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Development of a control strategy for a self-stop valve in production wells

Desarrollo de una estrategia de control para una válvula de autocierre en pozos de producción

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Abstract: One of the primary challenges in automated oil wells is maintaining operational continuity during abrupt pressure fluctuations that cause unscheduled shutdowns. Traditional continuous PID control schemes fall short when process dynamics become highly variable, while advanced alternatives like Managed Pressure Drilling (MPD) remain expensive and complex to implement. This paper presents an event-based alternative using operational severity levels to control choke valves. The architecture combines PLC control, SCADA supervision, alarm escalation, and a progressive reopening strategy to manage critical events autonomously. During field testing, the system recorded 62 automatic interventions without plant shutdowns, achieving response times under 3 seconds and recovery rates above 90% during transient events. This shows that it is possible to stabilize the process and reduce operator dependence, but not eliminate it from the operation, through a practical solution that's easy to integrate into existing plants.

Keywords: event-based control, operational resilience, choke valves, automation, industrial automation, PLC control, SCADA systems, oil production systems, adaptive recovery.

Resumen: Uno de los mayores retos en los pozos petroleros automatizados es mantener la continuidad de la operación frente a los cambios repentinos de presión que provocan paradas no programadas. Los esquemas tradicionales de control PID continuo se quedan cortos cuando el proceso se vuelve muy dinámico, mientras que alternativas avanzadas como la perforación con presión controlada (MPD) resultan costosas y difíciles de implementar por su complejidad técnica. En este artículo se presenta una alternativa basada en eventos y niveles de severidad operativa para operar válvulas de estrangulación (choke valves). El desarrollo combina controladores PLC, supervisión SCADA, escalamiento de alarmas y una reapertura gradual para controlar eventos críticos de forma autónoma. Durante las pruebas en campo, la arquitectura registró 62 intervenciones automáticas sin paros de planta, reaccionando en menos de 3 segundos y logrando una recuperación superior al 90 % en eventos transitorios. Esto demuestra que es posible estabilizar el proceso y reducir la dependencia del operador mas no eliminarlo de la operación mediante una solución práctica y fácil de integrar en plantas existentes.

Palabras clave: control basado en eventos, resiliencia operativa, automatización de válvulas de estrangulación, automatización industrial, control PLC, sistemas SCADA, sistemas de producción de petróleo, recuperación adaptativa.

1. INTRODUCTION

In the oil industry, automating production processes has become essential to keep plants operating continuously, avoid costly shutdowns, and respond in time to process variations [1]–[3]. Therefore, implementing autonomous control schemes helps make facilities more stable and reduces the need for constant human supervision in day-to-day operation [1], [2].

1.1. Operational Challenges

Keeping wells producing without interruptions is a complex task, especially when pressure surges or unexpected flow variations occur [4]–[10]. In these high-variability scenarios, conventional control systems may fall short in reacting in time, which can lead to unplanned shutdowns, crude oil losses, and the need for manual operator intervention [1], [2], [6], [8].

Problems such as overpressure, sudden changes in separator levels, and fluctuations inherent to multiphase flow are among the causes of operational instability in the field [6]–[10]. In addition to causing equipment wear, these failures reduce operational continuity and affect overall productivity. For this reason, the industry increasingly seeks automated solutions capable of absorbing these disturbances and reducing the need for manual well interventions [1]–[5].

1.2. State of the art

Most production systems in the industry operate using traditional PID loops designed to regulate pressure and flow continuously [13], [14]. Although they perform adequately under steady-state conditions, this type of control may present limitations when fast transients, nonlinearities, or sudden changes caused by multiphase flow within the well occur [6], [13], [14].

Under severe process variations, conventional strategies may react with delay or exhibit reduced performance, which can lead to pressure oscillations and require manual intervention by field personnel [6], [13], [14]. This lack of rapid response increases the risk of shutdowns, reducing system availability and complicating the restoration of operating conditions [1], [2], [8]–[10].

To address this issue, advanced technologies such as pressure control during drilling through Managed Pressure Drilling (MPD), predictive schemes, and intelligent algorithms can damp disturbances and control critical process variables [15]–[21]. However, these alternatives may require additional infrastructure, more complex mathematical models, and high computational capacity, which can make their adoption difficult in conventional fields or facilities [17]–[21].

