IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 7, March 2025

Foundation Fieldbus with Control-In-Field and Control-In-Controller-An Analysis

Shah Aayush D.[1], **Chaitanya J. Talati**[2], **Mrs. Namrata K. Prasad**[3],
Prof. Chirag S. Dalal[4], **Dr. Himanshu Kumar R. Patel**[5]
Dy. General Manager, L&T, Hydrocarbon[3]
Dharmsinh Desai University, Nadiad, India[1,2,4,5]

Abstract: *Foundation Fieldbus (FF) is an advanced digital communication protocol widely used in industrial automation, particularly in process control industries.[1] It enables enhanced communication between field devices and control systems, offering improved efficiency, reliability, and scalability. One of the key advantages of Foundation Fieldbus is its ability to support distributed control architectures, allowing control strategies to be implemented either at the field level (Control In Field, CIF) or at the central control system (Control In Controller, CIC).Control In Field (CIF) leverages smart field devices with built-in control capabilities, allowing control loops to be executed locally without relying on a centralized controller.[2] This reduces communication latency, minimizes bandwidth usage, and enhances system resilience against network failures.[3] CIF enhances plant availability, as the failure of a central controller does not disrupt local control operations. On the other hand, Control In Controller (CIC) involves executing control logic at the central Distributed Control System (DCS) or Programmable Logic Controller (PLC). This traditional approach simplifies system management, enables easier modifications to control strategies, and allows centralized monitoring and diagnostics.[4]The choice between CIF and CIC significantly impacts system performance, reliability, and maintenance complexity. This study provides an in-depth evaluation of CIF vs. CIC by analyzing their impact on system performance, fault tolerance, response time, and overall operational efficiency.*

Keywords: Foundation Fieldbus (FF), Control systems, Control In Field (CIF), Control In Controller (CIC), Implementation, System performance

I. INTRODUCTION

Industrial automation has seen remarkable progress with the development of advanced digital communication protocols, notably Foundation Fieldbus (FF), which has revolutionized process control industries. Unlike traditional analog communication methods, FF provides a completely digital, two-way communication system that enhances data exchange, improves device interoperability, and supports distributed control. A key aspect of this technology is its ability to execute control functions either directly at the field device level, known as Control In Field (CIF), or within a centralized control system, referred to as Control In Controller (CIC). The decision between these two control strategies is crucial in determining the overall performance, reliability, and efficiency of an industrial automation system.

Control In Field (CIF) is an advanced method where intelligent field devices, such as field transmitters, positioners, and smart controllers, independently execute control logic.[5] This approach reduces latency, network dependency, and communication overhead while enhancing system availability. By decentralizing control functions, CIF ensures that local control loops remain operational even if network failures or central controller malfunctions occur. However, implementing CIF requires highly capable field devices with advanced processing power, which can increase initial setup costs and complexity in configuration. Despite these challenges, CIF is widely adopted in critical process industries, such as oil and gas, petrochemicals, and power generation, where system uptime and fault tolerance are of utmost importance.[6]

On the other hand, Control In Controller (CIC) follows the traditional centralized control framework, where the Distributed Control System (DCS) or Programmable Logic Controller (PLC) manages all control logic execution. This method facilitates easier modifications to control strategies, enhances centralized monitoring and diagnostics, and reduces the computational load on field devices. CIC is particularly beneficial in large-scale plants where extensive data processing, advanced analytics, and supervisory control functions are required. However, network failures, communication delays, and high bandwidth usage pose significant risks in CIC-based systems, potentially leading to operational disruptions.

The choice between CIF and CIC depends on several factors, including system complexity, process criticality, fault tolerance requirements, and maintenance feasibility. This paper provides an in-depth comparison of CIF and CIC, analyzing their impact on real-time control performance, fault resilience, cost-effectiveness, and industrial applicability. Additionally, the study explores how emerging technologies such as Industrial IoT (IoT), edge computing, and cloud-based control systems are reshaping the future of industrial automation, influencing the adoption of CIF and CIC. By understanding the strengths and limitations of both approaches, engineers and researchers can make informed decisions when designing modern control systems for industrial applications.

