White Paper

Virtualized Control Systems: Enabled by Workload Consolidation and Real-Time Converged Networks

As industries move towards more flexible, data-driven operations, the stalwart programmable logic controller (PLC) has become a barrier to progress. Virtual PLCs (vPLCs) have emerged as a solution to this challenge, replacing fixed-function PLC hardware with software-defined systems. vPLCs address many longstanding challenges in industrial automation, enabling organizations to digitalize their operations in ways that were impossible with traditional PLCs, reducing cost and increasing flexibility in the process.

The shift to vPLCs is underpinned by two key technologies. First is workload consolidation, which enables multiple vPLCs and other tasks to run on shared hardware. The second is the real-time converged network, which brings together information technology (IT) and operational technology (OT) communications.

This white paper explains the basics of vPLCs, explores their benefits, and highlights the crucial role of the real-time operating systems (RTOS) in enabling the underlying technologies of real-time converged networks and workload consolidation. By understanding these concepts, industrial leaders can better prepare for the future and gain a competitive edge in an increasingly digital manufacturing landscape.

INTRODUCTION TO VIRTUAL PLCS AND WORKLOAD CONSOLIDATION

Virtual PLCs can be seen as an evolution of the deterministic soft PLC concept. In this earlier approach, control logic was decoupled from the underlying hardware, allowing a soft PLC to run on a general-purpose computing platform.

vPLCs take this concept to the next level by leveraging virtualization for better resource utilization. In general, only one instance of a soft PLCs could run on a single hardware platform. In contrast, multiple vPLCs can be hosted on the same hardware—a capability known as workload consolidation.

The key advantages of vPLCs include:

1. **Enhanced data accessibility:** With multiple vPLCs running on a centralized platform, data from all control processes becomes more readily available for artificial intelligence (AI) and machine learning, data analytics, and decision-making.

2. **Improved flexibility:** vPLCs can be easily reconfigured, updated, or redeployed without physical hardware changes.

3. **Simplified maintenance:** Virtualized systems make it much easier to utilize IT practices for redundancy, software deployment, version control, and diagnostics.

While vPLCs represent a significant shift in control architectures, they maintain compatibility with existing PLC programming languages, methodologies, and tools. This allows organizations to reuse their current expertise while transitioning to more flexible, software-defined control systems.

The implementation of vPLCs relies heavily on two key technologies:

1. **TSN:** This set of IEEE 802.1 standards enables deterministic, real-time communication using Ethernet, allowing vPLCs to maintain the strict timing requirements of industrial control systems.

2. **Virtualization:** Embedded virtualization partitions the cores, memory, and other resources of a multicore processor so multiple vPLC instances can run concurrently on the same hardware without disrupting each other’s timing requirements.

A virtualization-enabled real-time operating system (RTOS) is essential to enabling both technologies within a single, physical platform running one or more vPLCs alongside additional workloads.

REDUCING COSTS WITH VIRTUALIZED CONTROL SYSTEMS

The consolidation of multiple control functions onto fewer physical devices through the use of embedded virtualization technology can significantly reduce cost. These include savings on hardware platforms, but also the cost of maintenance and future system upgrades.

Software updates can be deployed centrally, and version control becomes easier to manage. As a result, automation operators can leverage a centralized management infrastructure to deploy new capabilities onto deployed hardware far more efficiently than in the past.

The move to a unified architecture also makes it easier to scale industrial automation. By adopting standardized hardware and protocols, vPLCs using TSN can work with devices from different manufacturers, facilitating easier integration and expansion of industrial systems while reducing the need for specialized networks for different types of traffic. This interoperability and flexibility allow manufacturers to scale their operations more easily and adapt to changing requirements without significant infrastructure overhauls.

