International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

Novel Techniques for Sealing Leaks of Sulfur Hexafluoride (SF6) Gas: Saudi Energy (SE) Field Application

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International Journal of Science and Research Archive, 2026, 18(03), 1203-1214

Publication history: Received on 09 February 2026; revised on 16 March 2026; accepted on 18 March 2026

Article DOI: https://doi.org/10.30574/ijsra.2026.18.3.0563

Abstract

Sulphur hexafluoride (SF_6) gas is widely used in gas-insulated substations (GIS) due to its superior insulation and arc-quenching properties, particularly in medium- and high-voltage equipment. Careful use and continuous monitoring of SF_6 are essential, as gas leaks can negatively impact both equipment performance and the environment. Traditional methods for repairing gas leaks have several drawbacks, including lengthy procedures, extended equipment outages, and challenges related to the availability and cost of original parts. To address these issues, the Saudi Energy (SE), in collaboration with the Electric Power Research Institute (EPRI), applied a lab-tested, innovative sealing technique at a 380kV GIS substation in Saudi Arabia national grid. This technique is low-cost, simple, and quick to apply—while the equipment remains in service. This paper presents the novel SF_6 gas leak sealing technique and outlines the stages of its site application. The results demonstrated significant benefits, including 80% and 59% annual reductions in gas refilling quantities over two years, along with enhanced reliability, as no equipment shutdown was required for maintenance.

Keywords: Sf_6 Gas; Gas-Insulated Substation (Gis); Grid Reliability; Leakage Sealing; Online Maintenance

1. Introduction

Compact design of substations and reliable operation of their switchgear necessitate use of insulation media that is characterized by high dielectric strength and superior arc extinguishing. Compared to other insulation materials currently used in substations such as oil, SF6 gas has self-healing capability after extinguishing an arc as it rapidly recombines back into its original molecular formula [1]. The SF6 gas leakage causes pressure drop in the gas compartment and accordingly deteriorates the insulation and interruption features of the gas [2], lifetime of the equipment, reliability of system [3], compliance with the environment regulations [4], besides increase of the gas refilling costs. Assets ageing is a major contributor to SF6 leak as well as uneven tightening torque of the joint bolts, cracking of expansion joint and corrosion of aluminum shell. Figure 1 depicts break-down voltage against gas pressure. According to the latest International Electrotechnical Commission (IEC) standard IEC 62271-203:2022, the allowable leak rate for new equipment during type tests has been lowered from 0.5% to 0.1% per year for each gas compartment [5].

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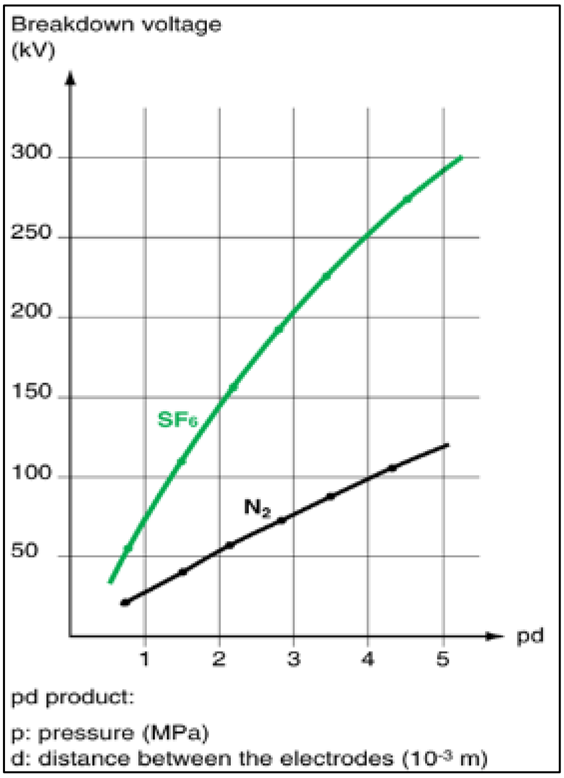


Figure 1 Break-down voltage against gas pressure [3]

It is important to highlight that SF6 gas has another downside, as it is found to be the most potent greenhouse gas known to date, and a relatively small amount of SF6 can have a significant impact on global climate change. Hence, with the widespread use of SF6 gas insulated substations (GISs) in electricity grids, electricity providers need to monitor, manage, and reduce this gas leakage.

