negative Offset Mho Relay (NOMR) protection has received a lot of attention, Positive Offset Mho Relay (POMR) protection has received significantly less[9]. This piece examines the two types of mho relay protection, positive offset and negative offset, when STATCOM is present. Section 2, introduced the LOE basic phenomena, including its explanation of what triggers LOE. In Section 3, we cover the design of the LOE relay, with the first half of that section covering the POMR and the second half covering the NOMR. Section 4 details the STATCOM and its effects on the protection relay used in the electrical grid. In Part 5, we display the simulation results and study the system. In Section 6, we discuss the mitigating strategy and the effect of STATCOM on LOE security. In the final paragraph, section 7, a contrast is drawn between POMR and NOMR.

1.1 Loss of Excitation

To convert mechanical input power into electrical power, a synchronous generator or alternator is employed. The synchronous generator maintains a steady, or synchronous, rotational frequency. The synchronous generator's rotor requires a constant DC supply to maintain synchronous speed. The LOE condition occurs when this DC supply stops feeding input to the generator. Short circuits in the field, the opening of a field breaker, or a faulty LOE relay can all lead to a LOE, making it one of the most often occurring errors. When excitation is lost, the generator and the entire system suffer. The P comes from the mechanical input, while the Q comes from the field current. As soon as the excitation is lost, the field current drops and the emf begins to decay; the power output drops[10].

The power transfer equation demonstrates that the amount of power transferred is proportional to the emf present. $P=EV/X \sin\delta$. P denotes the P, E the voltage at the generator's output, V the terminal voltage, X the reactance of the transmission line, δ the phase angle between the voltages at the two ends[11]. As the excitation was lowered, the magnetic connection between the rotor and stator weakened. This means that not all of the

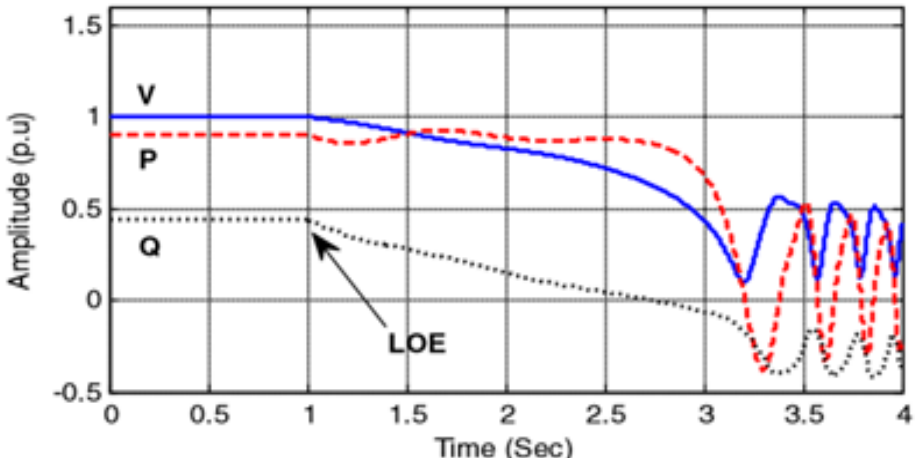


Figure 1. P, Q and V of the generator.

energy produced by the turbines can be converted into electricity.

This means that the generator's speed drops below synchronous speed because the input P_m is higher than the output P_e, causing the rotor to accelerate. The rotor slips because of an eddy current created on its surface by the slip. In the generator's air gap, this eddy current acts as a source of field current[12].

In other words, the emf to be generated, as stated by Faraday's law, i.e., emf = N dφ/dt. slowing the rotor's rotation, the generator can function as an induction generator, drawing *Q* from the grid while supplying P.

Precisely depicted in Figure 1, LOE occurs at t = 1 sec, when the generator draws *Q* from the grid and the generator voltage drops. *Q* must be supplied by a robust grid to run a synchronous generator in induction mode. Let's say a generator is capable of producing Q_1 MVAR, but after experiencing a LOE, it can absorb only Q_2 M_{VAR}. This results in a net impact of Q_1+Q_2, which leaves the grid vulnerable to voltage decay and eventual collapse due to a lack of available M_{VAR}[13]. Therefore, the grid needs to be solid. Excitation for the generator is drawn from the grid via the stator winding. Both the excitation current and the I_L are carried by the stator winding[14].

