Journal of Basics and Applied Sciences Research (JOBASR)
ISSN (print): 3026-9091, ISSN (online): 1597-9962
Volume 4(3) June 2026 Special Issue
DOI: https://dx.doi.org/10.4314/jobasr.v4i3.17s

Hospital Power System with Voltage Sag Mitigation Mechanism

Abdulkabir A.[1*] & Ikechiamaka F. N.[2]
[1,2]Department of Physics, Federal University Dutsin-Ma, Katsina State
[*]Corresponding Author Email: abdulkareemabdulkabir3@gmail.com

ABSTRACT

Continuous and stable electrical power is important in healthcare facilities, where critical medical equipment relies on a dependable voltage supply. Temporary reductions in voltage, commonly referred to as voltage sags, may affect the performance of sensitive medical devices. Such as ventilators, magnetic resonance imaging (MRI) scanners, computed tomography (CT) scanners, and patient monitoring systems. Although uninterruptible power supplies (UPS) and standby generators are commonly employed to enhance supply reliability, their effectiveness may be constrained by response delays and maintenance requirements. This study presents the design and simulation of a hospital power system incorporating a Static Synchronous Compensator (STATCOM) for voltage sag mitigation. The system was modelled in MATLAB/Simulink using the Simscape Electrical toolbox, and voltage sag conditions were introduced through fault simulations to assess network performance with and without compensation. The simulation results indicate that, in the absence of STATCOM support, the system voltage decreased to approximately 0.5 p.u., accompanied by poor voltage stability and a recovery time exceeding 0.2 s. Following the integration of the STATCOM, the voltage profile improved to about 0.95 p.u., the sag duration decreased from 0.1 s to 0.05 s, and the recovery time was reduced to less than 0.05s, sag reduction percentage increases from 50% to 5. These findings demonstrate the capability of the STATCOM to enhance voltage regulation, reduce the severity of voltage sag, and improve the operational reliability of hospital electrical systems. The study highlights the potential application of STATCOM technology in hospitals and other facilities containing voltage-sensitive equipment.

Keywords:
Voltage sag,
Power system,
STATCOM,
Power quality

INTRODUCTION

A voltage sag is a short-duration reduction in the root mean square (RMS) voltage, typically lasting from 0.5 cycles to one minute (Tang, 2022). Voltage sag commonly occurs as a result of network disturbances such as short-circuit faults, the starting of high-power motors, abrupt variations in load demand, and switching operations within the power system. While these voltage reductions usually last for only a short period, their consequences can be significant, particularly in environments that depend on a continuous and stable electricity supply. Sensitive electronic equipment may experience operational interruptions, unexpected shutdowns, or performance degradation during such events. In healthcare facilities, the impact can be even more critical because medical devices used for patient monitoring, diagnosis, and life support require reliable operating voltages to function properly (Gupta, 2006; Milanović, 2006).

To minimize the adverse effects of voltage sag, a variety of mitigation techniques have been proposed. Conventional solutions, including uninterruptible power supply systems, voltage regulators, and capacitor banks, provide a certain level of protection; however, their effectiveness may be limited during severe voltage disturbances because of response-time constraints and reduced compensation capability (Bollen, 2000; Milanović, 2010). Consequently, increasing attention has been directed toward power-electronic compensation technologies, particularly devices classified under Flexible AC Transmission Systems (FACTS). Among these technologies, the Static Synchronous Compensator (STATCOM) has emerged as an effective solution due to its ability to rapidly exchange reactive power with the network, thereby supporting voltage regulation during disturbance conditions (Hingorani & Gyugyi, 2000).

Numerous studies have examined the application of STATCOM and related technologies for improving

How to cite this article: Abdulkabir A. & Ikechiamaka F. N. (2026). Hospital Power System with Voltage Sag Mitigation Mechanism. *Journal of Basics and Applied Sciences Research*, *4*(3), 157-164. https://dx.doi.org/10.4314/jobasr.v4i3.17s

voltage stability and mitigating voltage sag. As a shunt-connected FACTS device, STATCOM enhances power quality by providing dynamic reactive power compensation and fast voltage support. Its rapid operating characteristics make it particularly suitable for critical installations such as hospitals, where continuous and reliable power supply is essential for medical operations. Through simulation studies, Kumkratug (2010) showed that STATCOM contributes significantly to voltage stability improvement in a single-machine infinite-bus system. Similarly, Roy and Singh (2012) designed a distribution-level STATCOM model capable of maintaining acceptable voltage levels under unbalanced operating conditions. Furthermore, Venkatesan and Nagarajan (2018) utilized STATCOM for compensating nonlinear loads and reported noticeable improvements in system voltage performance. Musa *et al*. (2020) modelled nonlinear loads in hospital environments and observed that electronic imaging systems malfunctioned during voltage sag periods.

