

VANESSA TRIPLE OFFSET VALVES OFFER ADVANTAGES IN CRITICAL EMERGENCY SYSTEMS

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Liquid hydrocarbon storage facilities have used Triple Offset Valves (TOVs) in traditional tank farm applications for decades. Due to more stringent Health, Safety & Environmental (HSE) requirements, tank farm operators are now selecting TOVs for critical emergency systems as well, in particular, as first tank-body valves. The main drivers supporting the use of TOVs in tank farms include a growing need to reassess emergency valve risks and identifying alternative solutions to traditional gate, plug and ball valves.

INTRODUCTION. Over the past four decades, TOVs have gained popularity in tank farms due to their ability to perform bidirectional zero leakage after several operational cycles, a ground-breaking innovation for the industry.^[1] Many technical variations of the basic TOV design are available, including the use of removable seats and soft sealing components. Metal-to-metal TOVs are known to ensure extremely long Mean Time Between Failure (MTBF) due to their non-rubbing qualities. Operators can therefore eliminate the need for scheduled maintenance (only re-tightening of the packing may be necessary), thus reducing total costs over the lifecycle of the valve. Metal-to-metal TOVs were first adopted in the 1980s to isolate hydrocarbon storage tanks, and were used as fire-safe shut-off valves, i.e. capable of maintaining a leak-proof seal under anticipated fire exposure. Compared to traditional gate isolation valves, TOVs feature optimized seating angles that minimize the risk of jamming; the absence of body cavities prevents the risk of reduced operability (and possible leakage) and minimizes medium contamination. Sometimes confused with butterfly utility valves, TOVs are true process valves with an extremely compact design. They are easy to operate due to the quarter-turn rotation and have often been adopted for the isolation of matrix manifolds and pump areas (**FIG. 1**) instead of ball and plug valves. In addition, TOVs can be used as general shut-off/on-off valves to provide the flow logic by selecting one flow path vs. another and to connect external equipment to the system.

NEW TRENDS. Critical developments in the management of safety integrity, in response to several serious accidents, have triggered a search for more reliable valve solutions. Automated TOVs are capable of achieving the Safety Integrity Level (SIL) 3 according to safety standard IEC 61508, and they are increasingly selected to handle several functions within emergency systems:

- Emergency valves on storage tank inlets and outlets. As illustrated in **FIG. 2**, TOVs provide the rapid isolation of the vessel in response to an emergency signal. These Emergency ShutDown valves (ESDs) are also called Remotely Operated Shut-Off Valves (ROSOVs). They are designed, installed and maintained for the primary purpose of achieving rapid isolation of tanks containing hazardous substances, in the event of a failure of the primary containment system including leaks from pipework, flanges and pump seals.^[1] This occurs independently from the functioning of second tank-body valves, that are usually controlled under the standard tank operating system. Being automated valves, ESD valves are operated remotely and respond to predetermined "emergency close" safety logic parameters.
- Emergency valves on storage tank overflow lines. As shown in **FIG. 3**, the ESD function can also be performed on the overflow line (whenever present), which is responsible for the discharge of excessive product to prevent an overfill event. Often used as an "emergency open" process function, these valves recirculate the extra product, thus fulfilling a key safety function. Several recently recorded accidents in tank farms involved vessel overfilling.^[2] The adoption of TOVs in storage-tank safety systems is driven by basic design principles applied to emergency valves, and the resulting intrinsic advantages.



FIG. 1 - Example of TOVs installed in tank farm applications for liquid hydrocarbon services

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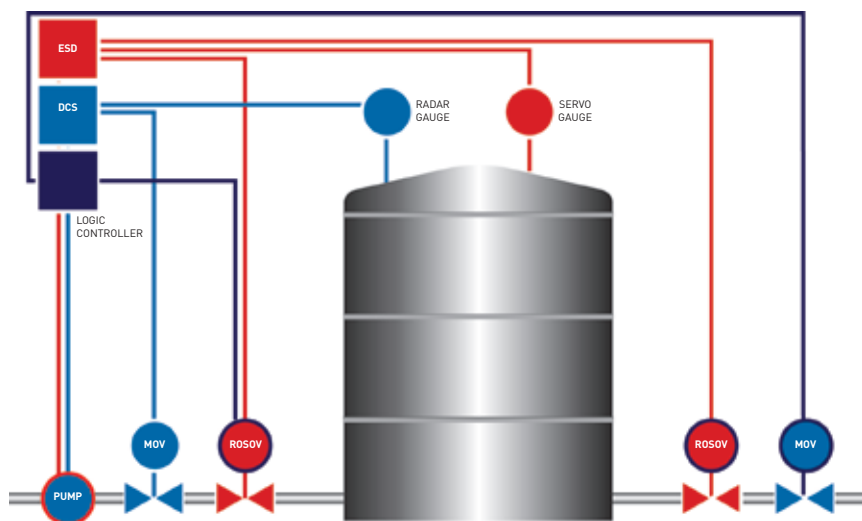