FF with Control-In-Field (CIF)

Basic process

The Foundation Fieldbus protocol, compliant with IEC 61158-2, introduced an innovative feature known as Control in the Field (CIF), which revolutionized distributed control systems by enabling the integration of control function blocks directly into field devices. This advancement allows control loops to be configured and executed locally without reliance on a centralized controller, resembling the decentralized control model of traditional pneumatic systems. While this may appear to be a regression, CIF offers significant application opportunities by enhancing flexibility, reducing dependency on central controllers, and improving system reliability. In contrast, traditional Distributed Control Systems (DCS) centralize control loop processing within high-performance controllers, typically utilizing one or two controllers for most applications.[7]

PID control loop

A fundamental component of control strategies in Foundation Fieldbus is the PID (Proportional-Integral-Derivative) control loop, which is implemented using three essential function blocks: an Analog Input (AI) block, a PID block, and an Analog Output (AO) block. The AI block captures process variables from measuring instruments, the PID block computes the control action, and the AO block transmits the control signal to the final control element, such as a valve or actuator.[8]

For more complex control strategies, such as cascade control, additional function blocks are employed, including two AI blocks, two PID blocks, and one AO block. This configuration ensures accurate signal processing, control action computation, and actuation.The execution sequence of these function blocks is critical for maintaining reliable control. AI blocks are always associated with measuring instruments to ensure accurate process variable capture, while AO blocks are positioned within the final control element to convert control signals into physical actions. The placement of PID blocks, however, offers flexibility, as they can be located either within the measuring devices or the final control element.

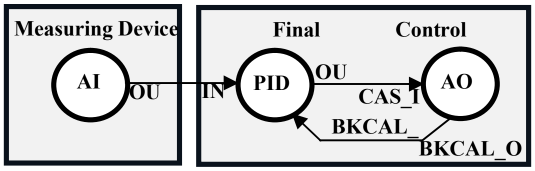


Figure.1 Function block diagram for PID control

This decision significantly impacts communication network loading. Placing PID blocks within measuring devices necessitates transmitting control calculations to the final control element via communication protocols, increasing network traffic and response time. Conversely, positioning PID blocks within the final control element minimizes network load, reduces scheduled data exchanges, and enhances control performance by eliminating delays associated with data transmission.

DOI: 10.48175/IJARSCT-24410

Optimizing communication efficiency is a key consideration in Foundation Fieldbus systems. Locating PID blocks within the final control element is generally preferred, as it reduces network traffic, improves system responsiveness, and enhances overall control performance. This approach aligns with the decentralized control philosophy of Foundation Fieldbus, leveraging the capabilities of field devices to execute control functions locally while maintaining efficient communication and system reliability. By integrating control function blocks directly into field devices, Foundation Fieldbus enables a more distributed, flexible, and efficient control architecture, offering significant advantages over traditional centralized control paradigms.

Example of liquid level control using CIF

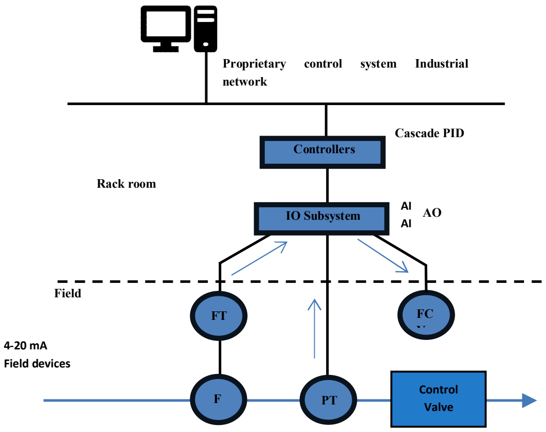


Figure.2 Control the liquid level in tank using CIF

In this example, a Foundation Fieldbus (FF) segment is utilized to control the liquid level in a tank, leveraging the Control in the Field (CIF) capability. The control valve and level sensor are integrated intothe same FF network, with the valve incorporating abuilt-in PID function block. This configuration enables the control loop to be closed directly between the level sensor and the valve, eliminating the need for a centralized controller such as a Distributed Control System (DCS) or Programmable Logic Controller (PLC).[9] This decentralized approach enhances system flexibility, reduces dependency on central controllers, and improves response times.