Under these conditions, event-based control is presented as a practical option for managing discrete disturbances without continuously executing control actions [22]–[24]. By executing actions only when the variable exceeds certain thresholds or critical conditions, a rapid response can be achieved with fewer control actions and without necessarily requiring the complexity of an advanced predictive model [22]–[24].

1.3. Scientific Gap

Despite advances in the automation of oil facilities, a gap is identified in the reviewed literature regarding how to integrate level-based severity classifications with gradual recovery mechanisms in real industrial infrastructures [1]–[24]. Most of the studies analyzed focus on continuous, predictive, robust, or adaptive control schemes to respond to abrupt changes and nonlinear phenomena in multiphase flow [6], [13]–[21]. Therefore, a hybrid supervisory architecture is proposed that combines event-based logic with adaptive reopening of the choke valve, contributing to the prevention of plant shutdowns without necessarily relying on highly complex predictive models for field processing [22]–[26].

1.4. Contribution of the work

To address this problem, this work proposes an autonomous event-based control strategy that classifies faults according to severity levels in oil production systems. The system combines PLC logic, SCADA supervision, and a gradual recovery scheme to automatically regulate the choke valve opening in response to process variations.

The main contributions of this research are summarized below:

1. Event-based control design: A control logic oriented to respond automatically to transient disturbances in multiphase flows was developed.
2. Severity classification: A tiered scheme was implemented to adjust choke valve actions according to the severity of the disturbance in real time.
3. Gradual recovery mechanism (Slow Recovery): A staged reopening strategy was designed to prevent pressure surges and avoid reactivating alarms after clearing the fault.
4. Standard industrial architecture: The solution was integrated using commercial hardware (PLC-HMI-SCADA), facilitating its implementation via retrofit on existing facilities without modifying the infrastructure.
5. Field validation: The system was tested in real operation, achieving response times under 3 seconds, automatic recovery above 90%, and reducing plant shutdowns by more than 45% compared to traditional control.

Figure 1. General diagram of the proposed control strategy to mitigate disturbances in production wells. The chart illustrates the integration between process variable measurements, PLC logic structured by severity levels, SCADA/HMI supervision, and the gradual adjustment of the choke valve.

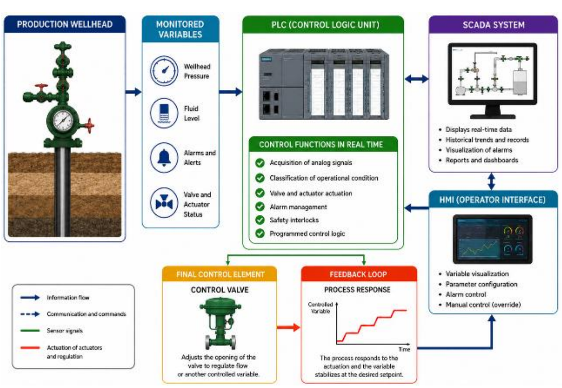

Fig 1. Conceptual architecture of the proposed strategy.
***Source:** The author*

2. MATERIALS AND METHODS

The methodological development was structured from an industrial automation perspective, aiming to enhance operational stability and prevent unscheduled shutdowns in oil wells. The solution combines event-based logic, a severity-based alarm hierarchy, and a gradual reopening of the choke valve, all implemented on a standard PLC, SCADA, and HMI interface architecture [27]–[30].

The design was conceived for deployment in actual field facilities, enabling real-time monitoring of key process variables and automatic actuation of the choke valve according to the well's dynamics.

2.1. System Architecture

A modular architecture was selected to facilitate system installation in existing operating wells without requiring drastic infrastructure modifications. The structure is organized hierarchically, comprising field instrumentation, the PLC controller, the supervisory SCADA system, and an HMI screen for operator interaction and real-time variable tracking [29], [30].

The programmed logic continuously monitors well behavior and automatically actuates the choke valve when a critical condition is detected, following the principle of event-conditioned actuation [22]–[24]. Built with commonly used industrial components, the platform ensures compatibility with conventional automation environments and allows the solution to be scaled to other wells within the facility [29], [30].