FIG. 2 - Emergency valves installed on storage-tank inlet and outlet

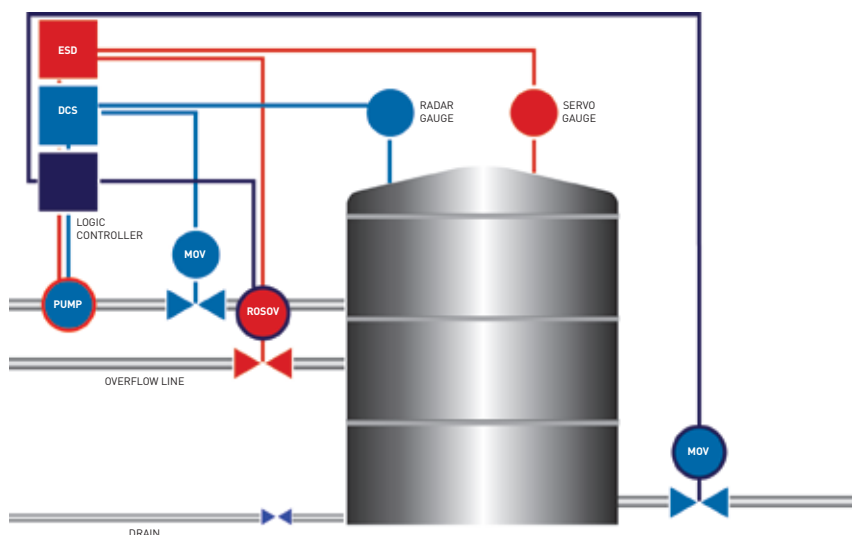


FIG. 3 - Emergency valves installed on storage-tank overflow line

METHODOLOGY. The first main distinction when storing a wide variety of liquid hydrocarbons involves working temperatures. Indeed, it is always safer to handle hydrocarbons at ambient temperatures. The examples will focus on the ambient conditions as defined by three sub-categories based on tank structural architecture:^[3]

1. **Fixed-roof and conical-roof tanks** are made of a vertical cylinder side and feature a fixed cone-shaped roof welded to each other. They typically contain heavy products, such as fuel oils, asphalt, and vacuum or atmospheric residue.
2. **Open-top floating-roof tanks** are made of a vertical, cylindrical aboveground shell similar to the previous category but with a pontoon-type roof. Such roofs will rise and fall on the stored fuel surface to minimize fuel/vapor emissions.

3. **Internal floating-roof storage tanks** are a combination of the two previous types and consist of a conical floating roof that floats directly on the fuel surface. This design decreases the potential of ignition and helps to prevent fires.

The SIL level requirements for tank farms are established based on the risks posed to people and the environment. In particular, they must take into consideration the distance from the facilities to highly populated areas, piping efficiency and codes. The second and third tank sub-categories are typically used for more volatile (higher-risk) liquid hydrocarbons such as crude oil and lighter products including jet fuel, diesel and gasoline. The analysis of TOV adoption on ESD systems will focus on these two architecture types.

ANALYSIS. Protective services are often associated with two main valve safety functions:

- Valve close - to intercept a flow/pressure source
- Valve open - to release a flow/pressure source

Usually, valve safety functions involve two clearly defined parameters: a flow/pressure direction and a differential pressure (ΔP) when the valve is closed and sealed. The basic approach to handling such functions is to adopt single-direction self-operated valves, such as check or pressure relief valves. The symmetric valve design, mechanical springs, gravity and weights perform the opening and closing of the valve and it is the most immediate solution as it responds to predetermined ΔP variations with a single flow direction.