Thus, the *P* must be within a limit, i.e. 20-30 % of the *P* rating, to prevent the high current that could harm the stator winding. Overheating of the rotor can occur if the slip exceeds 0.2%; therefore, keeping it in that range is ideal. Under these three scenarios, using a synchronous generator in induction mode is not a good idea. A reliable relay that can detect the fault precisely & send a trip signal to the circuit breaker is essential for preventing such scenarios.

1.3 Impact and Mitigation of STATCOM on LOE Protection

Both voltage source converters and thyristor controls can be used in the FACTS. Multiple power electronic components, such as a thyristor, MOSFET, IGBT, etc., come together to form a FACTS device. One kind of voltage source converter is the STATCOM[15-18]. Transmission over a great distance is often referred to as STATCOM. STATCOM's use of DC capacitors limits its P output. Connecting the right storage device across a DC source increases *P* capability[19].

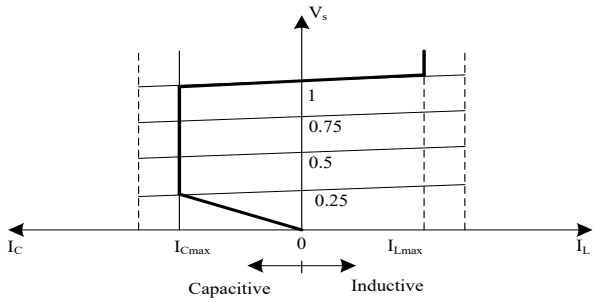


Figure 2. V-I attributes of STATCOM.

STATCOMs are strategically located and sized for maximum efficiency. STATCOM is employed to mitigate voltage swings[20]. The cosφ and voltage regulation of the electrical system can both benefit from the installation of a STATCOM like this one. A reactive current is produced by STATCOM if the $V_t > V_{ac}$ at the point of connection. When the $V_t < V_{ac}$, STATCOM takes on the *Q* and compensates for it in the power grid. STATCOM can be used to reduce flicker, cancel harmonics, and increase transient stability[21-23].

The STATCOM's *V-I* curve is depicted in Figure 2. It is demonstrated that their *P* can be modulated across the L and C range without affecting the V_{ac}. The STATCOM's capacitive current output is voltage-independent.

The primary drawback is that having STATCOM present in the power system can lead to the maloperation of the LOE protection relay. LOE in a synchronous generator reduces the generator's reactive output, necessitating voltage injection by STATCOM. As a result, the relay's ability to recognize the performance of LOE may be diminished[24].

Since the existence of STATCOM alters the total impedance value, the relay will not be able to determine the system's true performance based on its attributes. With STATCOM in place, voltage drops more slowly than in a system without it. The potential for armature winding damage is increased when a delay is multiplied[25].

1.4 Simulated and Modelled Investigation

In a strategic effort to augment both power transfer capabilities and voltage profile within the line network, an IGBT-based STATCOM is strategically positioned at the central nexus of the transmission grid. The primary objective behind integrating STATCOM into the system is to provide reactive power compensation. As

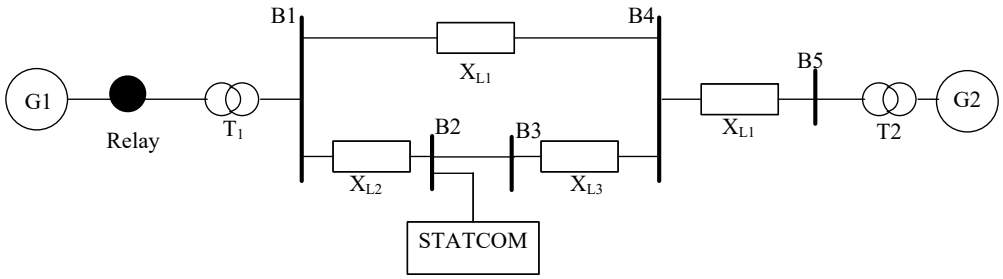


Figure 3. STATCOM network.