Voltage sag has become one of the most significant power quality concerns in modern electrical networks because even short-duration reductions in voltage can disrupt the operation of sensitive equipment. According to IEEE Std 1159 (2019), a voltage sag is aon ranging from 0.5 cycle to one minute. Although such disturbances are often temporary, their consequences can be severe in environments where electrical continuity is essential. Hospitals represent one of the most sensitive categories of electrical consumers because many life-support, diagnostic, and patient-monitoring systems are designed to operate within narrow voltage limits. Equipment such as ventilators, magnetic resonance imaging (MRI) systems, computed tomography (CT) scanners, infusion pumps, and intensive care monitoring devices may experience malfunction, interruption, or loss of functionality when subjected to voltage sags, potentially compromising patient safety and the quality of healthcare delivery.

Sandoval *et al*. (2020) carried out a simulation-based comparative study of DVR and STATCOM under voltage sag conditions. The results indicated that STATCOM exhibits a faster dynamic response, particularly during deep voltage sags. Okafor and Bello (2021) evaluated power disturbances in Nigerian hospitals and concluded that 73% of complaints were voltage sag-related. While, Ebrahim and Omar (2021) simulated STATCOM using (dq)-axis control and achieved a 0.93 p.u. recovery within 0.1 seconds, Yusuf *et al*. (2023) investigated radial hospital feeders using a simulation-based load flow analysis and recommended STATCOM placement nearer to sensitive loads. Silva and Costa (2023) carried out an experimental study using a STATCOM connected to the grid and demonstrated its capability to lessen voltage sag severity by about 65%. In a related study, Anwar and Li (2024) analyzed the impact of different fault conditions on voltage profiles through MATLAB/Simulink simulations. Their results indicated that three-phase faults caused the greatest drop in voltage magnitude among the fault scenarios examined.

The reviewed studies confirm that STATCOM is an effective solution for enhancing voltage stability due to its fast response characteristics and operational adaptability. However, limited studies have focused specifically on the application of STATCOM for voltage sag mitigation in hospital electrical networks under different fault conditions. In addition, many previous investigations concentrated primarily on industrial or utility systems without considering the voltage sensitivity requirements of hospital equipment. Therefore, this study investigates the performance of a STATCOM-based voltage sag mitigation scheme in a simulated hospital power system under single-line-to-ground and three-phase fault conditions. The objective is to evaluate the ability of the compensator to maintain acceptable voltage levels and improve power quality for critical healthcare facilities.

Theory: Reactive Power Compensation, Voltage Sag and Sensitivity Index

Reactive power plays an important role in maintaining acceptable voltage levels within a power system. During system disturbances, voltage regulation can be improved through the injection or absorption of reactive power. The relationship among reactive power, voltage magnitude, current magnitude, and phase angle is represented by Equation (1) (Kundur, 1994; Hingorani & Gyugyi, 2000).

$$Q = VI\sin\varphi \tag{1}$$

where Q denotes reactive power (VAR), V represents the RMS voltage, I is the RMS current, and φ is the phase difference between voltage and current. An increase in reactive power demand generally results in a reduction in bus voltage if adequate compensation is not available.

According to IEEE Std 1159 (2019), a voltage sag refers to a short-duration decrease in RMS voltage magnitude, typically ranging from 0.1 to 0.9 per unit of the nominal value and lasting from 0.5 cycle to 60 cycles. Such events are commonly associated with network faults, large motor starting operations, and transformer energization. The severity of a sag can be quantified using Equation (2).

$$S_d = 1 - \frac{V_{sag}}{V_{nom}} \tag{2}$$

where Sd represents the sag depth, Vsag is the voltage level during the disturbance, and Vnom is the rated system voltage. In healthcare facilities, severe voltage sags may interrupt the operation of sensitive equipment, including ventilators, imaging systems, and other electronically controlled medical devices (Bollen, 2000). Modern hospitals contain a large number of electronic loads that rely on microprocessor-based controllers for accurate and continuous operation. Examples include infusion pumps, patient monitoring equipment, CT scanners, MRI systems, and intensive care support devices. Because these systems are designed to operate within a narrow voltage tolerance, even moderate reductions in supply voltage may affect their performance and reliability. For most critical hospital loads, the preferred operating range is approximately 0.95–1.05 p.u. (IEEE Std 1159, 2019; Tang, 2022).