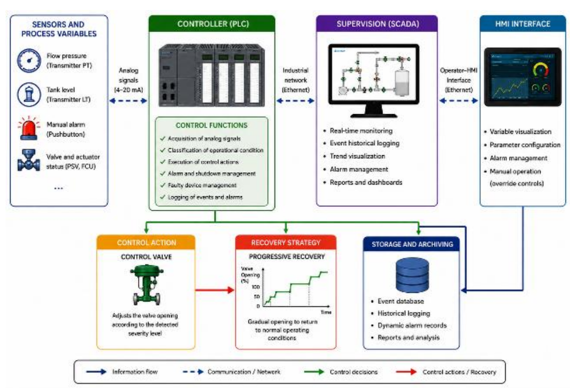

Fig 2. Functional architecture of the proposed system.
***Source:** The author*

Figure 2. Functional structure of the PLC/SCADA system. The diagram illustrates the integration between instrument readings, severity level classification within the controller, and automatic

mitigation and gradual reopening actions applied to the choke valve during transient events.

2.2. Monitored variables

The system continuously reads key well variables to evaluate pressure stability, vessel/separator levels, and emergency shutdown (ESD) statuses. All these signals feed into the PLC, where the algorithm processes the data to determine process conditions and execute the appropriate response.

Monitored parameters include wellhead/line pressure, vessel level, active alarm history, and sharp variations in multiphase flow. The joint consideration of process variables and alarms provides information to detect anomalous behavior and assign the event severity level in real time [27], [28]. By integrating these measurements into the control scheme, the system responds to transients and minimizes the manual actions required from the operator during critical situations.

Table 1. *Operational severity matrix and response logic for the choke valve.*

Severity	Operational Condition	Applied Action	Persistence Time
Level 1	Slight pressure variation	Moderate choke reduction	5 s
Level 2	Persistent alarm	Progressive reduction	10 s
Level 3	High criticality	Aggressive choke closure	15 s
Level 4	Shutdown risk	Maximum mitigation	20 s

Source: *The author*

Table 1. Monitoring parameters and persistence times according to severity level. The table summarizes the actions applied to the choke valve and the required dwell times to confirm process conditions.

2.3. Severity model

The core of the strategy relies on a tiered model that classifies the severity of disturbances as they occur. In this way, the algorithm adjusts the aggressiveness of its response based on how critical the detected condition is in the well. The scheme considers four severity states. Each level triggers a specific movement in the choke valve, accounting for fault persistence over time, the amplitude of the pressure spike, and the overall impact on the facility.

From a control theory perspective, this architecture can be represented as an event-driven hybrid dynamic system by combining the continuous response of process variables with discrete supervisory logic [22]–[26]. Thus, each transition between severity levels represents a state transition that modifies the valve opening or closing to contain the disturbance without destabilizing the plant [25], [26].

$S(t+1) = f(S(t), P(t), L(t), A(t))$, where $S(t)$ represents the operational severity state, $P(t)$ corresponds to system pressure variables, $L(t)$ represents separator level conditions, and $A(t)$ denotes the set of active alarms at the evaluation instant. This formulation allows the dynamic evolution of the system to be modeled as a discrete process supervised by operational events [25].

$u(t) = Ks \cdot S(t)$, where $u(t)$ represents the control action applied to the choke valve and Ks corresponds to the mitigation factor associated with the detected severity level. Under this architecture, valve opening does not rely on a conventional continuous response, but rather on a hierarchical proportional logic based on operational criticality.

$Ec = [P > Pmax, L > Lmax, A = 1]$. Critical events are triggered by the simultaneous evaluation of well pressure, level, and operational alarms. This logic enables discrete decision-making for automated process supervision, following an event-conditioned actuation scheme [22]–[25]. Indeed, this hybrid approach allows the Autochoke 1.0 architecture to be conceptualized as an event-oriented system capable of responding to sudden changes in multiphase flow. Thus, the transition from one severity level to another acts as a progressive mitigation mechanism that seeks to stabilize the plant without causing sudden closures or pressure surges.