illustrated in Figure 3, Transmission Scheme Including STATCOM, this device operates as a shunt-connected FACTS controller based on a voltage source converter. The specifications of the study system are detailed as the transmission system under study comprises four transmission line segments with lengths L1=300 km, L2=L3=140 km and L4=50 km. The system includes two transformers: ST1=2100 MVA and ST2=1400 MVA, both with a voltage rating of 13.8/500 kV. A D1/Yg winding connection is used for both transformers. For generation, two synchronous generators are considered: SG1=2100 and SG2=1400 MVA, both rated at 13.8 kV

Thus, a 48-pulse VSC is utilized to represent the research system; specifically, four 12-pulse voltage-source converters with a 3Φ, 3-level inverter, and 4-phase shift transformers. The voltage drops because Q is sucked out of the grid when excitation is lost. STATCOM is utilized to provide the necessary amount of Q. It provides the system with the correct quantity of Q.

The path patterns for impedance of a NOMR are shown in Figure 4(a), both with and without the presence of a STATCOM. At *t=10 s*, when the generator's P is 0.5 p.u., the complete LOE condition is applied.

When no STATCOM is present in a system, the impedance path enters Z_1 at 11.58 s, and at 11.82 s when STATCOM is present. This means that there is a lag time of 11.82 - 11.58 = 0.24 s.

Figure 4(b) depicts similar positive offset LOE relay impedance attributes. In the Z_2, the impedance arc first arrives. It will eventually make its way across Z_1 after some delay. The alarm signal is made available. The system with STATCOM has the same performance. Figure 5(a) and 5(b) show that a POMR using a directional relay may send

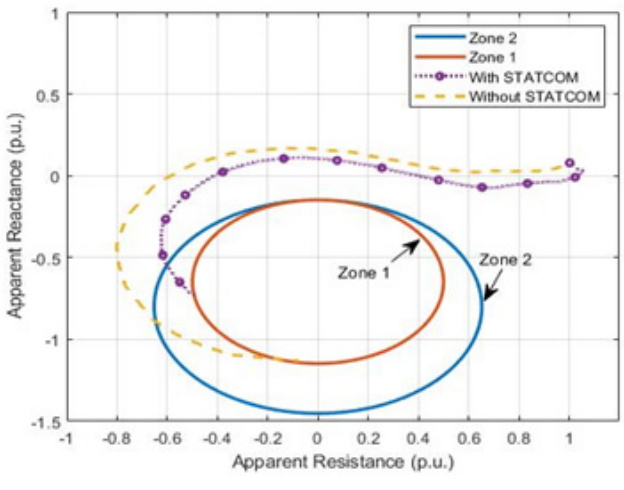


Figure 4(a). Impedance attributes of the negative offset LOE relay.

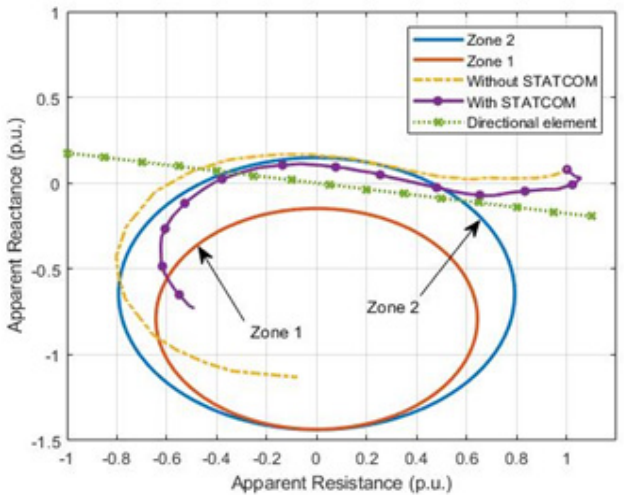


Figure 4(b). Impedance attributes of positive offset LOE relay.