Customary practice for SF6 gas sealing, referred to as a permanent leak fixing method, has several drawbacks and problems. It is resource consuming and comprises a long series of processes including degassing, dismantling, repairing, and re-gassing, with extended equipment outage. Besides, the original spare parts are often scarce, expensive, or simply no longer available. These difficulties have drawn the attention of electric utility companies and research institutes to explore alternative techniques for SF6 leak sealing of less burden that can ease mitigating SF6 gas leak sealing.

Various online solutions have been developed and evaluated by research institutes and energy providers, with certain approaches showing effectiveness under specific conditions such as the adhesion and diversion [6], and the sealant and clamp [7]. However, some methods are difficult to implement and require further research, such as the significant effort needed to seal with epoxy at near-zero temperatures.

A previous Saudi Energy (SE) experiment for permanent fixing of a SF6 leak by replacement of the faulty part involved long processes of coordination with manufacturer, compartment removal, replacement of the faulty part and re-installation of the compartment, SF6 de-gassing and re-filling, and performing essential electrical and leakage tests. These processes kept the equipment out of service for a period of ten days, and to avoid such cases SE screened possible alternatives sealing techniques that are simple and fast to apply, techno-economically effective, easy to remove when needed, and applicable while gas pressure maintained, and equipment in service.

SE in collaboration with the Electric Power Research Institute (EPRI) pioneered the power utilities in Middle East and North Africa (MENA) to apply a novel technique to mitigate the SF6 gas leak problem. The key objective is to evaluate the method for sealing SF6 leaks in operating equipment at full pressure, without the need to remove it from service. This paper presents the laboratory experiment, field application of a novel technique and its results, and highlights effectiveness on system reliability.

2. Materials and Methods

The methodology considered for development of the innovative leak sealing technique includes indoor and outdoor laboratory tests, and field deployment, as detailed below:

2.1. EPRI Laboratory Test

EPRI investigated effective methods for locating and repairing SF6 leaks to improve equipment reliability, reduce operating costs, and avoid adverse environmental impacts. The research effort reported here involves evaluating sealing materials and developing application techniques to repair SF6 leaks on gas-filled substation equipment.

Based on possible topologies and the criteria for materials set forth, EPRI adopted three different techniques, and tested short-listed adhesive candidates in the laboratory for these techniques to seal leaks on pipes and threaded fittings, on flanges and on threaded bolts. After lab evaluation, the novel leak sealing methods were applied using the promising sealing materials to a pressurized, out-of-service Gas Insulated Equipment (GIE) containing SF6 gas at the EPRI Charlotte laboratory [8]. The GIE represented in Figure 2 was located outdoors, exposed to direct sunlight, wind, and precipitation.

Figure 2 Outdoor Gas Insulated Equipment, EPRI GIS Lab, Charlotte, NC

Researchers created leaks on several types of GIE components with different sizes and geometries to simulate various real-world leak conditions and sealing challenges. Figure 3 presents procedure that had been followed in the lab for performance evaluation for each of the novel sealing techniques.

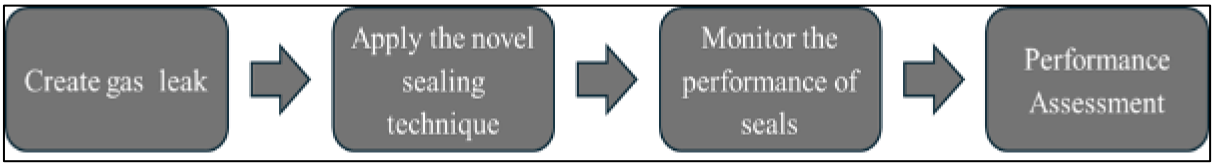


Figure 3 Novel Sealing Techniques Lab Evaluation Procedure

2.2. The leak types and topologies included

Leaks on pipes and threaded fittings: A sealing approach that involves silicone putty and an adhesive-free silicone compression tape was investigated. As shown in Figure 4, the silicone putty was applied directly over the leaking area and many compressive wraps of the tape were used. Application of more wraps increased the compressive force, eventually sealing the leak.