The execution order of function blocks, such as Analog Input (AI), PID, and Analog Output (AO), is managed by the Link Active Scheduler (LAS). The LAS is a centralized bus scheduler responsible for controlling medium access and maintaining a transmission schedule for all devices on the network. Devices classified as Link Master (LM) or Bridge are capable of functioning as the LAS, with only one LAS active per link. In the absence of an LAS during startup or in the event of a failure, the LM device with the lowest node address assumes the role. The LAS also handles both scheduled and unscheduled communications, as well as link maintenance tasks.

In systems with redundant H1 interface cards, the secondary H1 card typically serves as the backup location for the LAS.The placement of regulatory control functions significantly impacts macrocycle timing. Foundation Fieldbus technology offers three options for locating control functions: in the host system, within the field transmitter, or in the field positioner attached to the final control element (e.g., control valve).[10]

In this example, the PID and AO function blocks reside in the control valve positioner, while the AI block is located in the level sensor. This configuration minimizes network bandwidth usage, as communication is only required between the AI and PID blocks. The PID and AO blocks, being co-located in the valve positioner, do not require additional network communication, thereby optimizing system performance.

The decision to implement CIF depends on several factors, including the project's control philosophy, the availability of control blocks in field devices, and the requirement for input and output devices to reside on the same physical network segment. This decision should be made early in the project, as it influences subsequent design choices. Furthermore, as Fieldbus devices become more power-efficient, the primary design constraint often shifts to the number of messages that can be transmitted within a single macrocycle. Calculating macrocycle loading is therefore critical for optimizing the distribution of instruments across FF segments, ensuring efficient communication and system performance. This approach underscores the importance of strategic planning in leveraging Foundation Fieldbus technology for advanced process control applications.

Macro cycle

A "macrocycle" represents a single iteration of scheduled communication within a Foundation Fieldbus (FF) system. Figure 3 illustrates the relationship between the absolute link schedule start time, the Link Active Scheduler (LAS) macrocycle, device macrocycles, and their respective start time offsets. In this configuration, system management in the transmitter triggers the execution of the Analog Input (AI) function block at offset 0. At offset 20, the LAS issues a Compel Data (CD) command to the AI function block buffer in the transmitter, causing the data to be published on the Fieldbus.

At offset 30, system management in the valve initiates the execution of the PID function block, followed by the Analog Output (AO) function block at offset 50. This pattern repeats cyclically, ensuring the integrity and stability of the control loop dynamics. During function blockexecution, the LAS sends Pass Token (PT) messages to all devices, allowing them to transmit unscheduled messages, such as alarm notifications or operator setpoint changes. The only period when the Fieldbus is unavailable for unscheduled messages is between offsets 20 and 30, during which the AI function block data is being published.[11]