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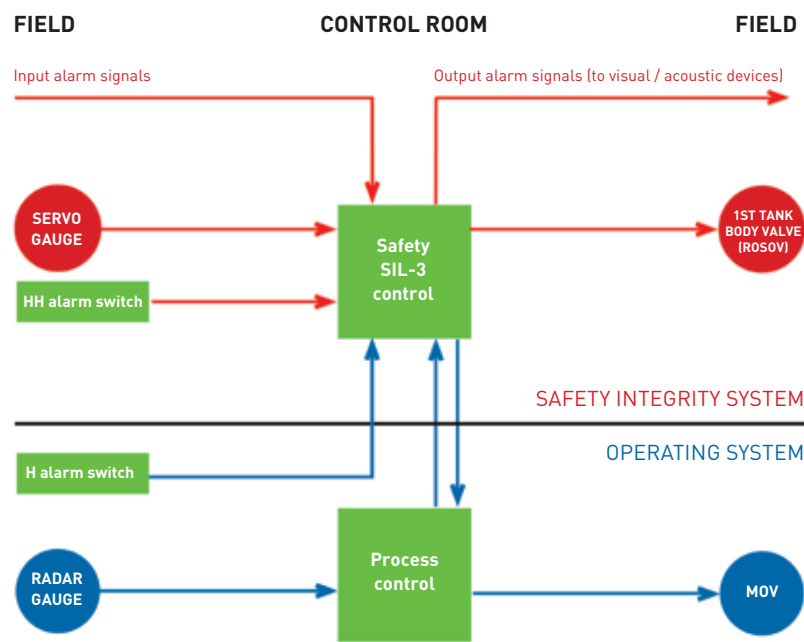


FIG. 4 - Typical SIL-3 architecture and control system

Although this rationale is applied to several applications, the main tank-safety valve functions are too critical to purely rely on such basic principles. The ESD on inlet and outlet lines (emergency close), and on overflow line (emergency open) functions have been historically handled by other valves, primarily automated gate, plug and ball valves. Gate, plug and ball valves have symmetric designs with respect to the pipe axis, and, therefore, their behavior is independent from flow direction and ΔP . Although this can be considered an advantage in terms of simplification of the installation procedure and actuator selection as the flow/pressure direction is irrelevant, they do not intrinsically support a specific safety function. As a consequence, they require higher contribution from the actuation to be moved from their "stable" and "balanced" operating conditions.

COMPLYING WITH SIL 3. To increase the safety and reliability of the end user's production facilities, the safety standard IEC 61508 has identified four different SILs, which are defined by applying risk assessment criteria in various areas - personnel, environmental, production and equipment. Two critical aspects of the valve's performance are usually assessed:

- The failure rate of the valve to deliver full stroke
- The failure rate of the valve to deliver tight shut-off

The required SILs in liquid hydrocarbon storage tanks have been increasing and can reach SIL-3 compliance (FIG.4).

Frequently, the first tank-body valves must also fall within the same PFD limits, as shown in TABLE 1.

Top-range quarter-turn non-rubbing torque seated metal-to-metal TOV design can achieve SIL-3 due to inherent design features. Similarly to a globe valve, TOVs use a sealing system consisting of a stationary seat and a rotating sealing surface sharing an identical conic section shape. However, utilizing a rotational movement instead of an axial movement, TOVs rely on the cones with an inclined apex, offset in respect to the pipe axis to achieve shutoff.

This makes TOVs a "quarter-turn globe valve," as illustrated in FIG. 5.^[4] As in a globe valve design, TOVs provide closing with no rubbing, thanks to a single, instantaneous contact between sealing elements only when closed position is reached. However, unlike globe valves, TOVs are bidirectional valves and are capable of full shut-off. This is achieved due to three "offsets":

1. The shaft is placed behind the plane of the sealing surface.
2. The shaft is placed to one side of the pipe/valve centerline.
3. The seat and seal cone centerlines are inclined with respect to the pipe/valve centerline.

The asymmetric design of the valve prompts an asymmetric behavior: depending on the flow direction, shaft side or disc side, the valve will tend to close or open. This means that, when ΔP is acting on the shaft side, it generates a torque that is acting to keep the valve closed. Conversely, when ΔP is acting on the disc side, the valve will tend to open (FIG. 6).

TABLE 1 - Probability of failure for various SILs

SIL	PFD
4	$\geq 10^{-5}$ to $\leq 10^{-4}$
3	$\geq 10^{-4}$ to $\leq 10^{-3}$
2	$\geq 10^{-3}$ to $\leq 10^{-2}$
1	$\geq 10^{-2}$ to $\leq 10^{-1}$

IEC 61508-1, par. 7.62.9

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Due to the asymmetric design, TOVs also benefit from an intrinsically safer valve installation for fail-open/fail-close protective functions. When the valve is open, the offset shaft produces a large region of low velocity flow whenever the flow is coming from the shaft side, therefore generating a large pressure differential between the upstream and the downstream of the disc. This dynamic effect will also push the valve to close (dynamic torque, **FIG. 7**)

Metal-to-metal valves are also inherently firesafe, as their construction does not involve the use of any soft components. In any case, these valves are capable of undergoing API 607-compliant firesafe testing and performing with zero leakage under those conditions. In view of all these considerations, metal-to-metal TOVs are an increasingly adopted solution for emergency functions directly connected to storage tanks.