Figure 4 Leaking Threaded Fitting Sealed Using Tape and Putty

Leaks on flanges: The technique of putty and tape shown in Figure 5 was applied to seal the O-ring leak from the flange interface with sealing washers on the bolts to stop the leak spreading. Leaks were not detected on the O-ring but were detected on some close bolts. Sealing that bolts' leaks using the adhesive and vent pipe technique, caused leaks to shift to next weak points.

Figure 5 Leaking Flange O-ring Sealed Using Tape and Putty

Leaks on threaded bolts: The approach for sealing the threaded bolt leak shown in Figure 6 involves directing the leaking gas through a perforated tube wrapped around the leaking area, covering the area with epoxy adhesive and then, once the adhesive has cured, capping the tube to seal the escaping gas.

Figure 6 Leaking Bolt Sealed Using Adhesive and Vent Pipe

2.3. Saudi Energy Experimental Field Trial

Since SF6 gas leakage poses a challenge for power utilities worldwide, SE, like other utilities, is seeking new, effective, and simple techniques to seal these leaks as alternatives to conventional GIS leak sealing methods.

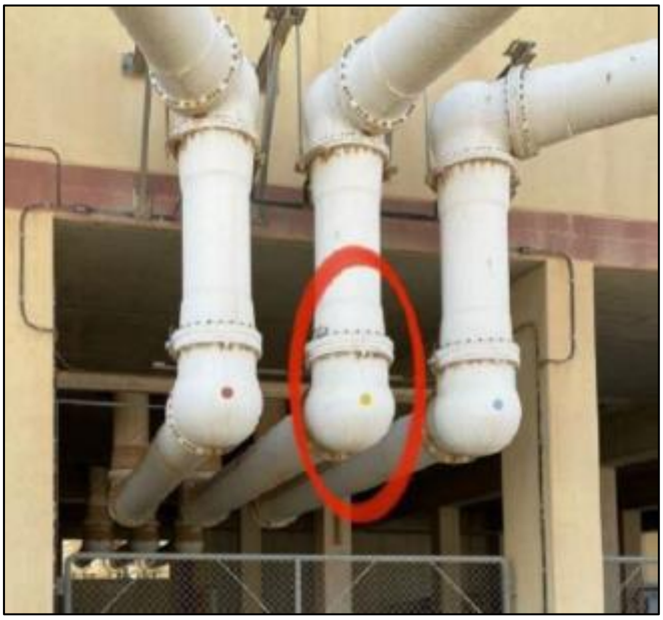
SE and some other power utilities around the world participated with EPRI to assess effectiveness, durability, use of readily available materials, and ease of application of the novel leak sealing techniques. Figure 7 presents 8 global sites where these techniques are installed and one upcoming site, and Table 1 summarizes the leak location, sealing method, applying date and status of the seal in each.

