Refining Single Leg Philosophy in Jafurah Gas Plant [1]

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ABSTRACT

Jafurah Gas Plant is the first Unconventional Gas Plant in the Kingdom of Saudi Arabia. The plant consists of various components, including Gas Inlet, Condensate Stabilization, Acid Gas Removal Unit, Dehydration Unit, Natural Gas Liquid (NGL) and Sales Gas Compressors. The project aims to identify and mitigate single point of failures in order to prevent interruptions to production. Risks were identified based on different categories including mechanical, partial air, electrical and fire failures; for instance, failures on the Sales Gas, Condensate, and NGL common headers, HP Fuel Gas Line failures, Flare main header failures, cooling water supply and return failures as well as Switchgears failures. The single point of failures (SPF) was developed in considerations of: design constraints, equipment redundancy, and Load Distribution among several Motor Control Centers (MCC).

To mitigate such risks, Jafurah Gas Plant has modified the instrument air system, added piping and isolation valves, and segregated air supply isolation valves from the main instrument air distribution headers. Moreover, the plant has implemented fire suppression measure to prevent pressure indications failures and ensure safety of the facility. The plant's safety measures aim to minimize the impact of these failures on the plant operations.

Keywords: *Design Improvement, Gas Trains Design, Project Management, Gas Plant Efficiency*

INTRODUCTION

Single point of failure is defined as any system failure that would cause the entire system to fail which can lead to 100% production losses. Jafurah Gas Plant program is the first unconventional gas in the Kingdom of Saudi Arabia that constructed to produce, process and transport gas to satisfied the In-kingdom energy demand. Jafurah Gas Processing Train Facility consists of Gas Inlet, Condensate Stabilization, Acid Gas Removal Unit, Dehydration Unit, Natural Gas Liquid (NGL) as well as Sales Gas Compressors. The

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Jafurah Gas Plant project conducted a study to identify all the Single Point of Failures (SPF), to ensure no effect or interruption to the Plant production.

The main purpose of the identification of these points is to identify potential failures and its impact in order to reduce and eliminate the possible risks. This will maintain the Operational continuity and contribute to the business sustainability.

LITERATURE REVIEW

The concept of a Single Point of Failure (SPF) is central to risk management in industrial and energy systems. Defined as a failure in one component that halts entire system functionality, an SPF in an unconventional gas plant, including dehydration units, casing systems, and processing facilities, can lead to catastrophic outcomes ranging from production interruptions to environmental hazards and regulatory non-compliance. This review explores existing research on SPF vulnerabilities, with emphasis on unconventional gas plants. It synthesizes findings across well integrity, surface systems, and risk analysis methodologies.

a) Well Integrity & Subsurface SPF

Well integrity, particularly in unconventional gas, remains the most critical SPF factor. Michanowicz et al. (2017) investigated the Aliso Canyon blowout, attributing its cause to repurposed wells lacking proper barrier redundancy—specifically, a casing design that left a single vulnerable failure point. Their national analysis revealed that 2,715 active underground storage wells shared this risky design, mostly built prior to 1979, and were highly susceptible to SPF failure.

Their work laid the foundation for regulatory recommendations, urging operators to phase out such well configurations. These outdated wells, rich in SPF potential, underscore the systemic risk in reusing legacy infrastructure. Complementary research on wellbore integrity (Wood, 2024) details casing, cement sheath, and barrier failures as critical SPF contributors under stress cycles. The convergence of these findings suggests SPF mitigation must start below ground.

b) Surface Process Systems & Operational SPF

Above-ground systems also carry significant SPF risks. Chiodo & Lauria (2015) analyzed a failed gas-dehydration unit, where blockage from formed hydrates cascaded to shutdowns—highlighting how a single subsystem can cripple entire processing chains.

Similarly, Vicente (2012) developed cost-overview models demonstrating how Mean Time to Failure (MTTF) and repair times (MTTR) quantitatively pinpoint SPF in gas plants.

These systems are especially critical in unconventional gas plants, with their higher operational pressures and variable feed gas compositions. The lessons from these studies underscore that redundancy and maintenance protocols must extend beyond wells into dehydration, compression, and flare units to safeguard against SPFs.

c) Risk Assessment Methodologies

Evaluating SPF vulnerabilities demands robust methodologies. Failure Mode and Effects Analysis (FMEA) is widely used in petroleum engineering to prioritize risks. While conventional FMEA assigns Risk Priority Numbers (RPNs), new hybrid approaches promise improved clarity in identifying cascading SPFs.

Likewise, Vicente (2012) advocates for Reliability-Centered Maintenance (RCM), embedding MTTF and MTTR into risk models. However, despite their conceptual rigor, methodological gaps remain in integrating subsurface well failures with operational SPF in a unified risk framework.

d) Environmental & Health Impacts as SPF Outcomes

SPF events are not only operational concerns—they can trigger significant environmental and health crises. Aliso Canyon released ~0.1 million tons of methane, confirming the vast consequences of an SPF. Such leaks can exacerbate air emissions -especially methane- driving both public health and regulatory scrutiny.