System response

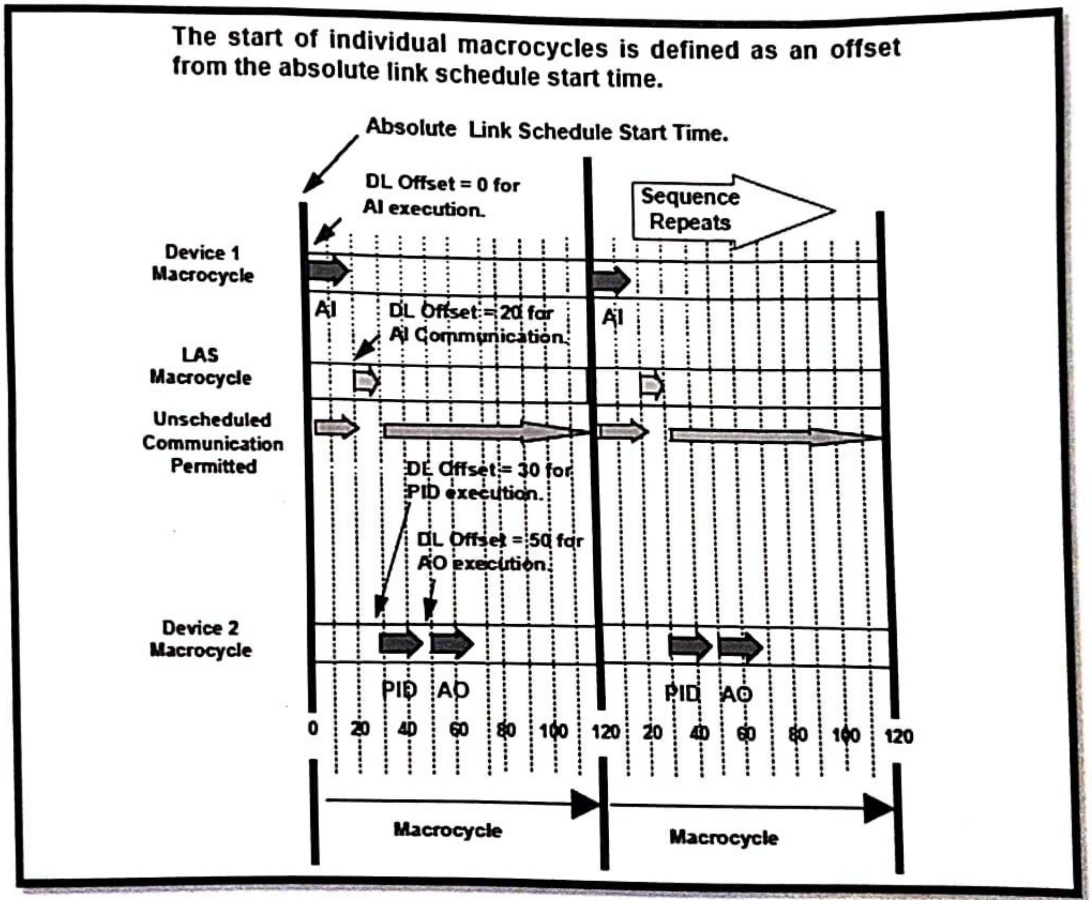


Figure.3 Macro cycle

The system response of the tank level control using Foundation Fieldbus with Control-in-Field (CIF) is characterized by speed, stability, and reliability, as the control loop is executed directly within the field devices. With the PID function block embedded in the control valve, communication delays are minimized, resulting in a deterministic and responsive control system. The absence of a central controller (DCS or PLC) for real-time loop execution reduces network congestion risks and ensures consistent process control, even during communication failures.

In the event of a disturbance, such as a change in the tank's inflow rate, the level sensor promptly updates the AI function block with the new process variable (PV). The PID controller in the valve compares the PV with the setpoint (SP) and adjusts the valve position accordingly to maintain the desired liquid level. The reduced loop latency and direct control execution within the valve enable faster settling times and minimal overshoot compared to traditional Control-in-Controller (CIC) setups, where additional communication delays can degrade system performance.

When PID parameters are well-tuned, the system exhibits a critically damped or slightly underdamped response, achieving the setpoint smoothly without excessive oscillations. Suboptimal tuning, however, may result in oscillatory behavior or sluggish responses, which can be rectified by adjusting the proportional, integral, and derivative gains. Furthermore, the system remains operational even if communication with the DCS or monitoring station is disrupted, as the control loop execution is entirely independent of the central controller. This fault-tolerant design enhances reliability, making it suitable for critical applications in industries such as oil and gas, petrochemicals, and power plants.

In summary, the Foundation Fieldbus with CIF implementation delivers a high-performance, low-latency, and resilient control system, making it an ideal solution for continuous level regulation in demanding industrial environments.