Figure 7 Selected Sites for Novel Sealing Techniques

Table 1 Global Experience from Ongoing Field Trials

	Leak Location	Sealing Method	Seal Applied On	Status and Age of Seal
1	Damaged O-ring in a 138kV disconnect switch flange	Adhesive and Vent Pipe	Sealing successfully completed in November 2019	First leak reported after 4 months Repaired leaking seal Repaired seal leaked after 6 months
2	Leak from monitoring port on the flange interface in SF6 filled current transformer	Metal Patch and Adapter	Sealing successfully completed in January 2021	3 years 7 months Monitoring performance
3	Leak from monitoring port on the flange interface in GIS bus	Metal Patch and Adapter	Sealing successfully completed in January 2021	2 years 8 months Monitoring performance
4	Leak from damaged O-ring at the interrupter end of a 121kV dead tank circuit breaker	Adhesive and Vent Pipe	Sealing successfully completed in November 2022	Monitored seal for 7 months. In place when experiment was stopped.
5	Leak from damaged O-ring at the interrupter end of a 230kV live tank circuit breaker	Adhesive and Vent Pipe	Sealing successfully completed in January 2023	Monitored seal for 4 months. Seal still in place when breaker was decommissioned in April 2023.
6	Leak from damaged O-ring at the interrupter end of a 132kV live tank circuit breaker	Adhesive and vent pipe	Seals applied with partial success in October 2023	8 months Monitoring performance
7	GIS Pipework and Valves	Tape and Putty; Adhesive and Vent Pipe	Sealing successfully completed in December 2023	8 months Monitoring performance
8	Glass in inspection window of 11kV busbar selector	Adhesive and Vent Pipe	Sealing successfully completed in December 2023	8 months Monitoring performance

For SE experimental field trial, the leak sealing was applied on a bus at 380 kV GIS substation in Saudi Arabia national grid where the exact location was the partial discharge sensor slot on one of the flanges on the gas insulated bus. Figure 8 (a) and (b) show pictures of the gas insulated bus, and the specific leak location, respectively.



(a)

(b)

Figure 8 (a) GIS 380 kV Bus and (b) Leak Location

Considering the leak topology and recommendations drawn from the lab trials, it was determined to use a custom prepared patch which consisted of stainless-steel shim stock, perforated with a threaded sealing adaptor as shown in Figure 9. The patch was fitted to the leak area and fixed using an adhesive, and the adapter was closed after curing.

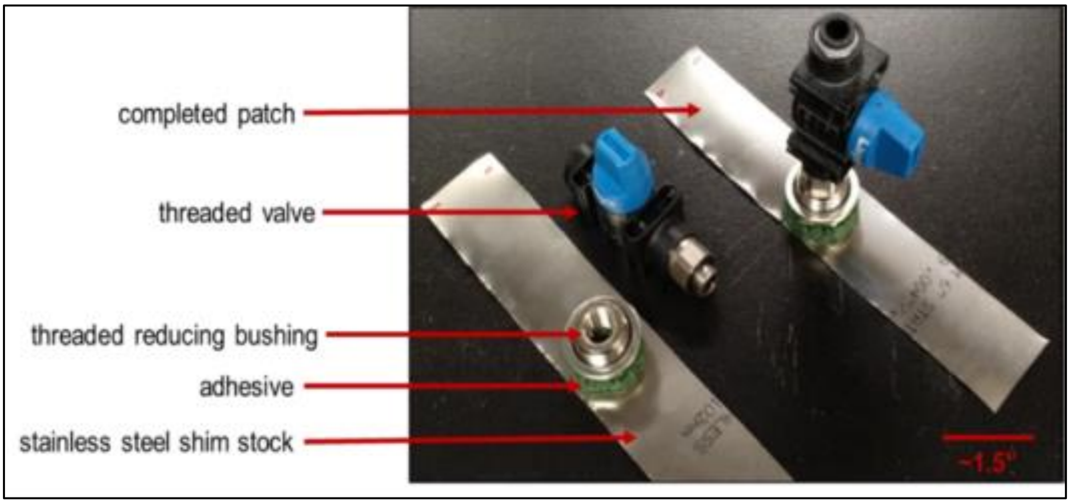
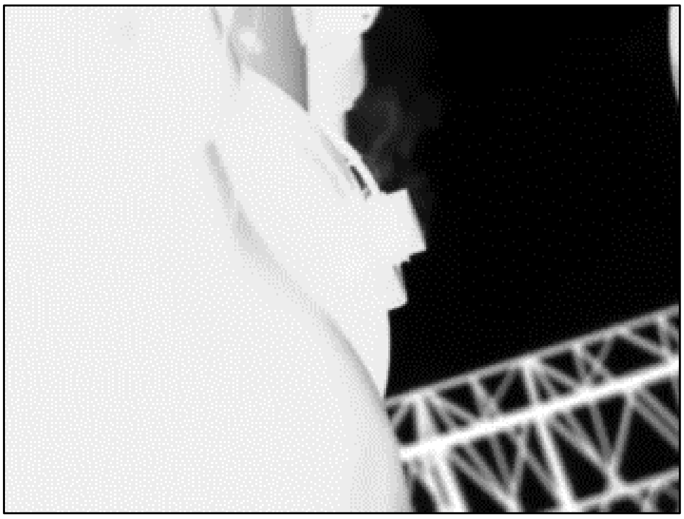