The voltage sensitivity coefficient is expressed by Equation (3):

$$K_L = \frac{\Delta v}{\Delta t} \quad (3)$$

where Δv denotes the magnitude of voltage variation and Δt represents the corresponding disturbance duration. An increase in the value of K_L suggests a greater likelihood that equipment performance will be affected by relatively small changes in supply voltage.

MATERIALS AND METHODS

MATLAB/Simulink was selected as the primary platform for the modelling and analysis conducted in this research because of its extensive capabilities for power system studies and control system development. The required simulation components, including three-phase voltage sources, transformers, electrical loads, measuring devices, and FACTS controllers, were implemented using the Simscape Electrical toolbox. A Powergui block was incorporated into the model to manage simulation settings and facilitate system analysis. Furthermore, waveform monitoring and data evaluation were achieved through the use of scope blocks, RMS measurement units, and signal-processing components, which enabled the extraction and interpretation of relevant electrical parameters.

The simulations were executed on an HP ProBook 450 G8 laptop powered by an 11th Generation Intel Core i5 processor operating at 2.4 GHz. The computer was equipped with 8 GB of RAM, a 64-bit Windows 10 operating system, and a solid-state drive (SSD) for improved computational performance. These hardware specifications provided adequate resources for the simulation tasks and ensured stable model execution without noticeable delays, convergence issues, or processing interruptions. The simulation procedure was carried out according to a structured sequence of operations, as illustrated in Figure 1.

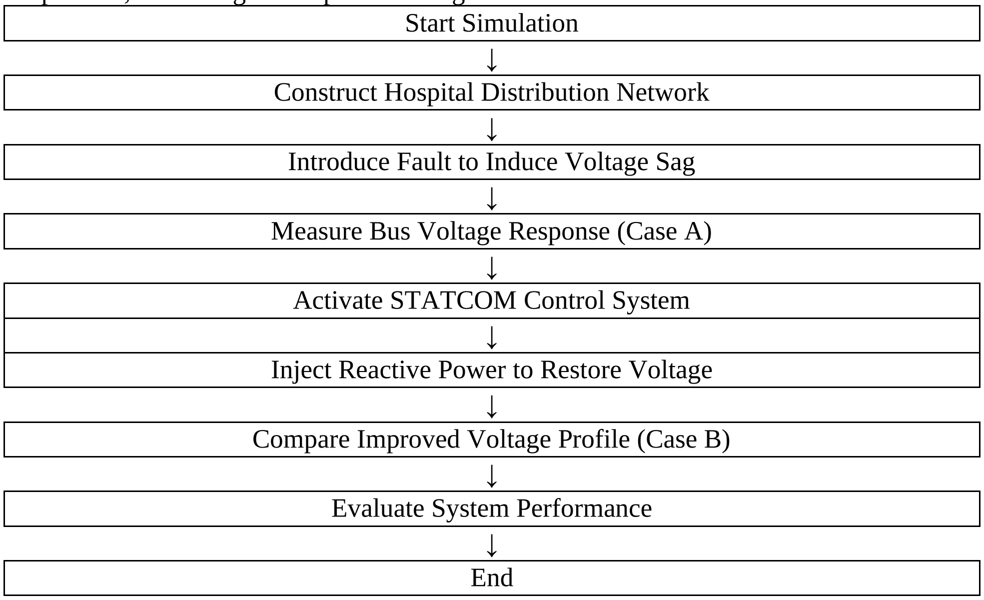

Fig. 1: Simulation Workflow

The procedure adopted for this research is illustrated in Figure 1.0. The workflow was developed to provide a systematic approach for modelling, simulation, and performance evaluation of the proposed hospital power system. A detailed three-phase electrical network representing a hospital environment was created in MATLAB/Simulink using the Simscape Electrical Specialized Power Systems toolbox. The model was structured to reflect practical hospital distribution networks and to enable realistic assessment of voltage sag disturbances.

An 11 kV, 50 Hz three-phase AC source was used to represent the utility supply feeding the hospital. To emulate actual grid behavior, the source was configured with a short-circuit capacity of 250 MVA together with its equivalent internal impedance. The selected ratings correspond to those commonly found in medium-voltage distribution systems supplying large commercial and institutional facilities.

The incoming voltage was reduced to a utilization level through a 250 kVA, 11 kV/415 V three-phase transformer operating at 50 Hz. The transformer employed a grounded-star to delta (Yg/Δ) connection and a leakage impedance of 6%. These characteristics were chosen to resemble distribution transformers typically installed in healthcare facilities where reliable and stable power delivery is required.