Furthermore, construction deficiencies, to illustrate Improper Cementing have been linked to groundwater contamination and respiratory illnesses near fracking sites. These reinforce that SPF risk management measures should anticipate not only production loss, but also multi-domain repercussions like: Public Health, Environmental, Legal, and Reputational.

e) SPF in Unconventional Gas Reservoirs

Unconventional reservoirs present unique SPF challenges. They typically rely on extensive fracturing, multiple wells, and complex surface systems. They also feature high heterogeneity in permeability and pressure. These reservoirs depend heavily on well integrity and hydraulic fracturing techniques to enable gas flow.

In this context, SPF can arise from casing failure leading to casing-cement-channel formation, loss of isolation zones, or unexpected pressure interactions. Michanowicz's findings are especially pertinent: subsurface SPFs in deeper wells or shallow casing failures can propagate through connected fracture networks.

f) Induced Seismicity & SPF

Seismic events, sometimes unrecognized as failure precursors, are emerging SPF risks in underground gas storage. European case studies indicate that injection operations can induce seismicity above felt levels (up to magnitude 4.3), triggering shutdowns and regulatory intervention. Spain's Castor project, once shuttered due to seismic events, illustrates how an induced seismic event can collapse entire storage operations; demonstrating another form of SPF.

g) Integrated Energy Systems & Cascading SPF

Modern energy systems increasingly couple gas with electric infrastructure. A breach or failure in gas supply due to SPF can cascade, destabilizing electricity networks. Tang Y (2020) model gas leakage in pipeline-integrated systems using Markov-based risk modelling, showing how a localized failure can propagate risk across power grids.

Similarly, Chertkov M (2014) model coupling between intermittent renewables and natural gas infrastructure, revealing pressure fluctuations in pipelines during transient events; demonstrating another form of SPF risk. These studies stress the need for inter-disciplinary SPF assessments that cross energy vectors.

In short, SPF in unconventional gas plants poses multifaceted risks—from production upheavals and regulatory breaches to environmental disasters. The reviewed literature points clearly to casing integrity as a major SPF, particularly in repurposed wells, and calls for both well barrier redundancy and process-system backups. A combination of FMEA, RCM, monitoring tools, and cross-domain risk models is needed. To truly fortify unconventional gas operations, future frameworks must unify subsurface and surface together, embed environmental and systemic risk, and anticipate cascading energy-sector impacts.

SINGLE POINT OF FAILURE EVALUATED RISKS

In Jafurah Gas Processing Trains, any failure on the Sales Gas, Condensate and NGL common headers connected to the export pipeline, as well as Gas/Condensate lines, will lead the Operator to close the relevant isolation valves to isolate the fire zone, leading to 100% loss of production as consequence.

The failures of the HP Fuel Gas Line feeding the Cogeneration Plant, will lead to loss of plant capacity including High- and Low-Pressure Steam (HPS & LPS), which will result in 100% loss of production.

Failures on the flare main header will result in a 100% loss of plant capacity.

Failure of the cooling water supply and cooling water return will result in losing cooling water to the Sulfur Recovery Unit (SRU) and machinery cooling service. This will increase the Sulfur Dioxide SO_2 emission from the SRU, and will result in losing air compressors, which lead to 100% loss of production.

Loss of Switchgears will result in Global Power Failure (GPF) to critical Utility systems as the Substations are feeding utilities including Instrument Air (IA) and Cooling Water (CW) utilized for the SRU and machinery cooling for common utilities.

SINGLE POINT OF FAILURE RISK MITIGATION

Mechanical Failure

Failure in the main instrument air common header will lead to an instrument air total failure. Jafurah Gas Plant can continue production for twenty (20) minutes with additional time of three to four hours maximum then 100% loss of plant capacity. To mitigate such failure, Jafurah modified the instrument air system by adding some piping and isolation valves to maximize the system availability in case of piping and equipment failure.

Partial Air Failure

When a critical single point of failure occurs in the common condensate product line due to a design or installation flaw, the upstream scraper trap launcher is impeding the operation of the required isolation valves which will risk the plant safety and operations. Jafurah Gas Plant can continue production for two (2) hours. Moreover, failure on common Natural Gas Liquid (NGL) product line, the upstream scraper trap launcher is impeding the operation of the required isolation valves as well as the control valves. Jafurah can continue production for eight (8) hours until the high-high liquid level within the NGL spheres. Failures on the common sales gas product line, the upstream scraper trap launcher is impeding the operation of the required isolation valves. Jafurah Gas Plant can continue production till high-high pressure at discharge of sales gas compressors. To mitigate such failures, Jafurah Gas Plant segregate air supply isolation valves from the main instrument air distribution headers.