FF with Control-In-Controller (CIC)

Basic process

Foundation Fieldbus with Control-in-Controller (CIC) represents an advanced industrial automation architecture that centralizes control functions within controllers rather than relying exclusively on field devices. Foundation Fieldbus is categorized into two primary network types: H1 Fieldbus and High-Speed Ethernet (HSE). The H1 Fieldbus operates at 31.25 kbps and is primarily utilized for real-time process control applications, connecting field instruments such as pressure transmitters, flow meters, and control valves. It supports function blocks, enabling devices to execute predefined control algorithms and share process data efficiently. In contrast, HSE serves as a high-speed backbone network, facilitating the integration of multiple H1 Fieldbus segments. It enables rapid data exchange between controllers, operator workstations, and enterprise-level systems, ensuring the automation system can manage large data volumes and complex computations effectively.

Implementing Control-in-Controller (CIC) within a Foundation Fieldbus system offers several advantages, including centralized control, enhanced loop management, and improved diagnostic capabilities.[12] This approach is particularly advantageous in large-scale process plants where complex control strategies, interdependent loops, and high-speed response times are critical. By leveraging H1 Fieldbus for field-level communication and HSE for higher-level integration, Foundation Fieldbus provides a robust and scalable solution for modern industrial automation, meeting the demands of advanced process control applications.

H1 Fieldbus (31.25 kbps)

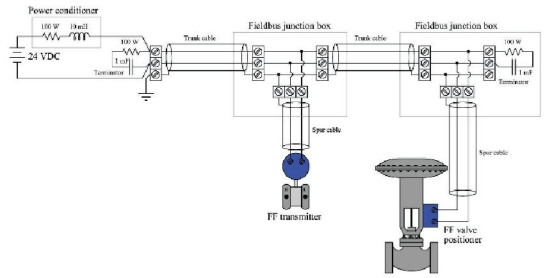
H1 Fieldbus is a key component of Foundation Fieldbus (FF) and is widely used for real-time process control applications in industries such as oil & gas, petrochemicals, power plants, and pharmaceuticals. Operating at 31.25 kbps, H1 Fieldbus allows multiple field devices, such as transmitters, sensors, actuators, and controllers, to communicate over a single twisted-pair cable, significantly reducing the wiring complexity compared to traditional analog 4-20mA systems. It enables digital communication, device interoperability, and advanced diagnostics, making it an efficient and reliable solution for industrial automation.

An H1 Fieldbus segment consists of a power supply, a Fieldbus cable, terminators, field devices, and a host system (such as a DCS or PLC). Devices such as pressure transmitters, temperature sensors, flow meters, and control valves are connected to the fieldbus segment. Each device is assigned a unique device address and communicates using Function

DOI: 10.48175/IJARSCT-24410

Blocks (FBs), which define control logic and data exchange methods. The Link Active Scheduler (LAS), typically hosted in a DCS or a field device, manages communication timing by assigning time slots for devices to transmit data.
Figure.4 H1 protocol physical layer

H1 Fieldbus follows a publisher-subscriber model, where control devices share process variables in real-time with controllers and operator stations. Communication is deterministic and cyclic, ensuring precise execution of control loops without the delays common in traditional polling-based systems. Device Description (DD) and Capabilities Files (CFF) are used to integrate new devices with the Fieldbus network, ensuring interoperability between different manufacturers.



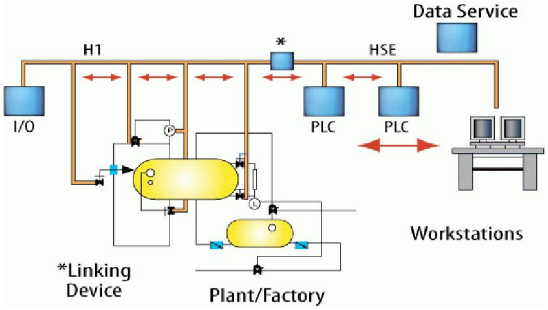


Figure.5 FF with High-Speed-Ethernet

HSE (High-Speed-Ethernet)

High-Speed Ethernet (HSE) constitutes an essential element of Foundation Fieldbus (FF), engineered to facilitate high-speed data transfer and seamless integration among field-level devices, controllers, and enterprise systems. Operating at speeds of 100 Mbps or higher, HSE functions as a robust backbone for extensive industrial automation networks. It supports real-time communication, centralized control, and efficient data exchange, rendering it particularly suitable for complex and data-intensive applications such as refineries, petrochemical plants, power generation facilities, and pharmaceutical manufacturing.