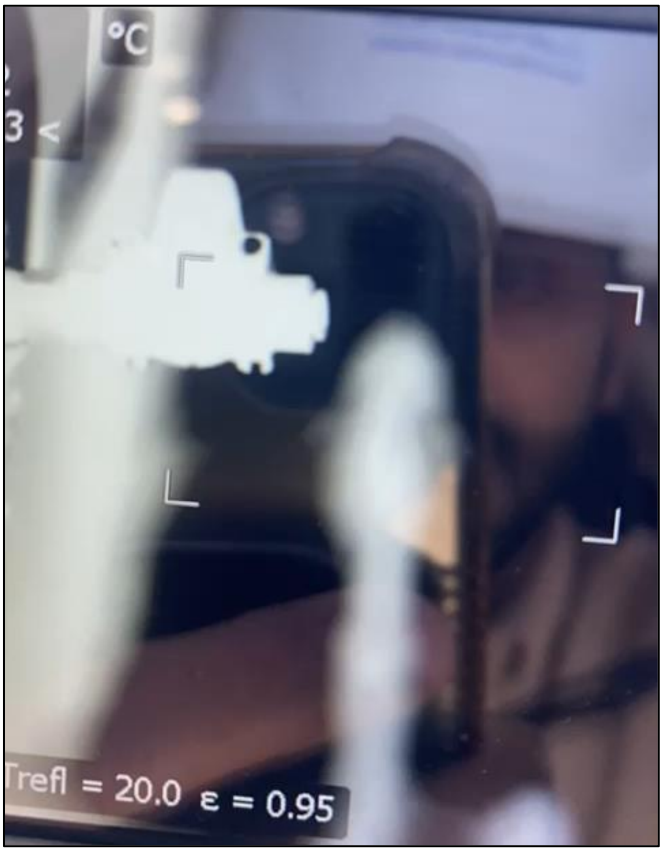
Figure 9 Preassembled Patch with Sealing Adaptor/Valve

Figure 10 shows the leak location after the patch and adhesive application was complete and Figure 11 (a) and (b) show SF6 camera recording before and after leak seal application, respectively.

Figure 10 Leak Seal Using Patch and Adhesive



(a)



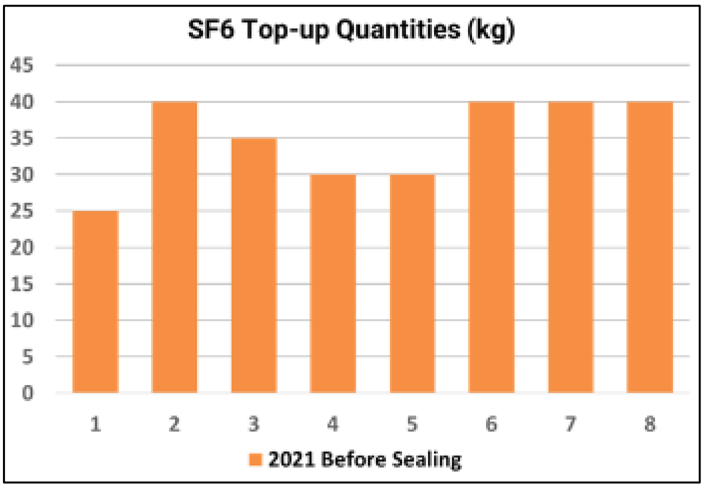
(b)