Air failures will automatically close the isolation valves on the gas manifold to each gas train. Jafurah Gas Plant located each valve within the gas train close to inlet condensate separator and connecting it to an instrument air header independent from the other one.

Fire Failure

Loss of pressure indication transmitters on the common discharge header of the product storage and export of the ethane and natural gas liquids will lead to closure of the isolation valves and shut down the NGL export pumps which will result to 100% loss of ethane and NGL productions. Jafurah Gas Plant provided additional set of transmitters that assigned to the second risk area with the export area control system and each transmitter will act on one parallel isolation valves.

Recommendations

Several key practices emerge to mitigate SPF in unconventional gas plants, such as:

1. Eliminate repurposed well designs lacking redundant barriers, as per Michanowicz's regulatory recommendations.
2. Adopt FMEA and RCM strategies in surface units, identifying MTTF and MTTR bottlenecks.
3. Monitor subsurface integrity rigorously, employing casing-cement logging, pressure testing, and seismic sensing to detect early failures.
4. Design for redundancy in Dehydration and Compression Units, ensuring parallel capacity and bypass options to avoid single-point outages.
5. Embed systemic risk models at the energy-vector level, evaluating how gas system SPFs can cascade into grids.
6. Incorporate environmental externalities into failure planning, recognizing that SPFs can precipitate health crises and methane leaks.

CONCLUSION

Jafurah Gas Plant is the Kingdom first Unconventional Gas which includes Gas Inlet, Condensate Stabilization, Acid Gas Removal Unit, Dehydration, Natural Gas Liquids (NGL), and Sales Gas Compressors. The main goals are to find and fix any single points of failure that could stop productions. Some of the key risks include failures in the Sales Gas, Condensate, and NGL headers, cooling water system and electrical Switchgears.

To eliminate these risks, the Plant has made improvements, like enhancing the instrument air system, adding extra piping and isolation valves, and separating air supply valves from the main air distribution lines. Fire suppression systems have also been fixed to avoid pressure failures and improve safety. These actions help sustain the plant running smoothly and safely, even if operational interruption occurred.

Gaps & Future Research Directions

Despite the progress, notable gaps remain:

- Unified SPF frameworks covering both subsurface and surface systems are rare.
- Real-time monitoring tools that integrate well integrity, seismicity, and process data remain an open area.
- Economic-spill modeling of SPF that quantifies environmental and social costs in production risk frameworks is underdeveloped.
- Cross-sector SPF risk integration, especially involving gas-electric coupling, is nascent but increasingly relevant.

Future studies should aim to develop holistic SPF risk tools that consider:

- Barrier redundancies in casing and cement.
- Equipment network dependencies in plants.
- Environmental thresholds and health triggers.
- Energy-system interdependencies and cascading failure dynamics.

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Saad A. Al-Wahaib, a Senior Project Engineer with over 13 years of professional experience in the oil and gas sector specifically in project management across various project phases from detailed engineering to construction in both greenfield mega-projects and brownfield projects. Saad obtained B.S. in Mechanical Engineering from California State University, Long Beach (CSULB) in 2011 and a Master of Engineering in Construction Engineering and Management from King Fahd University of Petroleum and Minerals (KFUPM) in 2024. He is a certified Project Management Professional (PMP) with proven expertise in delivering complex projects in multidisciplinary skills and driving excellence in high-impact project environment. He can be contacted at saad.wahaib@aramco.com

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Abdullah F. Al-Baroot, a Supervisor Project Engineer with background of Chemical Engineering Science, graduated from King Fahd University of Petroleum and Minerals (KFUPM) in 2008. Since joining the energy industry in 2009, he has accumulated 15 years of extensive experience in the oil and gas sector. Currently, He is involved in the Jafurah gas plant development, where he has applied expertise to drive innovative solutions and contribute to the development of this significant project. His passion for engineering and commitment to excellence continue to fuel his journey in the energy sector.

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Saud A. Al-Qurashi, a Project Engineer working at Saudi Aramco, holding a degree from King Abdulaziz University (KAU) in Industrial Engineering Science (2022). He currently plays a pivotal role in the Jafurah Gas Program, where he leads the construction and commissioning of the Dehydration Unit and Utilities Systems. Saud has successfully managed multidisciplinary contractors and sub-contractors, spearheaded interface management across multiple EPCs. Saud's career reflects a commitment to innovation, accelerated learning, and delivering value in complex projects. Beyond technical expertise, Saud is recognized for his strong communication and leadership skills, demonstrated by his success in forums such as the Toastmasters PM Club. His contributions to Jafurah directly support Saudi Arabia's strategic objectives in energy diversification and sustainability, reinforcing his role as a promising leader in the Kingdom's Energy sector.