A Foundation Fieldbus Linking Device (LD) serves as a bridge between H1 Fieldbus segments and the HSE network, enabling seamless communication between low-speed field devices and high-speed control systems. HSE integrates with distributed controllers, Distributed Control Systems (DCS), and Supervisory Control and Data Acquisition (SCADA) systems, facilitating centralized process monitoring and control. Field devices, including intelligent transmitters, control valves, and analyzers, communicate with controllers through Linking Devices and Fieldbus Gateway Modules.[13] HSE adheres to Ethernet and TCP/IP communication standards, ensuring compatibility with contemporary industrial automation networks.

HSE supports both cyclic (real-time control) and acyclic (diagnostics and configuration) communication, optimizing system performance and reliability. It plays a pivotal role in enabling Control-in-Controller (CIC) implementation, wherein control logic is executed within a DCS or Programmable Logic Controller (PLC), ensuring rapid response times and advanced loop management. Prior to full deployment, the network undergoes rigorous testing for latency, data integrity, and device connectivity. With its combination of high-speed communication, scalability, interoperability, reliability, and security, HSE in Foundation Fieldbus offers a future-proof solution for modern industrial automation and process control applications, meeting the demands of increasingly complex industrial environments.

System performance

The performance of Foundation Fieldbus with Control-in-Controller (CIC) is characterized by centralized control execution, deterministic communication, and enhanced system stability, making it a preferred architecture for large-scale process industries such as oil and gas, petrochemicals, power plants, and pharmaceuticals. Unlike Control-in-Field (CIF), where control algorithms are executed within field devices, CIC centralizes control functions within a Distributed Control System (DCS), Programmable Logic Controller (PLC), or Fieldbus Linking Device. This approach minimizes the computational burden on field instruments, enabling devices such as transmitters, sensors, and actuators to focus on data acquisition and execution, while complex control logic is managed by high-performance controllers. As a result, CIC ensures efficient loop execution, improved data coordination, and optimized plant-wide automation.[14]

A significant performance advantage of CIC in Foundation Fieldbus is its high-speed and deterministic communication. The Link Active Scheduler (LAS), responsible for managing network timing, ensures that each field device transmits and receives data at predefined intervals, eliminating communication delays and jitter. This is particularly advantageous for critical control loops requiring precise timing and real-time responsiveness. Furthermore, the integration of H1 Fieldbus (31.25 kbps) for process-level communication and High-Speed Ethernet (HSE) (100 Mbps or higher) for backbone networking facilitates rapid data exchange between field devices, controllers, and operator workstations. This capability enables real-time monitoring and decision-making, ensuring prompt detection and correction of process disturbances, thereby enhancing process efficiency and product quality.

Another critical aspect of CIC's system performance is its fault tolerance and diagnostic capabilities. Centralizing control functions within a controller, rather than distributing them across multiple field devices, simplifies troubleshooting and fault isolation. Foundation Fieldbus provides advanced diagnostic tools that allow engineers to monitor device status, communication integrity, and process conditions in real time. These tools support predictive maintenance strategies, enabling industries to identify potential failures before they lead to downtime. In the event of a field device failure, the controller can swiftly reassign tasks to backup devices or implement fail-safe mechanisms, ensuring uninterrupted plant operation. This robust fault management and system resilience significantly enhance the overall reliability of industrial automation systems.

The scalability and integration flexibility of CIC-based Foundation Fieldbus architectures further contribute to their superior performance. With HSE serving as the backbone, multiple H1 segments can be seamlessly integrated into a unified control system, allowing large industrial plants to expand their automation networks without compromising performance. Additionally, CIC facilitates seamless integration with higher-level enterprise systems, such as Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution Systems (MES), and cloud-based industrial analytics platforms. This integration enables industries to implement advanced process optimization, remote monitoring, and artificial intelligence-driven automation strategies, further enhancing operational efficiency and competitiveness.