THE ROLE OF CONVERGED NETWORKS IN VIRTUALIZING VPLC DEVICE CONNECTIONS

In the same way vPLCs allow control systems to use general-purpose hardware, Time-Sensitive Networking enables industrial networks to transition to a single, converged network built on standard Ethernet. As a set of IEEE 802.1 standards, TSN offers a number of features that enable deterministic communication over what was traditionally a best-effort networking technology:

- **Time synchronization:** TSN ensures precise time synchronization across all network devices using IEEE 802.1AS standards, derived from the IEEE 1588 Precision Time Protocol (PTP).

- **Traffic classes:** Traffic of different types is assigned to different parts of the schedule to separate it from other traffic types.

- **Frame preemption:** This feature allows high-priority frames to interrupt the transmission of lower-priority frames.

- **Path control and reservation:** TSN provides mechanisms for reserving network bandwidth and controlling the path of data through the network.

- **Reliability:** TSN includes features for seamless redundancy and fault tolerance, crucial for industrial applications.

As a result of these deterministic features, TSN allows multiple traffic types—such as control signals, video, and diagnostics—to be transmitted over the same Ethernet infrastructure without interference between the different traffic types. What's more, different industrial protocols can coexist on the same TSN network, eliminating the need for separate physical networks for each protocol.

The right combination of TSN features enables the provisioning of "virtual cables" throughout a network that replace traditional fixed connections with dynamic, software-defined paths. Not only does this approach reduce the physical complexity of the network, simplify reconfiguration, and streamline management, it also allows greater flexibility and cost reductions in control system deployments.

APPROACHES TO USING TSN IN CONVERGED NETWORKS

TSN has matured significantly in recent years, with improvements in stability and the development of TSN profiles for different industries. While some complexity remains in network configuration, tools are being developed to streamline TSN network management for developers and end-users.

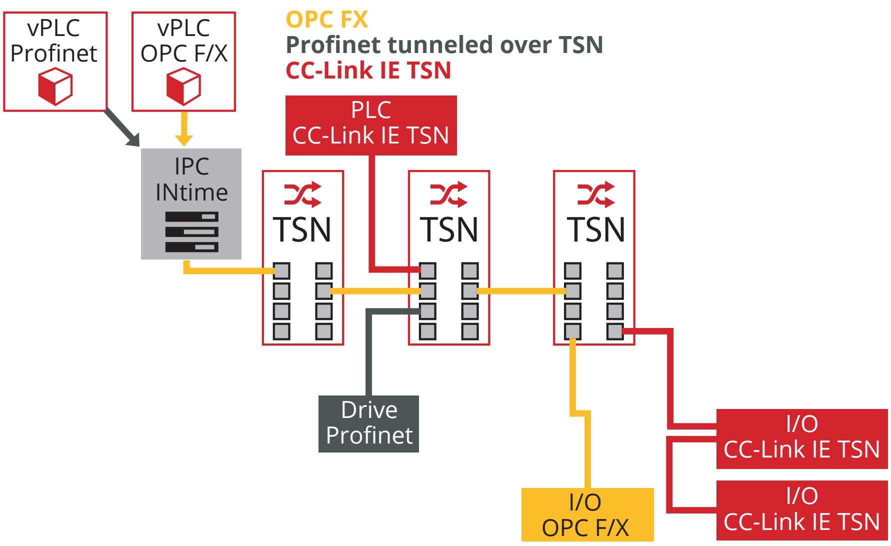
As the automation industry moves towards TSN adoption, there are typically three approaches to utilizing TSN for industrial applications:

1. **Tunneling legacy fieldbuses:** This approach encapsulates existing fieldbus protocols like Profinet within TSN, allowing for a gradual transition.

2. **TSN-based fieldbuses:** Some protocols, such as CC-Link IE TSN, are being redesigned to use TSN as their underlying technology. By using the technology rather than a network, they specify how everything should function on the network in a closed environment.

3. **TSN as a resource:** Some protocols like OPC FX assume the presence of a managed TSN network. TSN interacts with these protocols by allocating network resources to them.