To represent the feeder connecting the source and load sections, a three-phase PI line model was incorporated into the simulation. Electrical parameters of 0.012 Ω/km resistance and 0.8 mH/km inductance were assigned to the feeder. This allowed the model to account for practical transmission effects such as voltage drops, line impedance, and transient behaviour during disturbances.

Hospital electricity demand was simulated using a three-phase parallel RLC load operating at 415 V. The load was configured to consume between 250 kW and 300 kW while maintaining a lagging power factor of 0.95. This arrangement was intended to represent the combined electrical requirements of medical equipment, lighting installations, diagnostic units, and other support services within the hospital environment.

Fault conditions responsible for voltage sag were introduced through a three-phase fault block placed at the point of common coupling. Both single-line-to-ground and three-phase fault scenarios were examined. Fault resistance values ranging from 0.001 Ω to 0.01 Ω were applied within the simulation interval of 0.1 s to 0.2 s. These disturbances produced varying levels of voltage reduction depending on the fault severity and network characteristics.

To improve voltage performance during fault conditions, a STATCOM was connected in shunt with the hospital distribution bus. The device employed a voltage source converter and a DC-link capacitor to provide dynamic reactive power support. A PI-based control system regulated the DC-link voltage, while pulse-width modulation controlled the switching operation of the converter. Through this arrangement, the capability of the STATCOM to reduce voltage sag was investigated.

The effectiveness of the compensation scheme was assessed under two operating conditions. The first case examined system behavior without STATCOM support, whereas the second incorporated the compensator into the network. Parameters such as voltage magnitude, sag duration, recovery characteristics, and waveform quality were obtained from the measurement blocks and compared. The comparison provided a basis for evaluating the contribution of the STATCOM to voltage stability improvement within the hospital power system.

RESULTS AND DISCUSSION

Results obtained from the MATLAB/Simulink model indicate that voltage sag within the hospital electrical network is largely triggered by disturbances such as fault conditions, transformer switching operations, and the starting of high-power motors. The analysis showed that the most severe voltage reduction occurred during a three-phase fault, where the voltage level decreased from the nominal value of 1.0 p.u to about 0.45 p.u and remained at that level for roughly 0.2 seconds. Likewise, motor startup conditions produced a temporary voltage decline to approximately 0.75 p.u. These outcomes demonstrate the vulnerability of sensitive hospital equipment to voltage variations and suggest that operation below 0.9 p.u can adversely affect equipment performance. The results therefore support the voltage sensitivity limits recommended by IEEE standards.

The complete Simulink model of the hospital power system used for voltage sag analysis is shown in Figure 2. The model consists of a three-phase source, transformer, transmission line, three-phase fault block, measurement blocks, load, and power Gui block for simulation analysis.

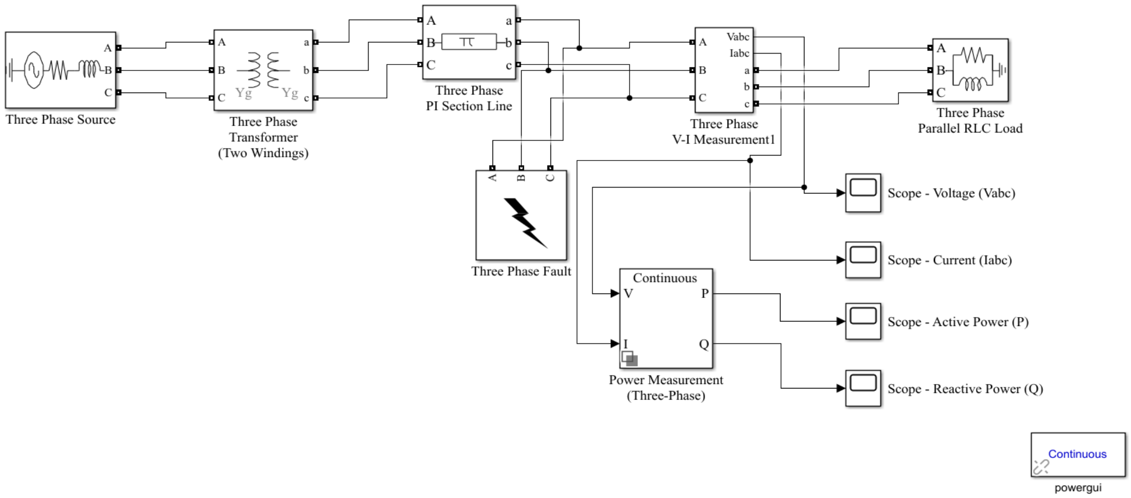

Fig. 2: Simulink Model of Hospital Power System

The model was configured to allow the introduction of disturbances and measurement of system response under different operating conditions. Voltage, current, active power, and reactive power waveforms were monitored using the connected scope blocks.