II. CONCLUSION

Foundation Fieldbus architectures utilizing Control-in-Controller (CIC) and Control-in-Field (CIF) offer distinct advantages and limitations, depending on the requirements of industrial automation systems. Control-in-Controller (CIC) centralizes process control in a DCS, PLC, or Fieldbus Linking Device, ensuring better coordination of complex control loops, improved fault tolerance, and simplified troubleshooting. It provides a structured and scalable architecture, where H1 Fieldbus devices act as data sources, while controllers execute loop management and logic processing. This method enhances system performance, communication speed, and diagnostic capabilities, making it ideal for large-scale process industries like oil & gas, petrochemicals, and power generation. However, CIC depends heavily on the controller's reliability, meaning a controller failure could impact multiple control loops unless redundancy is implemented.[15]

On the other hand, Control-in-Field (CIF) distributes control functions to intelligent field devices, reducing reliance on centralized controllers and improving system redundancy and decentralized decision-making. Each field device, such as a transmitter or valve, executes its own control logic, enabling faster response times and localized process adjustments without waiting for a central controller's command. This architecture minimizes communication delays and enhances system resilience against controller failures, making CIF suitable for applications requiring high-speed local control, such as chemical processing and batch manufacturing. However, its implementation is more complex, requiring intelligent field instruments with higher processing capabilities, which increases initial investment and configuration complexity.

Ultimately, the choice between CIC and CIF depends on the complexity of the process, network infrastructure, and reliability requirements. CIC is ideal for industries requiring centralized control, data analytics, and enterprise integration, while CIF is better suited for decentralized control environments demanding fast, independent decision-making.[16] By understanding the advantages, limitations, architecture, implementation, and performance differences between these two methods, industries can optimize their automation strategies to improve efficiency, reduce downtime, and enhance overall process control.

REFERENCES

[1]. Béla G. Lipták, Instrument Engineers' Handbook

[2]. Curtis D. Johnson, Process Control Instrumentation Technology

[3]. John M. Hughes, "Real-Time Embedded Systems and Components"

[4]. Peng, C., & Zhang, X. (2014). "Foundation Fieldbus Technology in Process Control." IEEE Transactions on Industrial Informatics, 10(3), 1457-1465.

[5]. Mehta, D., & Patel, J. (2018). "Analysis of Distributed Control Systems using Foundation Fieldbus." International Journal of Automation and Smart Technology, 8(2), 89-102.

[6]. Endress+Hauser Technical Papers & Whitepapers

[7]. ISA (International Society of Automation) – “Advanced Process Control with Foundation Fieldbus,” 2021.

[8]. Ian Verhappen and Augusto Pereira, “Foundation Fieldbus”, Fourth Edition.

[9]. FieldComm Group – Foundation Fieldbus Technical Guide, 2023.

[10]. Emerson Process Management – “Implementing Fieldbus-Based Distributed Control Systems,” 2022.

[11]. Yokogawa Technical Reports. Fieldbus Technology and Its Impact on Modern Industrial Automation.

[12]. Botros, R. (2015). Industrial Communication Technology Handbook. CRC Press.

[13]. Mackay, S., Wright, E., & Park, J. (2004). Practical Industrial Data Communications: Best Practice Techniques. Newnes.

[14]. Buchanan, W. (2017). Computer Buses: Design and Application. CRC Press.

[15]. Martinez, R., & Brown, P. (2020). "Control-in-Field vs. Control-in-Controller: A Comparative Analysis for Smart Manufacturing." Elsevier Journal of Process Automation, 45(2), 127-141.

[16]. Li, Y., & Zhang, H. (2018). "Performance Evaluation of Foundation Fieldbus in Process Control Applications." IEEE Transactions on Industrial Electronics, 65(5), 3901-3910.