As TSN continues to evolve, it's becoming an increasingly vital component in the transition to more flexible, efficient, and interconnected industrial control systems.



BOOSTING AGILITY WITH VPLCS ON A TSN-ENABLED CONVERGED NETWORK

The union of vPLCs and TSN amplifies the benefits of both technologies and represents a full migration to a converged IT/OT infrastructure that creates new opportunities for industrial automation and control systems. Specifically, this synergy paves the way for more flexible, efficient, and data-driven manufacturing processes.

With vPLCs running on centralized hardware and communicating over a TSN network, data from all control processes becomes more readily available. This improved data accessibility enables real-time analytics and decision-making capabilities, allowing manufacturers to optimize their processes and respond quickly to changing conditions.

CASE STUDY: EARLY ADOPTION IN AUTOMOTIVE MANUFACTURING

A major automotive manufacturer has successfully implemented vPLCs for control tasks in their production environment. This implementation uses vPLCs to control auxiliary systems and manage less time-critical processes, leveraging existing IT infrastructure to reduce the need for dedicated control hardware.

The benefits realized from this implementation have been significant:

- Hardware costs have been reduced by consolidating multiple control functions onto fewer physical devices.
- The manufacturer gained improved flexibility in reconfiguring production lines.
- Enhanced data collection capabilities have enabled better analytics and predictive maintenance.
- The use of a converged network has simplified the overall network architecture and reduced maintenance costs.

As the use of vPLCs spreads, more industries are discovering how it enables digitalization of industrial automation for real-world benefits. By providing a higher level of determinism with RTOS and technologies like TSN, automotive manufacturers and other OEMs can realize even greater ROI.

PRACTICAL IMPLEMENTATION OF VPLCS WITH TSN

While the benefits of vPLCs and TSN are clear, implementing these technologies in real-world industrial settings requires careful consideration of hardware, software, and networking aspects.

This section outlines key considerations for practical implementation.

HARDWARE CONSIDERATIONS FOR WORKLOAD CONSOLIDATION

Robust compute platforms are the foundation of a vPLC implementation. Features essential for effective workload consolidation include:

- Multi-core processing
- Advanced cache management
- Hardware-assisted virtualization support
- A TSN-compatible network interface

Accessible through solutions like Intel* Time Coordinated Computing (Intel* TCC), these capabilities ensure that multiple vPLC instances can run concurrently without interfering with each other's performance.

Networking hardware plays an equally important role. TSN-capable Network Interface Cards (NICs) are required, and the network infrastructure must include industrial-grade TSN switches capable of handling real-time traffic.

SOFTWARE STACK TO SUPPORT VPLCS

The RTOS is a key component of the software stack that abstracts the underlying complexity of TSN network synchronization, traffic shaping, and other requirements to plug vPLCs into the converged network.

The RTOS should support:

- Robust partitioning between applications to prevent resource jockeying and task interference that would disrupt deterministic task execution.
- Support for popular hypervisors, particularly the real-time hypervisors that ensure determinism
- Ability to run alongside general-purpose operating systems like Microsoft* Windows and Linux

The TenAsys® INtime® RTOS exemplifies these characteristics. It supports popular hypervisors out of the box, and is deployable as a companion to Windows and Linux while maintaining rigid separation from the host. This capability allows multiple vPLC instances to run on the same platform, with each isolated from the others to ensure stable and predictable performance. A comprehensive TSN protocol stack—like the one available for INtime—is also required. This stack should give access to the converged network without the applications needing detailed knowledge of the underlying implementation.

NETWORK CONFIGURATION AND MANAGEMENT IN A CONVERGED ENVIRONMENT

Depending on the structure and scale of a TSN network, different approaches to network configuration and management may be appropriate:

- Today, manual configuration and an RTOS can be sufficient to manage TSN endpoints and smaller scale infrastructure. For example, a deployment with a couple of machines running vPLCs connected via TSN.
- For large, complex installations, like an entire factory, configuration software is required to streamline the implementation of more advanced TSN features such as traffic classes, scheduling, and time synchronization.