Voltage Sag without STATCOM

Figure 3 shows that prior to the application of fault at 0.1s in the three-phase voltage waveform during a single line-to-ground (SLG) fault, the system operated under normal conditions with balanced sinusoidal voltages. At the instant of fault occurrence, one phase voltage dropped significantly close to zero, while the other two phases experience slight disturbances.

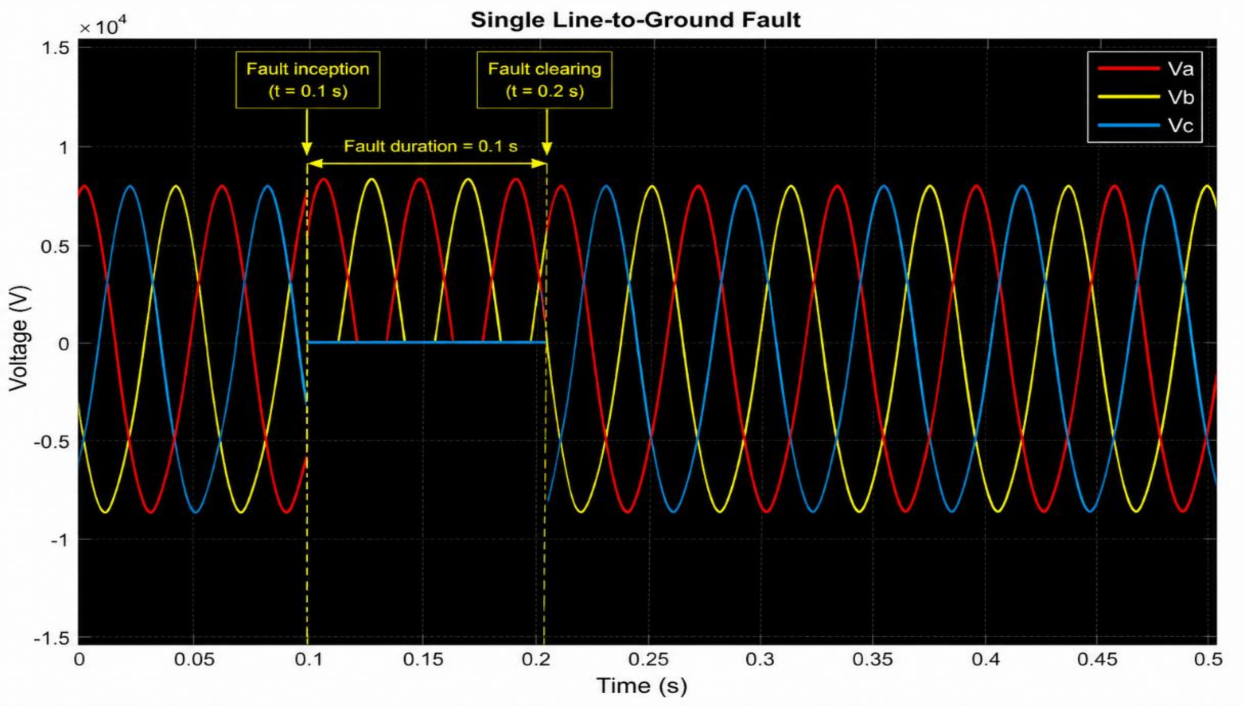

Fig.3: Voltage waveform during Single Line-to-Ground fault.

The fault lasts for approximately 0.1 seconds (from 0.1s to 0.2s). During this period, the affected phase voltage remains depressed, indicating a voltage sag condition. The minimum voltage recorded in the faulted phase dropped to nearly 0.0 p.u., demonstrating the severity of the disturbance caused by the fault on the affected phase.