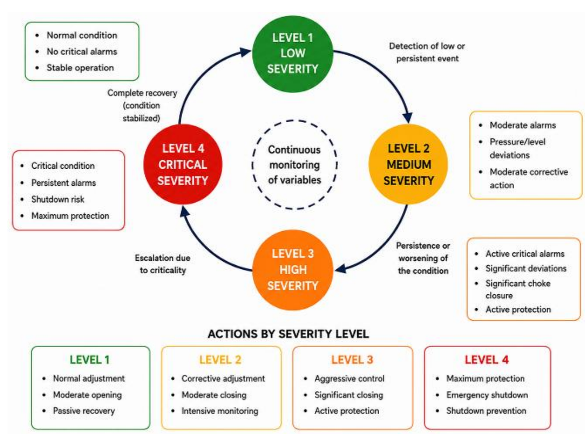

Fig. 3. *State machine for the decision logic and state transitions according to the severity level.* ***Source:*** *The author*

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The figure shows how the algorithm processes field alarms, evaluates persistence times, and switches between the four severity levels to adjust the valve opening.

The model dynamically adjusts its states by measuring pressure, level, and active alarms in real time. Depending on the severity level reached, the logic applies a specific action to the choke valve, scaling the response according to the magnitude and persistence of the event. Additionally, the algorithm incorporates a safe return sequence to restore normal operation once the fault has cleared.

When severity is low, the valve makes minor corrections to stabilize the process without disturbing the flow. If the condition worsens, the system closes the valve more aggressively to contain the pressure spike, preventing emergency shutdown trips and keeping the well online.

Table 2. Details the four operational severity levels defined in the algorithm. The structure shows how the logic transitions from one stage to another by evaluating alarm duration and the degree of process disturbance, executing valve closure or gradual reopening as appropriate.

Table 2. *Hierarchical classification of operational severities.*

LEVEL	SEVERITY	DESCRIPTION	TYPICAL CONDITIONS	ACTION ON CONTROL VALVE
1	LOW	Normal operating condition without critical alarms.	• Pressure and level within range. • No significant deviations.	**Normal adjustment:** Moderate increments/ decrements.
2	MEDIUM	Moderate deviations that require corrective action.	• Low or persistent alarms. • Moderate pressure/level variations.	**Moderate reduction:** Moderate valve opening reduction.
3	HIGH	Critical conditions with operational impact risk.	• Active critical alarms. • Significant deviations. • Worsening trend.	**Significant reduction:** Significant valve opening reduction. Active protection.
4	CRITICAL	Critical condition with high shutdown risk.	• Persistent critical alarms. • Overpressure/overlevel. • Imminent shutdown risk.	**Emergency closure:** Emergency shutdown (0 % opening). Maximum protection.

Source: *The author*

2.4. Recovery strategy

Once the critical event is contained, the system initiates a gradual recovery phase to restore the well to its normal operating parameters without retriggering field alarms. Rather than reopening the valve abruptly, the algorithm steps up the opening incrementally, dampening flow surges and maintaining stable line pressure.

This automatic reopening process is managed via adjustable timers within the PLC, which verify that variables remain within safe operating limits before advancing to the next step. In this manner, the system paces the recovery rate according to the well's real time response, safeguarding continuous production during complex transients.

Unlike traditional strategies that reopen abruptly, the Slow Recovery method acts as a buffer between the fault state and normal operation. This smooth transition prevents secondary pressure oscillations, avoids recurrent alarm trips, and stabilizes the process throughout the transient phase.

$V(t+1) = V(t) + \Delta V$, where V(t) represents the choke valve percentage opening and ΔV corresponds to the progressive increment applied during the recovery stage. This logic seeks to prevent sudden pressure surges and reduce secondary fluctuations that may occur when the valve is opened rapidly [8], [9].

2.5. Simplified dynamic model of the system

$$\frac{dP(t)}{dt} = -k_1\left(P(t) - P_{ref}\right) - k_2 u(t)$$

where $P(t)$ represents the system pressure, P_{ref} corresponds to the operational reference pressure, u(t) is the control action applied to the choke valve, and k1 and k2 represent dynamic constants associated with the hydraulic behavior of the process.

This formulation allows the process to be modeled through a simplified first-order dynamic response under the supervision of a hybrid event-based control scheme [17], [22]–[26]. With this approximation, valve actuation directly modifies the transient pressure response to sudden changes in multiphase flow.

In terms of operational stability, the strategy is designed to drive the system toward a safe operating zone, provided that the algorithm response remains proportional to the magnitude of the event and that transitions between severity levels do not occur too rapidly. Under this criterion, the architecture seeks to preserve stable behavior during transitions between the different operational states, following the general principles of hybrid systems [26]. However, formal system stability through analytical methods remains an aspect to be evaluated in future work.