EMERGENCY VALVES ON INLETS AND OUTLETS. In some cases, for example in crude oil or naphtha terminals, a single line is designed for both storage-tank inlets and outlets. Historically, the first tank-body valve is operated by electric fail-last actuators. For higher perceived risk scenarios (e.g., higher flammable hydrocarbons, such as LPG) and more modern safety architectures, fail-close pneumatic, hydraulic or electric fail-safe actuators are adopted with a distributed control system (DCS), which provides the emergency signal to shut down. In other cases, inlets and outlets are on two distinct lines featuring respective first tank-body valves (**FIG. 2**). For the valves that require a fail-close function, it is important to install a TOV with flow coming from the shaft side. The flow itself will act to close the valve and, therefore, the fail action may be assisted even in the case of a control system failure.

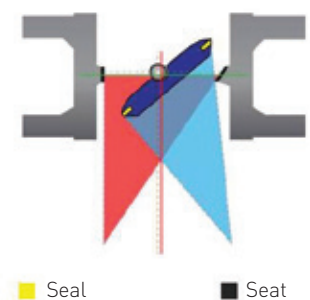
The flow will shut the disc, and the resultant pressure will keep the valve in the closed and seated position. When the valve is open, there is no contact between the sealing elements, thus resulting in a very low torque requirement to move the disc to the closed position even with no flow. This torque is mainly necessary to overcome packing friction and/or bearing friction specifically for dirty services. This friction is extremely low compared to standard ball (and plug) valves, where it is also necessary to overcome the rubbing of two seal rings compressed against a ball (or plug) surface for the entire 90° closing rotation.

EMERGENCY VALVES ON OVERFLOW LINES. Whenever a dedicated overflow line exists, TOVs can be used to provide emergency open upon a dedicated signal (**FIG. 3**). In this case, there are two conflicting requirements:

1. To have a valve properly seated to maintain excellent tightness performance
2. To minimize any unseating resistance and reduce any possible risk of failing the unseating of the valve

In a fail-open protective service, the most reliable TOV direction of installation that minimizes operability systematic failures is the one where the pressure promotes the seal ring unseating, and, therefore, with the design differential acting on the disc side when the valve is shut, as shown in **FIG. 8**. Again, this scenario is more reliable compared to a ball (or plug) valve where, normally, large efforts are required to move the trim from its seated position. Conversely, gate valves are universally renowned for their wedging effect caused by the extremely low seating angle that makes it difficult to open even manually operated valves.

TOV - ROTATIONAL MOVEMENT



GLOBE VALVE - AXIAL MOVEMENT

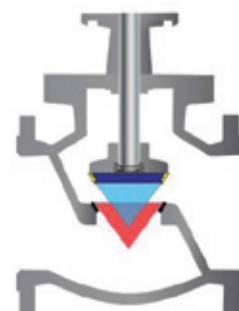


FIG. 5 - TOV vs. globe valve seating mechanism comparison

COMPARISON BETWEEN DISC AREA PORTIONS: $A > B$

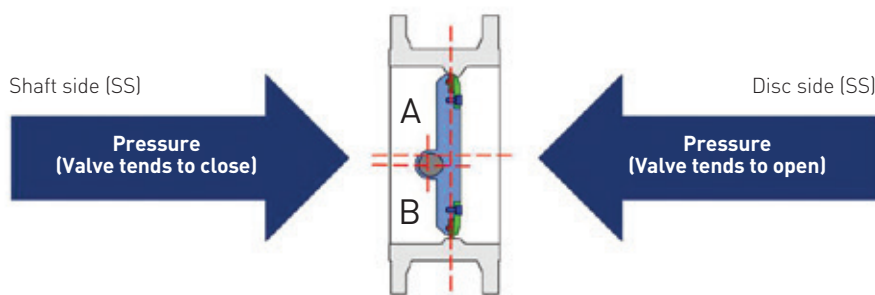


FIG. 6 - Comparison between disc areas of TOVs

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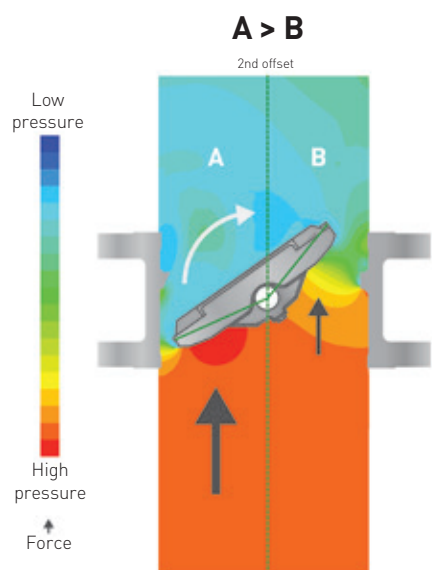