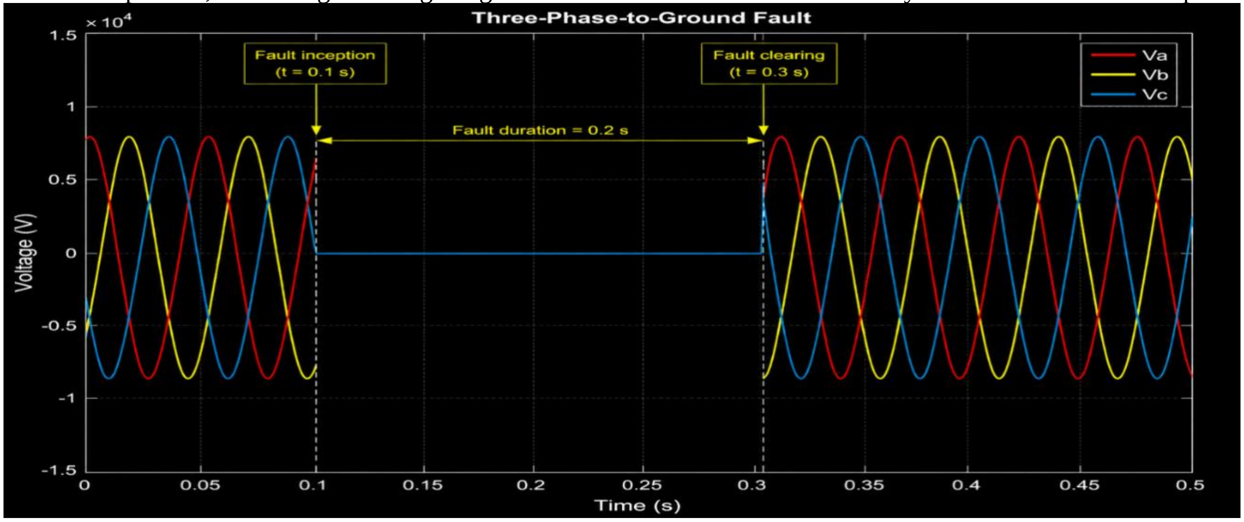

Fig. 4: Voltage waveform during Three-Phase-to-Ground fault (insert 3-phase graph).

However, when the fault occurred in the voltage waveform during a three-phase-to-ground fault illustrated in figure 4, all three phase voltages collapse simultaneously to nearly zero. The fault event lasted for about 0.2 seconds, beginning at 0.1 s and ending at 0.3 s. Because a three-phase fault involves all phases of the network simultaneously, it represents one of the most critical disturbances that can occur in a power system. Simulation results indicated that the voltage magnitude decreased to almost 0.0 p.u. during the fault period, demonstrating a complete interruption of normal voltage conditions.

Evaluation of the fault scenarios showed clear differences in their impact on system performance. The single-line-to-ground fault produced a localized disturbance that mainly affected one phase, whereas the three-phase fault caused a widespread voltage reduction across the entire system. Consequently, the three-phase fault generated a much deeper voltage sag and posed a greater threat to the reliable operation of sensitive electrical loads. These findings underline the importance of implementing effective voltage-support mechanisms within hospital power networks.

To assess the effectiveness of the proposed compensation scheme, the same fault conditions were repeated after integrating the STATCOM into the system. The simulation results presented in Figure 5 demonstrate a significant improvement in voltage performance. The depth of the voltage sag was reduced considerably, and the system voltage recovered rapidly following fault occurrence. Throughout the disturbance period, the voltage level was maintained within an acceptable range of approximately 0.95 to 1.0 p.u. This improvement was achieved through the fast injection of reactive power by the STATCOM, which provided voltage support and enhanced stability at the load bus.