Furthermore, the combination of gradual reopening with hierarchical mitigation rules seeks to reduce oscillations caused by abrupt valve movements [8], [9]. This facilitates smooth transitions between fault states and favors the return of the well to a safe operating condition.

3. RESULTS

3.1. Experimental environment

System validation for Autochoke 1.0 was conducted on an industrial platform equipped with a PLC, SCADA, and field instrumentation, designed to detect and mitigate disturbances caused by changes in pressure, level, and transient well dynamics. The testing evaluated the severity classification logic and automatic choke valve response.

The experimental setup included pressure and level sensors, analog/digital I/O modules, an EtherNet/IP industrial network, and a SCADA interface for real time monitoring, trend logging, and alarm management. The controller was programmed with the severity hierarchy, mitigation routines, and the gradual reopening sequence.

During field testing, line pressure, choke valve position, alarm activations, and fault durations were continuously logged. The system responded to process deviations by applying progressive closures and triggering staged protections.

Meanwhile, the gradual recovery routine executed only when process variables remained stable throughout the validation period programmed into the PLC, preventing abrupt valve openings that could re destabilize the line.

3.2. System operational performance

The results confirmed that the Autochoke 1.0 strategy responds autonomously to process transients, eliminating the need for manual operator interventions and maintaining stability at critical operating points. During the testing phase, the platform recorded 62 automatic interventions during disturbances without triggering a single emergency shutdown (ESD). Likewise, the algorithm responded in under 3 s to pressure spikes and achieved an automatic recovery rate above 90% during multiphase flow variations.

