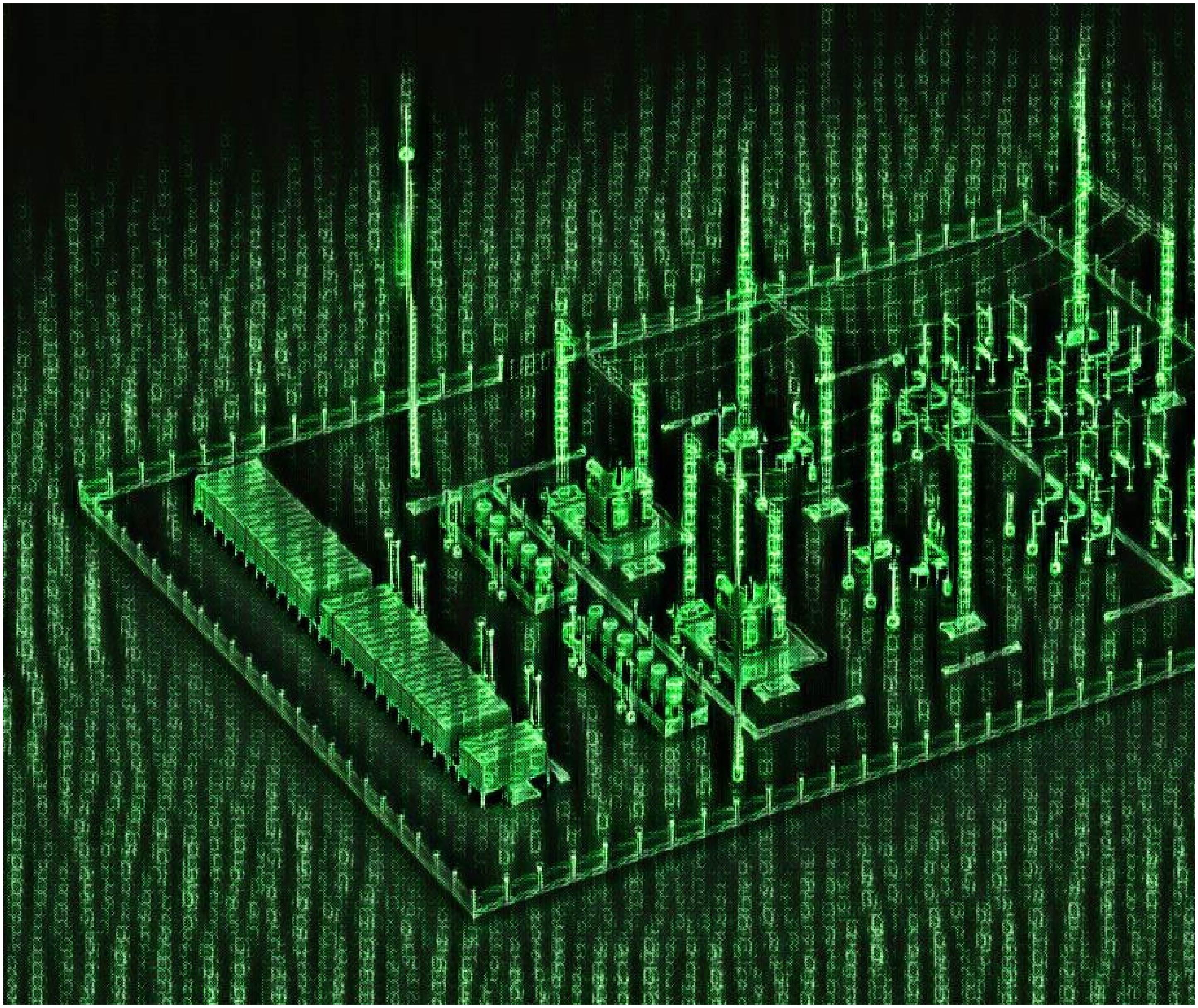

BREAKING BOUNDARIES

Architecting Virtual RTUs for Tomorrow's Grid

Garrett Schmidt

Berno Mattheaus

NovaTech AUTOMATION

In the rapidly evolving energy sector, the concept of virtualized protection and control (VPC) represents a significant technological advancement. Specifically, the paradigm shift from traditional hardware-based remote terminal units (RTUs) toward software-defined solutions, such as those offered by NovaTech Automation, allows grid operators to create innovative and flexible solutions for the grid of the future.

vPAC Alliance

The drive to address the challenges of creating a sustainable energy infrastructure has culminated in the creation of a consortium called the Virtual Protect and Control (vPAC) Alliance, which is comprised of a number of technology leading companies including VMware, Intel, and NovaTech.