In either deployment scenario, RTOS plays an essential role to scheduling network traffic from the device side as well as managing TSN-enabled applications running on the endpoint. However, very few of the RTOSs available today provide the necessary infrastructure to support TSN out of the box. Fewer still were designed to accommodate future changes to TSN standards, which will inevitably change the way TSN networks are configured and provisioned.

TenAsys INtime is one RTOS that supports TSN networking stacks and libraries out of the box and was designed to scale with the evolution of TSN. INtime's heritage is real-time Ethernet-based field-level communications between devices and controllers. It provides a flexible configuration interface to help developers harness TSN's potential now and in the future without the need for specialized tools and utilities.

In practice, INtime abstracts the gap between the control logic of vPLCs, the virtual network, and other connected control endpoints. This means it can help engineers map vPLC applications to network resources, properly assign TSN traffic classes, designate appropriate, Quality of Service (QoS) requirements, and more, all from the device level.

IMPLEMENTATION CHALLENGES AND SOLUTIONS

By focusing on clear, simple configurations and providing user-friendly tools for endpoint setup, the complexity of implementing a TSN network today can be significantly reduced for end-users. By selecting a forward-looking RTOS like INtime, these users can also streamline connected device processes and components while progressively realizing the benefits of vPLCs and TSN.

The adoption of vPLCs and TSN offers transformative advantages for industrial automation, but it also presents specific challenges. Some of the main considerations are as follows:

1. Transitioning from Traditional Systems

Challenge: Moving from traditional PLCs to vPLCs involves integrating new software-defined controls with existing legacy systems.

Solution: Adopt a phased migration strategy that begins with hybrid systems where traditional PLCs and vPLCs operate together. This approach allows all field components and software to remain identical by keeping the application layer intact and only exchanging the connectivity. This minimizes disruption and allows for a smoother transition.

2. Understanding Network Configuration and Management

Challenge: Implementing TSN introduces complexity in network configuration, requiring setup of time synchronization, traffic scheduling, and bandwidth control.

Solution: Using an RTOS like INtime RTOS is a best practice for TSN network endpoint configuration. It simplifies provisioning of the TSN network services required by connected devices through easy-to-use APIs. This approach abstracts network complexity, allowing engineers to concentrate on the system's application rather than exerting effort on the underlying TSN infrastructure enablement.

3. Ensuring Real-Time Performance and Determinism

Challenge: Maintaining real-time performance and deterministic communication in a virtualized environment, especially when consolidating multiple vPLC instances.

Solution: Determinism can only be achieved holistically, with an architecture that combines local system real-time capabilities with network real-time features. This involves choosing an RTOS like INtime with strong support for TSN to enable network-wide time synchronization.

THE ROLE OF INTIME® IN ENABLING VPLCS

The INtime RTOS, developed by TenAsys, plays a crucial role in enabling the implementation of vPLCs. By providing a deterministic environment and robust support for workload consolidation, INtime allows multiple vPLCs to run in parallel on the same platform while maintaining the real-time responsiveness expected of PLCs.

From a workload consolidation perspective, key features of INtime include:

- **Real-time Performance:** INtime®'s kernel ensures deterministic execution for critical tasks, essential for maintaining the real-time responsiveness expected of PLCs.
- **Robust Partitioning:** INtime offers mechanisms to partition CPU, memory, and I/O resources, ensuring each vPLC instance has the resources it needs in an isolated environment that prevents interference between different control applications.
- **Hypervisor support:** INtime supports virtualized environments, enabling consolidation with general-purpose operating systems like Linux and Windows. This makes it ideal for hosting vPLCs alongside human-machine interface (HMI) and data analytics applications.
- **Development and Debugging Tools:** A comprehensive set of tools for developing, testing, and debugging vPLC applications streamlines the development process.