Figure 11 SF6 Camera Recording (a) before and (b) after leak seal application

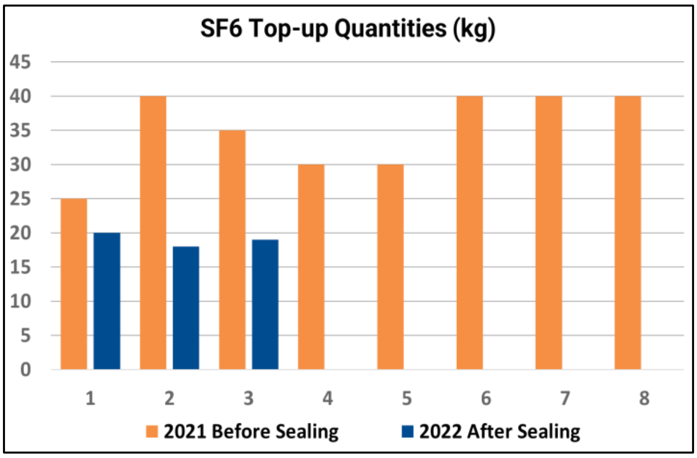
To assess the performance of the innovative technique, the annual gas refilling quantities pre and post application of sealing were measured and compared.

3. SE Field Experimental Results and Discussion

Figure 12 shows SF6 gas top-up frequency and quantities, one year before leak sealing, and first two years after leak sealing. Figure 13 shows annual SF6 Top-up requirements and percentage savings before and after leak sealing for the same years. Comparing top-up frequency and quantities of Figure 12, and annual top-up requirements and percentage savings before and after leak sealing prove that application of the innovative leak sealing technique at SE substation significantly reduced the gas refilling requirement.



(a)



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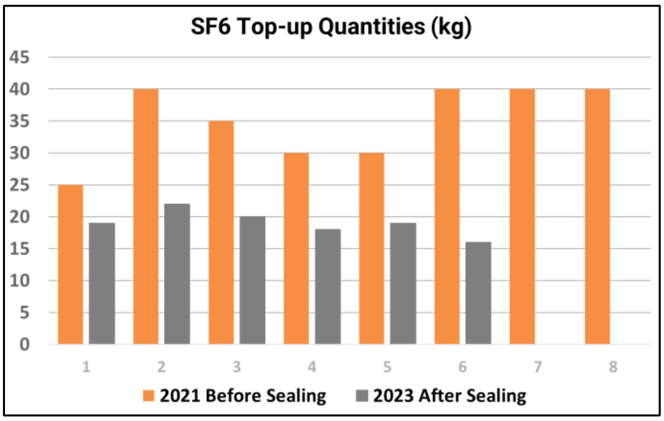

(c)

Figure 12 Annual SF6 Top-up Quantities Before and After Leak Sealing

It is obvious from Figure 12 (a) that, in the year preceding application of the innovative technique, gas refilling was necessary 8 times a year, with least top-up quantity of 25 kg. Figure 12 (b) depicts that, during the first year next to application of the technique, gas refilling frequency dropped to only 3 times with greatest top-up quantity of 20 kg. Figure 12 (c) reveals that, during the second year, gas refilling frequency was 6 times with greatest top-up quantity of 22 kg.