Figure 1: vPAC Alliance Members

A major effort has been undertaken by the vPAC Alliance to create a specification that covers the use-cases, architecture, foundational software, hardware, and cybersecurity to utilize virtualization technologies to deploy software-defined VPC systems in substations. The vPAC Alliance has a vision “to accelerate the creation of a standards-based, open, interoperable, and secure architecture. Using software-defined technologies and infrastructure to drive substation digitalization enables an adaptive, resilient, and intelligent grid for the future.”

What is Virtualization?

Virtualization is a foundational technology that enables the creation of virtual instances of multiple physical devices, such as RTUs, gateways, protection relays, or other computing devices within a single physical hardware system. This is achieved through a software layer called a hypervisor which sits between the hardware and the virtualized instances and manages the virtualized devices and the underlying physical resources efficiently. By decoupling software from hardware, virtualization offers several benefits, including increased resource utilization, cost savings through consolidation, enhanced flexibility and scalability, reduced footprint, faster deployment, remote maintenance, and improved disaster recovery capabilities. This also enhances security by isolating applications and workloads from one another.

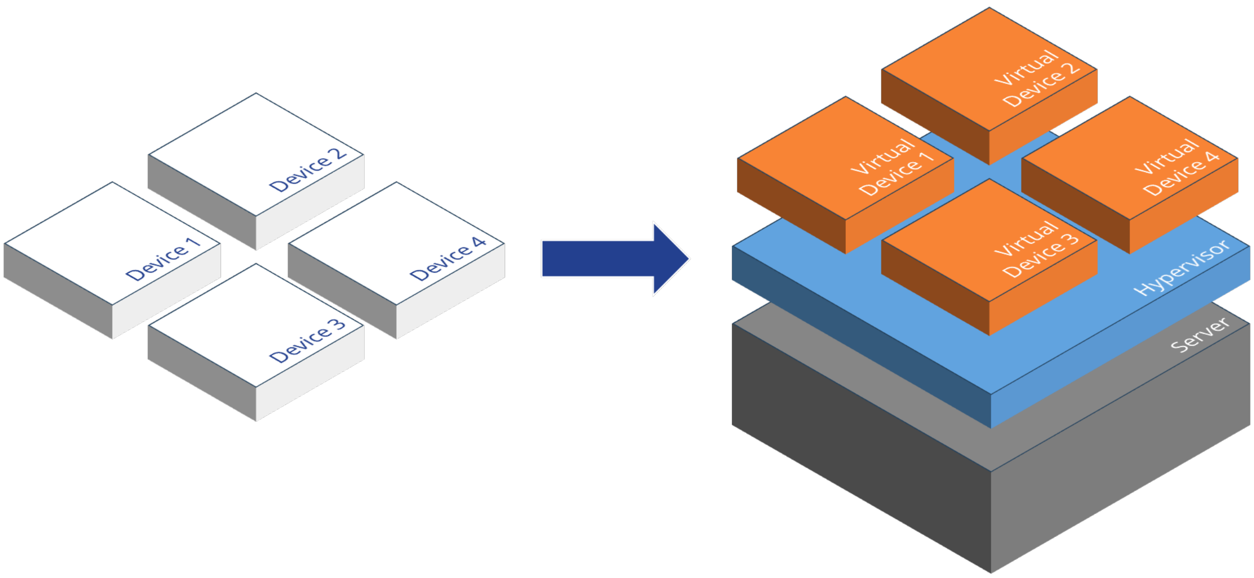

Figure 2: Moving from hardware devices to virtual devices

In practical terms, virtualization empowers organizations to optimize their IT and substation infrastructure by running multiple virtual machines (VMs) or containers on a single physical server. Each VM operates independently, with its own operating system and application such as RTU or protective relay. This allows for more efficient resource allocation, as unused capacity from one VM can be utilized by others, leading to higher overall resource utilization rates.

Server Selection

Selecting the right server for hosting a virtual RTU in a substation environment involves careful consideration of various factors to ensure optimal performance, reliability, and scalability. The server's CPUs (Central Processing Unit) play a critical role in handling the computational demands of virtualization. It is essential to choose a CPU with sufficient processing power and cores to support the number of virtual machines (VMs) running on the server. Typically, multi-core processors with high clock speeds are preferred to ensure smooth operation under heavy workloads. Intel's Xeon® processors, for example, provide comprehensive virtualization support, with a high number of cores per CPU and hyperthreading capability.

Storage is another crucial aspect to consider when selecting a server for virtual RTU deployment. Server-based virtual RTUs enable the acquisition and storage of more substation data than conventional RTUs. Therefore, storage performance is paramount for ensuring smooth operation and timely data processing. Utilizing SSDs (Solid State Drives) or NVMe (Non-Volatile Memory Express) drives can significantly enhance storage throughput and reduce latency compared to traditional HDDs (Hard Disk Drives). Additionally, RAID configurations can be implemented to improve data redundancy and fault tolerance, ensuring data integrity and system reliability. Finally, the server hardware must be hardened for the substation environment. A growing number of substation hardened servers with IEC 61850-3 and IEEE 1613 compliance are entering the market. This guarantees reliable performance in harsh electrical environments over a wide temperature range.