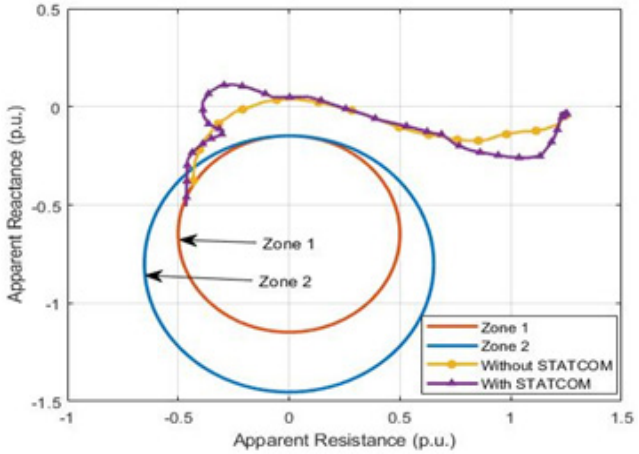


Figure 5(a). LOE at *t=10 s* for NOMR.

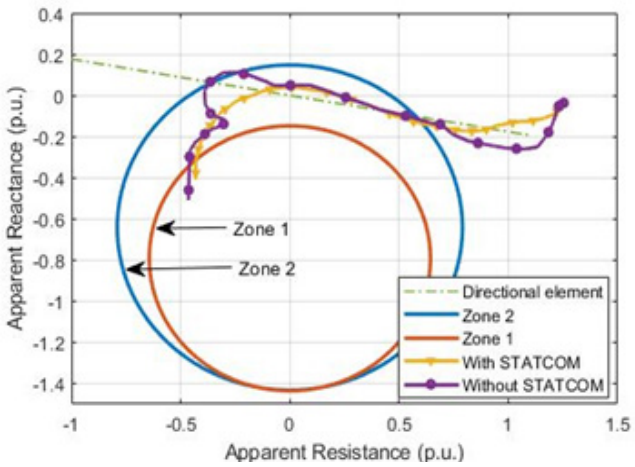


Figure 5(b). LOE at *t=10 s* for POMR.

out an alert signal much more quickly than a NOMR. Because the impedance attributes do not enter any relay zone, the relay will malfunction under a partial LOE scenario. Adjusting the relay setting to avoid the delay in relay operation and reduce the relay's underreaction. One such method is the artificial neural network. Created a neural network approach to link active and reactive energy.

Once a suitable load bus k is associated with the STATCOM, the magnitude of voltage, i.e. $|V_k|$, phase angle k, and reactive power Q_k of the adjusted bus can be calculated. The real and Q of all load buses were distorted by boosting their values proportionally, generating massive data for the STATCOM bus. After each disturbance, the voltages, phase angles, and Q_s of all buses are determined. In this method, a huge data set is collected that includes the magnitude of the STATCOM bus voltage $|V_k|$, the phase angle $k|$, and the reactive power Q_k to each other after each perturbation. Neural network design procedures for the aforementioned three scenarios are detailed in[26,27].

Furthermore, the connection between the two powers is calculated using the impedance measuring technique. Calculated from P and Q, are the impedance values. STATCOM's presence on the line network diminishes the generator's P_o, which in turn affects the impedance measuring the relay's accuracy. Add STATCOM's P/Q to the total system power before adjusting the relay's setting. Similarly, this effect of STATCOM on the LOE relay can be mitigated through knowledge of the values of P and Q of STATCOM. For reliable LOE relay operation, the updated equations are given in Equation (1) and (2).

$$P = P_G + P_{STATCOM} \tag{1}$$

$$Q = Q_G + Q_{STATCOM} \tag{2}$$

Figure 5(a) and 5(b) illustrate the LOE relay in action after 10 s of no stimulation; it then analyzes the apparent impedance of the POMR and the NOMR, accordingly. Despite the additional delay caused by STATCOM, the data shows that the impedance attributes are inside the zone. In contrast to Z_1 for NOMR, which takes longer to trip the signal, Z_2 for POMR includes both pathways.

2.0 Conclusion

The R-X and G-B techniques both result in a slower transmission of the trip signal. The LOE conditions that happen during condenser operation cannot be detected using either the G-B or U-I methods. R-X with a directed element and the P-Q scheme are both reliable and efficient techniques. When STATCOM is present, the LOE relay stops working. To reduce the negative impact, the relay settings should be modified so that STATCOM ratings are included in the total system ratings. By summing the station's active and Q_s, one may determine the generator's overall active and Q. Compared to the negative offset mho relay scheme, the positive offset mho relay system

provides better protection for LOE, according to the computer simulation findings.

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