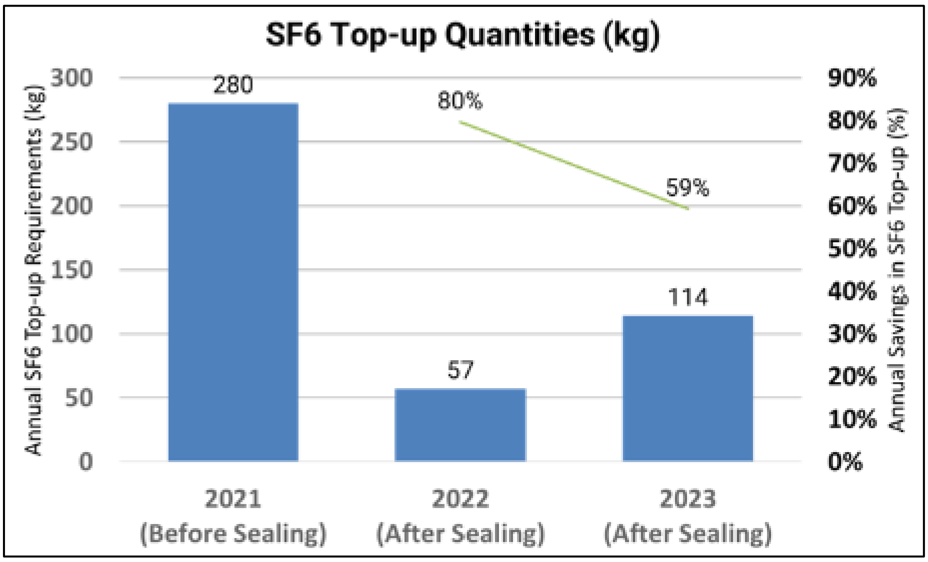

Figure 13 Annual SF6 Top-up Requirements and Percentage Savings Before and After Leak Sealing

It is seen on Figure 13 that, while it was necessary to refill with a quantity of 280 kg in the year preceding application of innovative sealing, this figure dropped to only 57 kg in the first year, and 114 kg in the second year next to sealing. Accordingly, benefits of the innovative leak sealing technique are reflected in 80% and 59% savings in the refilling gas quantities during the first and second years next to application and reducing the number of refilling processes per year.

Regularly used permanent SF6 leak repair techniques typically require significant resources and time, involving lengthy procedures and necessitating a power outage of the affected equipment for an extended duration. In its pursuit of innovative solutions, the Saudi Energy (SE), in collaboration with the Electric Power Research Institute (EPRI), evaluated alternative sealing techniques that are:

- Simple and quick to apply
- Techno-economically effective
- Easily removable when needed
- Applicable while maintaining gas pressure and keeping equipment in service

An EPRI-developed leak sealing technique, tested in laboratory conditions and exhibited superior features, was successfully applied to seal a gas leak at a 380kV GIS substation in the Saudi Arabian national grid. The results presented in this paper confirm the effectiveness of the technique, demonstrating gas refilling savings of 80% and 59% in the two years following its application.

This innovative approach defers the need for an immediate outage, providing a sufficient time window to plan for permanent leak repair. Moreover, the technique can be re-applied for an additional two years while maintaining its performance and reliability.

4. Conclusion

The findings of this study demonstrate that the innovative leak-sealing of SF_6 technique, developed through SE–EPRI collaboration and validated via laboratory and field trials, offers an effective, fast, and reliable alternative to conventional repairs, cutting annual gas refilling needs by 80% and 59% in the first two years. By enabling sealing while equipment remains energized, it reduces downtime, lowers maintenance costs, and improves grid reliability. Its simplicity and removability make it a practical solution for utilities aiming to reduce SF_6 emissions, ultimately supporting a more sustainable power sector and paving the way for broader adoption of environmentally beneficial online maintenance technologies.

Compliance with ethical standards

Acknowledgments

The authors gratefully acknowledge the support received from the Transmission and Distribution Research Division and the Research and Development Department of the Saudi Energy (SE), and the Electric Power Research Institute (EPRI).

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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Author short biography

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	Eng. Rayan Mohammed Hawsawi earned his bachelor's degree in electrical engineering, Power and Machine, from King Abdul Aziz University (2008), and his Master's degree in FINTECH from Midocean University (2025). Eng. Hawsawi served as Project Engineer at the PTD Project Department with SIEMENS LTD, Saudi Arabia from 2009 to 2012, and then as Project Manager at the EHV Project Department, Saudi Energy from 2012 to 2020, and he is currently Research and Development Engineer with the Saudi Electric Company since 2020.