Hypervisor Selection

A hypervisor is a software layer that enables the creation and management of virtual machines (VMs) on a physical server. It abstracts the underlying hardware, allowing multiple VMs to run independently on the same physical machine. One widely used hypervisor is VMware ESXi, which is a bare-metal hypervisor specifically designed for virtualization. ESXi installs directly on the server hardware, eliminating the need for a separate operating system, and provides a lightweight and efficient virtualization platform. It efficiently allocates hardware resources such as CPU, memory, storage, and network bandwidth among VMs, ensuring optimal performance and resource utilization. With features like live migration, high availability, and centralized management through vCenter Server, ESXi offers a robust and scalable virtualization solution for substation automation.

Virtualization Security

Security in virtual environments extends to both the hardware the virtual machines are running on and security software that can be deployed in virtual environments but is easier to manage than security in conventional systems.

On the hardware level, the Intel ecosystem and Xeon® processors provide numerous security technologies to protect the server from the BIOS up. Intel vPro® provides remote management capabilities and hardware-based security measures, including threat detection such as ransomware. Intel Hardware Shield minimizes the risk of malware injection by protecting the BIOS and preventing injected malware from damaging the operating system. Intel Threat Detection Technology (TDT) uses machine learning algorithms to profile malware as it attempts to execute on the CPU microarchitecture and can detect newly developed attacks. TDT alerts are sent to the server's security software for further action.

On the software level, security appliances such as firewalls or intrusion detection systems can be installed in addition to the OrionVX and other virtualized devices to comply with corporate security requirements. New appliances can be installed and configured at any later time. Segmentation and isolation provide additional application security and prevent attacks from moving through the system.

The hardware and software security features allow easy, comprehensive, and remote monitoring of the entire set of virtual applications as well as the server hardware.

In the case of a security event, golden images of virtual RTUs can be redeployed instantly as opposed to conventional RTUs which may require a physical reinstallation.

OrionVX: A Virtual RTU

NovaTech introduced OrionVX at DISTRIBUTECH 2024. OrionVX is the vPAC Alliance's first virtual RTU. Built on the same OrionOS™ as the line of hardware-based Orion RTUs, OrionVX offers the identical robust functionality, user experience, and reliability. In addition, OrionVX uses the same configuration tools, HMI, software options, and Ethernet-based protocols as all Orion RTUs.

Figure 3: OrionVX

OrionVX runs on Intel Xeon® scalable processors to ensure real-time performance and has been developed for VMware's ESXi 8 hypervisor. It can be deployed as a high availability system using either Orion's in-built redundancy features or vSphere's high availability and fault tolerance capabilities when deployed in a cluster.

Benefits for Substation Control Systems

Virtual RTUs enhance flexibility and scalability in substation automation.

- With traditional hardware-based RTUs, expanding or upgrading the system often involves significant time and resources in terms of installation, configuration, and wiring. In contrast, virtual RTUs enable use of sampled value streams, rapid deployment, and scaling of resources on-demand, allowing substations to adapt quickly to changing operational needs or expanding infrastructure while reducing outage time.

- Virtualization facilitates seamless integration with, and front-ending of, upstream software-based automation systems, such as SCADA (Supervisory Control and Data Acquisition) or EMS (Energy Management Systems), promoting interoperability and enhancing overall system efficiency.

- Virtually unlimited processing power and storage enable new RTU applications related to event storage, real-time logic execution and control operations, and asset management.

- Remote upgradability and management reduce ongoing maintenance costs.

Ultimately, by embracing virtual RTUs, utilities can achieve cost savings, operational agility, and improved reliability in their substations and automation processes.

Outlook for Virtual Substations

Today, substations can easily have 200 or more devices, each performing a specific function such as metering, indication, switching, or signal conversion. It requires a massive effort to install and maintain over time.

Virtualization offers utilities the opportunity to significantly reduce costs for new substation design, reduced copper wire, and the ability to easily replicate substation designs.

As the number of "Internet of Things" (IOT) devices increase on the grid, virtual RTUs will be well positioned to aggregate the massive number of nodes and data points, even potentially running on Enterprise level servers.

In order to maximize the success of a virtual RTU deployment, users should be cautious in their vRTU selection process. Choose a vRTU from an established market leader to ensure quality and support. Understand the software licensing model that's offered to avoid surprise fees and recurring charges. Selection of a vRTU that offers the same user experience and features as hardware-based RTUs will ease the transition between platforms to future-proof investments.