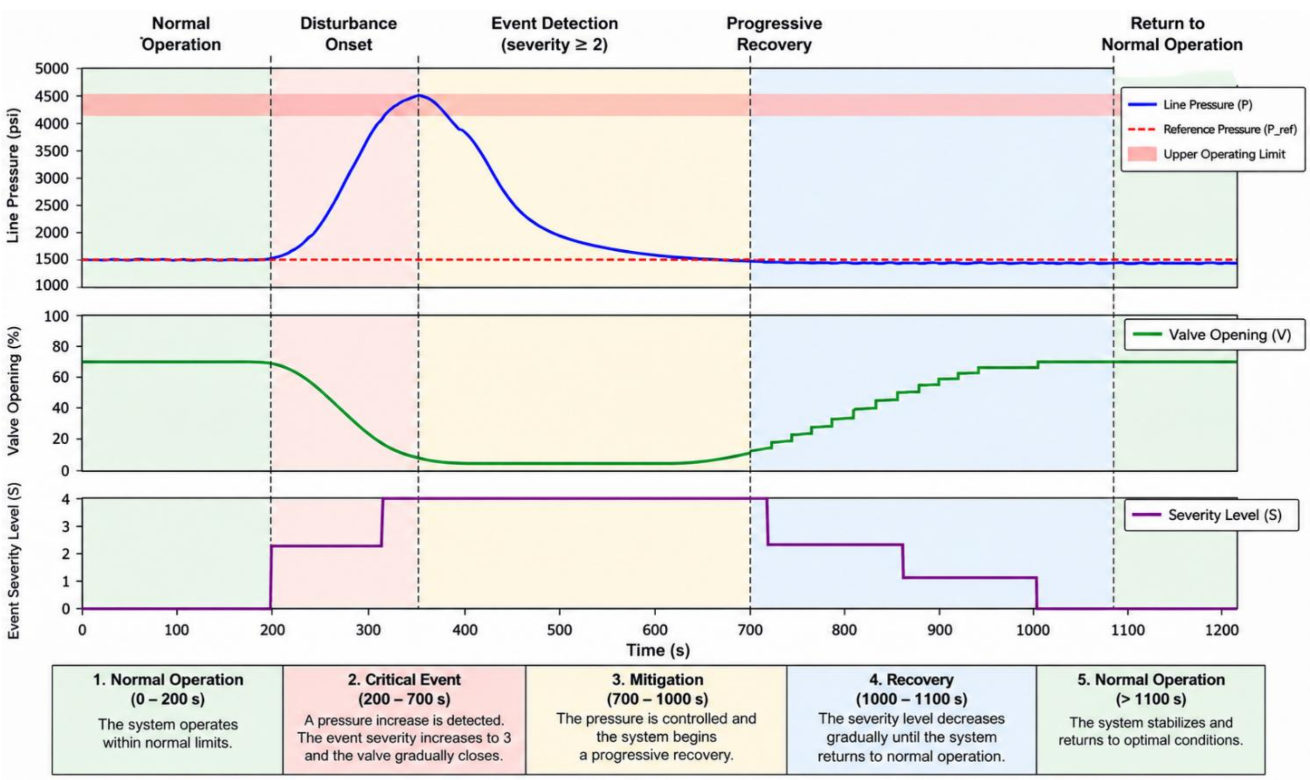

Fig 4. *Dynamic response of the Autochoke 1.0 system.* ***Source:*** *The author*

Figure 4 illustrates the time response of line pressure, choke valve position, and the severity level determined by the PLC. The trend shows how the algorithm detects the disturbance in time, applies staged closure to contain the overpressure, and performs gradual reopening until the flow is stabilized.

Plant trials demonstrate that the system enhances operational availability compared to traditional manual control, particularly during high variability transients where operator reaction time proves insufficient.

During abnormal pressure surges or persistent alarms, the controller responds based on fault level. Under medium severity conditions, it applies moderate closures to the choke valve, whereas during critical events, it triggers accelerated closures to prevent ESD trips. Testing confirmed that the tiered logic successfully filters minor disturbances from severe faults. This prevents the system from overreacting to transient shifts and avoids unnecessary full shutdowns.

Continuous monitoring of key variables stabilized operations against sharp pressure variations and multiphase flow slugging typical in the line.

Finally, gradual reopening returned the well to normal operating parameters through stepped valve positions. This strategy reduced critical alarm recurrence and eliminated pressure oscillations during production.

3.3. Comparative analysis

When comparing the Autochoke 1.0 architecture with manual operation or conventional PID control, the proposed strategy showed greater flexibility in managing transients and adapting to the variability observed during testing. This behavior is consistent with studies that have reported advantages of automatic choke control and advanced control strategies under variable operating conditions [1], [2], [6], [13], [14].

Manual control depends directly on operator judgment and reaction time, which may lead to variability in the response to a fault. Traditional PID loops, on the other hand, may exhibit degraded performance when operating under nonlinearities, abrupt pressure changes, and significant variations in the operating point [13], [14]. These limitations have motivated the development of robust, predictive, and adaptive strategies for pressure control applications using choke valves [15]–[21].

In contrast, the hybrid logic of the algorithm combines the severity hierarchy with continuous monitoring, executing differentiated actions according to event severity. This staged response improves preventive mitigation and prevents a minor disturbance from escalating into a complete well shutdown.

Table 3 compares manual operation, PID control, and the Autochoke 1.0 architecture, considering the behavior observed during field testing and findings reported in the literature for automatic and advanced choke valve control [1], [2], [13]–[21].

***Table 3.** Comparison of control strategies: Manual vs PID vs Autochoke 1.0.*

Criterion	Manual	Conventional PID	Autochoke 1.0 (Proposed)
Response time	High (variable)	Medium (sec–min)	Low (< 3 s)
Operational shutdown	Frequent	Moderate	Reduced (>45% reduction)
Automatic recovery	Low	Medium	High (>90% recovery)
Operator intervention	High	Medium	Low (autonomous)
Operational stability	Low	Medium	High
Adaptability to disturbances	Low	Medium	High (severity levels)
Prevention of critical events	Low	Medium	High (progressive mitigation)
Progressive recovery (*Slow Recovery*)	Not applicable	Limited or not implemented	Yes (gradual increments)
Dependence on advanced infrastructure	No	Medium	Low (standard PLC/SCADA)
Compatibility with existing facilities	Yes	Medium	High (retrofit strategy)
Implementation complexity	Low	Medium	Medium
Implementation cost	Low	High (models, infrastructure)	Medium (standard infrastructure)
Production continuity	Low	Medium	High (greater availability)
Ability to operate under multiple conditions	Low	Medium	High (transient events)

Source: *The author*

Additionally, gradual reopening offers an advantage over abrupt opening, as it allows the process variables to stabilize before returning the well to its normal production condition. This behavior is consistent with the use of the choke as an active element for mitigating multiphase flow oscillations reported in other studies [8], [9].