FIG. 7 - Dynamic effect of the flow acting to close the disc of a TOV

The pressure range inside a 30-m-tall liquid hydrocarbon storage tank is usually less than 10 bar (145 psi), and it is well below the rating of overfill valve, which are typically built in ASME class 150. Thus, the valve's fully rated trim is capable, with a large safety factor, of securely tightening against 10 bar of pressure pushing to open the valve. While quickly opening the valve by releasing the torque, the pressure supports the break-to-open torque provided by the actuator, and the flow contributes further by producing a dynamic torque (opening the valve).

KEY ADVANTAGES. There are several key advantages with TOVs over traditional process valves:

1. With an accurate valve, material and actuator selection, and the non-symmetrical design of the trim, systematic failure can be significantly minimized.
2. The non-symmetrical trim design of TOV valves triggers different valve behavior, depending on which direction the differential pressure is applied. In the preferred sealing direction of the valve, the pressure keeps the valve closed, allowing users to benefit from safer functioning in emergency shutdowns. In the opposite sealing direction, i.e., where the pressure facilitates the opening of the valve, TOVs improve safety whenever the function is to provide emergency open, including blow down/vent operation.

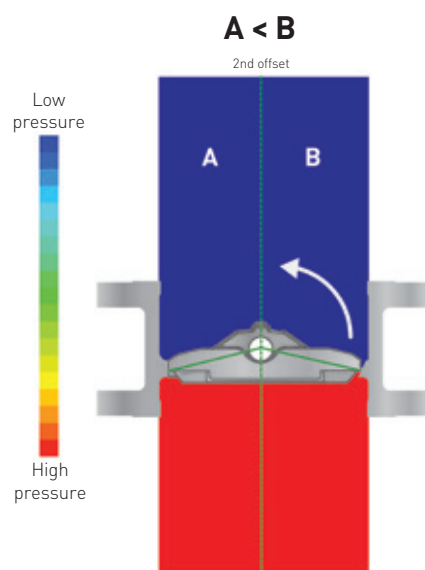


FIG. 8 - Pressure effect acting to open the disc of a TOV

EXAMPLES. There is a degree of variability in terms of how safety is applied to tank farms around the world. Often, safety failures are correlated with risk miscalculations that may be prompted by many different considerations.

Storage-tank fire. In a major Indian storage tank, a fuel leakage and a consequent fire resulted in several deaths and a significant number of injuries. In response to the recommendations by the investigating commission, TOVs were adopted to improve safety by introducing a ROSOV as the first tank-body valve. TOVs were selected to create an independent emergency-close function and were separated from the newly installed MOVs. The signal to manage the ROSOVs is generated independently from the standard operating devices for normal loading, offloading and inventory activities. Adopting TOVs in place of standard process valves will significantly improve the safety standards in these operations. Furthermore, one of the largest refineries in the world has also adopted TOVs as emergency shutdown valves. Depending on the risks arising from handling specific fluids, the refiner has increased the level of safety by combining different types of actuation with fail-close/fail-last functions with TOVs.

EU developments. In Europe, the Health and Safety Commission investigated, in 2005, the incident that occurred in the Buncefield oil depot in Hemel Hempstead, UK. The results

of the investigation were used as a guideline across several countries to review layouts and safety regulation in tank farm facilities.^[1] In the Netherlands, for example, new rules were introduced on the use of firesafe, fail-safe valves as the first shut-off valves installed on the tank wall, i.e., first tank-body valves. These valves must now be automated and controlled from the outside of the tank dyke. Personnel and the DCS should be able to remotely set the valves in a fail-safe position. To comply, several tank operators have switched from gate to non-rubbing torque seated metal-to-metal TOVs.

OPTIONS. With increasingly higher safety integrity level requirements, driven by developments in HSE laws and regulations, a rise in TOV adoption for liquid hydrocarbon storage-tank protective services is expected. Further investigations regarding ESD functions may find TOVs as suitable candidates. In particular, storage-tank venting could become a new area of research by manufacturers, engineering companies and end users to identify how TOVs may provide increased safety and performance.

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NOTE

- a. Zero leakage means no visible leakage when tested at high pressure with water and low pressure with air according to existing international standards.

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