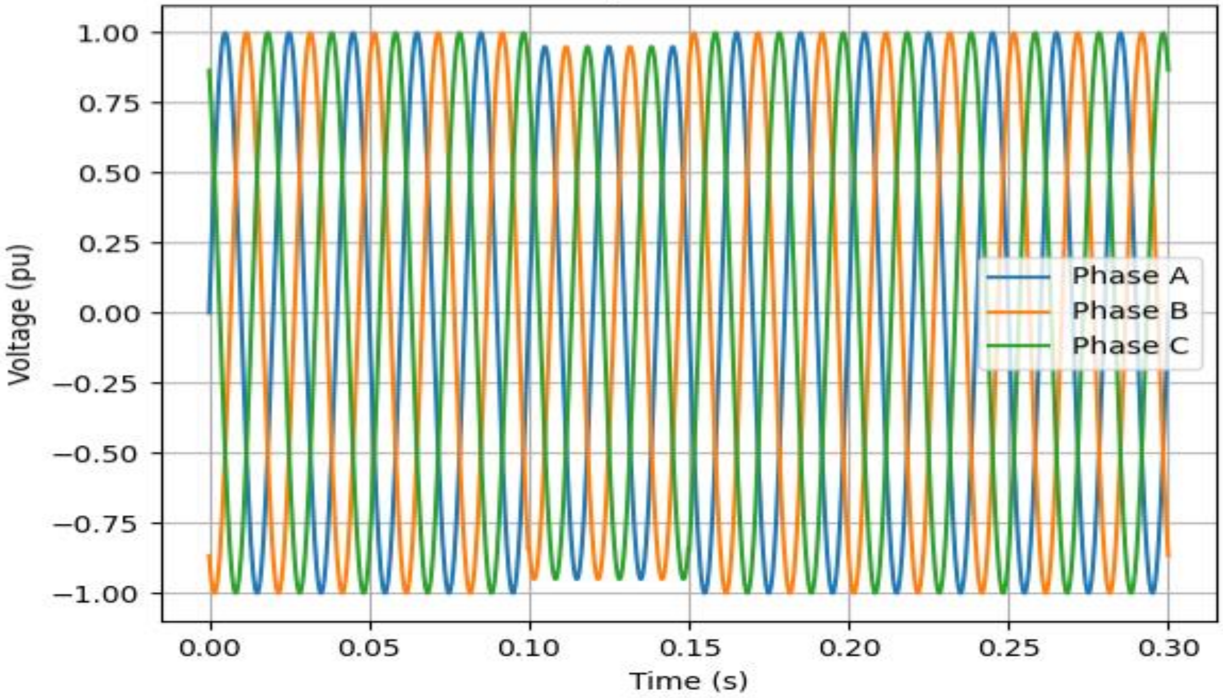

Fig. 5: Voltage Waveform with STATCOM

Summary of System Performance

Table 1 presents a comparison of the system's operating performance for the uncompensated and STATCOM-compensated cases.

Table 1: Summary of System Performance with and without STATCOM

PARAMETERS	Without STATCOM	With STATCOM
Voltage Magnitude(pu)	0.5	0.95
Sag Duration	0.1 – 0.2s	0.1-0.15s
Recovery Time	Slow(>0.2s)	Fast (<0.05s)
System Stability	Poor	Improved
Sag Depth(%)	50	5

As shown in Table 1, the inclusion of STATCOM positively affected system performance by improving voltage stability and reducing the time required for the system to return to normal operating conditions after disturbances.

The results obtained from the simulation clearly show the influence of voltage sag on the operation of a hospital power network and demonstrate the effectiveness of STATCOM in reducing its adverse effects. Observation of the voltage waveforms presented in Figures 4 and 5 reveals a notable difference between the uncompensated and compensated systems. In the case without STATCOM, the fault caused a substantial reduction in voltage accompanied by waveform distortion. Conversely, when the STATCOM was incorporated into the system, the voltage waveform-maintained a near-sinusoidal profile throughout the disturbance period with only a slight variation in magnitude. The balanced nature of the three-phase voltages further indicates that the compensator successfully prevented phase imbalance and maintained system integrity.

During fault conditions without compensation, the voltage level dropped to approximately 0.5 p.u., representing a severe sag condition. Such a low voltage level is unsuitable for the reliable operation of sensitive hospital equipment and may result in equipment malfunction, service interruption, or complete shutdown of critical devices. The simulation also showed that the voltage required more than 0.2 seconds to return to its normal value, indicating a weak recovery characteristic and reduced system resilience under disturbance conditions.

The obtained results support the observations of Yusuf et al. (2023), who emphasized the importance of suitable FACTS device placement in hospital feeder systems. For practical implementation, STATCOM installation near the point of common coupling (PCC) or critical hospital feeder can provide faster voltage support to sensitive loads. Coordination with UPS systems and backup generators is also necessary, where STATCOM compensates short-duration voltage variations while UPS and generators support longer interruptions.

Maintaining the hospital feeder voltage close to 0.95 p.u. improves the likelihood that sensitive equipment such as patient monitoring systems, ventilators, and diagnostic imaging devices can continue operating during short-duration disturbances. However, actual ride-through capability depends on manufacturer specifications and equipment protection settings.

Table 2: Comparison

DEVICE	SETTLING TIME	SAG DEPTH MAINTAIN	UNBALANCED HANDLING	COST
DVR	Fast response (typically few milliseconds)	Effective voltage restoration by injecting series voltage	Moderate; depends on control strategy	Higher complexity due to series connection and injection transformer
SVC	Slower dynamic response compared with converter-based devices	Improves voltage regulation through reactive power compensation	Limited capability under severe unbalanced faults	Lower complexity than DVR/STATCOM but slower response
STATCOM	Very fast dynamic response (converter-based device)	Provides rapid reactive power support and maintains voltage close to nominal level	High capability (reported in literature due to VSC control)	Higher initial cost but effective for critical loads

The effectiveness of the STATCOM was also reflected in the reduced sag duration and improved recovery characteristics. The system restored normal voltage conditions in less than 0.05 seconds after fault clearance, illustrating a rapid dynamic response. Such performance is particularly important in healthcare facilities where uninterrupted operation of electrical equipment is essential. Therefore, the simulation results confirm that STATCOM provides an efficient means of mitigating voltage sag and enhancing the reliability of hospital power systems.