From an applied control perspective, the ability to distinguish minor disturbances from higher-severity fault conditions constitutes a distinctive feature of the proposed strategy compared with a conventional PID loop. This characteristic is especially relevant in multiphase flows, where nonlinearities and high operational variability may occur [6]–[10], [17].

3.4. Progressive recovery dynamics

The Slow Recovery phase maintained stable behavior when restoring production after critical events had been controlled. The algorithm applied stepped valve openings only when pressure and level remained within safe limits during the validation periods programmed in the PLC.

This criterion eliminated recurring alarms and prevented fluctuations commonly caused by abrupt valve openings. The adaptive logic reduced oscillations in the line, protecting flow continuity during the reopening transient.

Overall, the tests demonstrate that integrating supervised recovery routines is an effective alternative for increasing resilience in wells with multiphase flow, where critical events and pressure variations are recurrent.

4. DISCUSSION

The results confirm that Autochoke 1.0 constitutes an effective alternative for mitigating critical faults in multiphase oil production systems under the evaluated conditions. Unlike traditional PID control or manual operation, the architecture integrates hybrid severity-based supervision and a Slow Recovery routine focused on protecting process stability. The use of choke valves as active elements for regulation and disturbance mitigation has shown favorable results in production applications and multiphase systems [1], [4]–[9].

The tiered hierarchy was able to distinguish minor transients from higher-severity fault conditions, avoiding excessive PLC responses and contributing to the prevention of unscheduled shutdowns. This response capability is particularly relevant in multiphase lines, where nonlinearities and abrupt flow changes may occur [6]–[10], [17].

From an automatic control perspective, the algorithm operates as an event-oriented supervisory system by combining continuous process variables with discrete transitions associated with severity conditions [22]–[26]. This characteristic provides a different response from conventional PID loops, which operate continuously and may present performance limitations when facing significant changes in the operating point and nonlinear dynamics [13], [14]. In this sense, Autochoke 1.0 does not necessarily seek to replace the existing continuous control system, but rather to incorporate a supervisory layer to respond to critical operational events.

Gradual reopening, in turn, showed favorable behavior compared with abrupt reopening. Applying staged increments with PLC validation reduced pressure oscillations and the recurrence of critical alarms during production restoration. This result is consistent with research on multiphase systems showing that controlled manipulation of choke opening directly influences the amplitude of pressure fluctuations and can be used as a stabilization mechanism [8], [9].

A key advantage for the industry is that the algorithm runs on standard PLC/SCADA platforms [29], [30]. This allows it to be installed on existing infrastructure through retrofit strategies without necessarily requiring the incorporation of more complex predictive control platforms. This characteristic may facilitate its application in existing facilities with infrastructure or processing-capacity constraints.

However, the system depends on accurate instrumentation calibration and manual adjustment of thresholds according to the well. In addition, the tests were conducted under specific field conditions, and the dynamic model used a simplified first-order approximation. Therefore, future work should include advanced multiphase models, formal stability analysis, and adaptive self-tuning mechanisms [17], [20], [21], [26].

As a future development, the integration of predictive algorithms for automatic severity adaptation, dynamic parameter adjustment, and early fault detection in production is contemplated [16], [18], [20], [21]. These tools could complement the event-based logic while maintaining the proposed supervisory architecture and allowing its parameters to be adjusted according to the dynamic evolution of the process.

5. CONCLUSIONS

The Autochoke 1.0 strategy consolidated an autonomous operational mitigation and recovery scheme, reducing the occurrence of critical events during complex transients in multiphase wells.

The architecture integrated severity-based supervision, staged choke valve closures, and the Slow Recovery routine, preserving process stability and preventing shutdown trips.

The hybrid event-based logic proved superior to manual control and conventional PID control by distinguishing minor fluctuations from persistent faults, improving flow continuity, and reducing human intervention.

Direct implementation on standard PLC/SCADA platforms confirms its technical and economic viability, offering a low-cost alternative for modernizing production infrastructure in mature fields.

This development establishes the foundation for the future incorporation of predictive algorithms, adaptive schemes, and artificial intelligence applied to autonomous control in wells and production facilities.

From an industrial perspective, the results confirm that Autochoke 1.0 increases operational resilience and optimizes the online operating time of production systems subjected to severe disturbances.

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