INtime also offers a strong foundation for TSN. One of INtime's key benefits is its ability to abstract hardware and network complexities from the application layer.

This abstraction allows control engineers to focus on the control aspects of their systems and applications, rather than exerting effort on how the underlying TSN infrastructure is enabled. For example, INtime handles:

- Chipset-specific features for precision time execution and synchronization
- TSN-capable network interface card (NIC) configuration and management
- Time synchronization across the local system and network interface

By managing these low-level details, INtime enables developers to create vPLC applications using familiar PLC programming paradigms, without needing to become experts in the underlying hardware or network technologies.

THE EMERGING TSN ECOSYSTEM

As vPLCs and TSN become more prevalent in industrial automation, a supportive ecosystem is emerging, composed of key players across hardware, software, and networking domains. This ecosystem is crucial for driving innovation, ensuring interoperability, and advancing the adoption of these technologies.

Key contributors include:

- **Hardware:** Intel*, NXP*, Renesas*, and Microchip* are developing TSN-enabled processors and network interface cards.
- **Networking:** Companies like HIRSCHMANN*, Kontron, and Moxa* are offering industrial-grade TSN switches and infrastructure.
- **Software and RTOS:** TenAsys® provides the INtime® RTOS with TSN support, while other players like Real-Time Systems GmbH offer hypervisors designed for deterministic applications.
- **Industrial Automation:** Siemens*, CODESYS*, and Rockwell Automation* are developing vPLC solutions and TSN-enabled devices.
- **Test and Measurement:** Keysight* and Calnex provide TSN testing and validation tools.

With multiple vendors involved, ensuring that components from different manufacturers work seamlessly together is essential. Standardization through IEEE and industry consortiums helps create a common framework that enables this interoperability.

Plugfests play a vital role in ensuring this ongoing progress. These events bring together vendors from across the ecosystem to test the interoperability of their products in real-world scenarios. Additionally, these events foster collaboration among industry leaders, driving the continuous improvement of the technology and accelerating its adoption across the industrial sector. For these reasons, TenAsys plays an active role in driving these events.

FUTURE OUTLOOK

As the adoption of vPLCs and TSN continues to grow, the ecosystem surrounding these technologies is expected to evolve rapidly, driving significant advancements in industrial automation. Industry leaders are continually refining their products to enhance interoperability, scalability, and performance. As more companies adopt these technologies, the ecosystem will mature, offering more robust solutions and fostering greater collaboration among vendors.

The future of vPLCs and TSN is closely tied to their integration with other emerging technologies such as AI and digital twins. AI can enhance predictive maintenance and process optimization, while digital twins can enrich virtual replicas of physical systems with data from vPLCs and TSN networks for more accurate simulations.

The convergence of vPLCs, TSN, and other advanced technologies will have a profound impact on a wide range of industries. Manufacturing, energy, and logistics are just a few sectors that stand to benefit from increased efficiency, flexibility, and scalability. As these technologies become more integrated into industrial operations, they will enable new business models, drive innovation, and significantly improve operational performance.

CONCLUSION

The convergence of Virtual PLCs and Time-Sensitive Networking represents significant advancement in industrial automation. These technologies have matured to a point where they are ready for practical implementation, offering tangible benefits in flexibility, efficiency, and data accessibility.

As the industrial landscape continues to evolve, organizations that start their transition to vPLCs and TSN now will gain a competitive edge. Early adopters will be better positioned to leverage emerging technologies and adapt to changing market demands.

TenAsys, with its INtime software suite, offers a robust platform for organizations looking to explore the possibilities of vPLCs and TSN. By partnering with TenAsys, companies can begin their journey towards a more flexible, efficient, and future-ready automation infrastructure.

Help us build critical mass for TSN. Visit TenAsys.com for more information.

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