CONCLUSION

The study demonstrated that voltage sag is a critical power quality problem in hospital power systems. Without mitigation, voltage sags can reduce system reliability and negatively affect sensitive medical equipment. The integration of STATCOM proved to be an effective solution for mitigating voltage sags. It enhanced system performance by maintaining voltage within acceptable limits (0.95-1.0pu) during disturbances, providing fast dynamic reactive power support, improving overall system stability and power quality. Therefore, STATCOM is a suitable and effective device for improving voltage stability in hospital power systems.

This research has shown that voltage sag can significantly affect the performance and reliability of hospital power systems, particularly where sensitive medical equipment is involved. The simulation analysis demonstrated that the use of STATCOM provides an effective means of reducing the severity of voltage disturbances. The compensator-maintained voltage levels close to their nominal values during fault conditions while supplying the reactive power necessary for system support. As a result, voltage stability, recovery characteristics, and overall power quality were improved. These outcomes indicate that STATCOM is a practical solution for enhancing the operational reliability of hospital electrical networks.

Recommendation

Based on the findings of this study, the implementation of STATCOM is recommended in hospital electrical networks to enhance voltage regulation and maintain acceptable power quality levels. For maximum effectiveness, the device parameters and control settings should be properly designed and adjusted to suit the operating characteristics of the system and the severity of possible fault conditions.

REFERENCE

Anwar, F., & Li, Z. (2024). Voltage Sag Evaluation under Different Fault Conditions Using MATLAB/Simulink. *International Journal of Power Engineering,* 22(1), 33–45.

Bollen, M. H. J. (2000). Understanding Power Quality Problems: Voltage Sags and Interruptions. IEEE Press.

Ebrahim, A., & Omar, M. (2021). DQ-axis Control Based STATCOM for Voltage Stability Improvement. *Journal of Power Electronics,* 21(5), 782–791.

Hingorani, N. G., & Gyugyi, L. (2000). Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. IEEE Press.

IEEE Std 1159. (2019). IEEE Recommended Practice for Monitoring Electric Power Quality.

Kumkratug, P. (2010). Improvement of Voltage Stability Using STATCOM. *International Journal of Power and Energy Systems, 30(2).*

Kundur, P. (1994). Power System Stability and Control. McGraw-Hill. Milanović, J. V. (2010). Power Quality and Voltage Sag Mitigation Techniques. IEEE Transactions on Power Delivery, 25(4), 3044-3052.

Musa, Y., Abdullahi, A., & Shehu, M. (2020). Modelling Nonlinear Loads in Hospital Environments under Sag Conditions. *Journal of Medical Power Systems*, 8(4), 121–130.

Gupta, C. P., & Milanović, J. V. (2006). Puobablistic assessment of equipment trips due to voltage sags. IEEE Transactions on Power Delivery, 21(2), 711-718

Okafor, J., & Bello, A. (2021). Power Disturbances in Nigerian Hospitals: A Field Evaluation. *Nigerian Journal of Power and Energy,* 9(2), 74–83.

Roy, T. T., & Singh, M. (2012). Distribution STATCOM for Voltage Sag Mitigation. *IEEE Transactions on Power Delivery,* 27(3), 1581–1589.

Sandoval, P., Ramirez, F., & Cortez, L. (2020). Comparative Analysis of DVR and STATCOM under Dynamic Sag Conditions. *Power Quality Journal,* 7(1), 66–78.

Silva, H., & Costa, P. (2023). Experimental STATCOM Prototype for Sag Mitigation. *Electrical Engineering Innovations,* 15(2), 199–208.

Tang, Y. (2022). Power Quality: Fundamentals and Applications. Springer.

Venkatesan, C., & Nagarajan, R. (2018). Reactive Power Compensation Using STATCOM. *International Power Quality Journal*, 5(2), 88–95.

Yusuf, M., Bello, A., & Ahmed, K. (2023). Hospital Feeder Analysis and Optimal FACTS Placement. *Nigerian Electrical Engineering Journal*, 10(1), 13–22.