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# Pushing the Frontiers of Technology

*For an efficient distribution grid operation, it is critical to manage both voltage levels and reactive power using VVO. This helps in reducing system losses and peak demand. Read on...*

Modern electricity grid is being powered by growing number of DER (Distributed Energy Resources) connections. DERs supply energy from the edge of the grid, close to load centres, to the local distribution grid and also to the transmission grid, in a bidirectional electricity flow. Integration of DERs into the grid necessitates a compatible design with higher level automation of the T&D infrastructure and substation that facilitates bidirectional flow, new measurements, controls and protection systems. Advancements in electric substation automation, monitoring, protection, and control systems are pivotal in decarbonizing the electricity grid while maintaining its stability and security.

Electric substations are undergoing significant advancements and innovations to enhance grid stability and resilience, with the integration of RE (Renewable Energy) sources, BESS (Battery Energy Storage Systems), and Electric Vehicles (EV). Innovative technologies driven by modern research and development are leading the way in modernizing the grid, and its components, in building efficiency, improving reliability and accelerating energy transition.

## Digital Substations

Digital substations replace conventional analog with digital communications, which enhances efficiency and reliability.

They use advanced sensors, automation, and communication technologies to monitor and control electrical equipment in real-time to optimize substation asset performance, reduce outages, and improve reliability. They support integration of RE sources by providing flexibility and responsiveness to manage variable power inputs, and taking timely control and protective actions. It enables real-time data integration, facilitating accurate decision-making, reduced downtime and maintenance costs, increased asset safety and reliability, and improved data analytics.

IEC 61850 standard ensures multi-vendor interoperability between Intelligent Electronic Devices (IEDs) within the digital substation. The key benefits of digital substations are enhanced safety and protection, improved monitoring with real-time data, asset optimization, lifespan increase, reduced downtime and lesser maintenance costs.

The first digital substation (400 KV) was commissioned at Maler Kotla in Punjab by POWERGRID (PGCIL). Few other utilities namely BRPL (BSES Rajdhani Power Limited), GETCO (Gujarat Energy Transmission Corporation), and OPTCL (Orissa Power Transmission Corporation Limited) have also commissioned digital substations. More digital substations are planned across the country to accommodate growing DER connections, along with scaling up of the grid capacity and substation infrastructure.

## Volt/VAR Optimization (VVO)

For an efficient distribution grid operation, it is critical to manage both voltage levels and reactive power using VVO. This helps in reducing system losses and peak demand. In VVO, voltage control devices at the substation are used to reduce the voltage drop from the substation to the load end, while maintaining the service voltage to customers within defined limits.

VVO practices result in reduced peak demand or reduced energy consumption or both, and increased real-power throughput from reactive power management. The efficiency gains are realized from a reduction in the system voltage and power losses.

## Phasor Measurement Units (PMUs)

PMUs are used for transmission system monitoring, control and protection. They measure time-stamped voltage and current phasors using GPS clock. These time-synchronized (synchrophasor) units provide real-time observability and state estimation of the transmission system, enabling operators to assess the state of the network and respond quickly to grid disturbances. PMUs transmit time-synchronized data from geographically diverse network locations to the Wide Area Monitoring, Protection and Control System (WAMPACS) or WAMS.

## Wide-Area Monitoring System (WAMS)

Transmission SCADA (Supervisory Control and Data Acquisition) system is used for high-level monitoring and control of the grid. However, due to structural changes in the grid to cope with demand volatility and growing integration of renewable energy systems, SCADA alone is not sufficient and WAMS is used to monitor fast system transients in modern power systems.

WAMS receives dynamic phasor data (voltage, current and frequency) from PMUs that are used to monitor the grid in real-time, detect fluctuations and identify vulnerabilities. With this data, WAMS keeps track of situational awareness and maintains stability of the grid when unpredictable Distributed Energy Resources (DERs) connect to it.

## Substation Cybersecurity

As transmission and distribution grids become increasingly digitalized, they are also exposed to new vulnerabilities. Substations become prime targets for cyber threats due to their critical role in power systems. Cyber threats to digital substations include virus, malware, ransomware, phishing attacks, etc. Impacts of attacks by cybercriminals on a substation can lead to power outages, grid collapse, substation equipment failure and data breaches with severe operational and financial implications.

Electrical utilities are implementing advanced cybersecurity technologies, such as Firewalls, Proxy Servers with access control, Advanced Encryption Standard (AES), Intrusion Detection/ Prevention Systems (IPS/ IDS), and secure data communications to protect data and asset integrity. AI/ ML tools are also being used for early detection and prevention of suspicious activities, unauthorized access, cyber intrusions and man-in-the-middle attacks.

## Supervisory Control and Data Acquisition (SCADA)

The primary function of SCADA is data acquisition, visualization and control of T&D parameters from across the network, to enable safe grid operations. The Arithme¬tic Logic Unit (ALU) in SCADA is used for Automatic Demand Response (ADR) management, condition-based load shedding and under-voltage, overload or other critical monitoring.

The Control Unit (CU) in SCADA is used for automatic grid protection, circuit switching and network restoration. SCADA application is useful to manage grid contingencies, protect the grid against voltage or load overshoots, prevent cascade tripping and blackouts, and balance electricity demand. Advanced SCADA also includes automated tools e.g. Advanced Distribution Management System (ADMS) and Energy Management System (EMS), for energy accounting, dispatch scheduling, feeder management, demand response, voltage and frequency control, and grid balancing.

## Innovations in Grid Modernization and Decarbonization

Most of the leading innovations in grid modernization are aimed to make it more resilient (self-healing), adaptive (flexible), secure and reliable, for example:

- **Solid-State Transformers (SSTs):** SSTs have emerged as a better alternative to traditional transformers. They use solid-state electronics, enabling better control of voltage and current, bidirectional power flow, integration of RE sources and grid decarbonization.
- **Battery Energy Storage System (BESS):** Substations are being equipped with battery energy storage systems, powered by clean energy, to manage peak loads, stabilize voltage, and provide backup power during outages. Tata Power-DDL has installed South Asia's first 10 MW grid-connected BESS, which is being used for demand side management, peak load reduction, frequency regulation and supply reliability.
- **Automatic Power Factor Correction (APFC):** Inductive loads require active power (KW) to perform actual work, and reactive power (KVAR) to maintain the magnetic field. Though reactive power is necessary for inductive loads, it imposes an undesirable burden on supply by causing the current to be out of phase with the voltage. APFC calculates the reactive power consumed by inductive load and compensates the lagging power factor using capacitor bank. Low PF can be due to significant phase difference between voltage and current at load terminals or high harmonic content, which can be improved by APFC or harmonic filters.
- **EV Charging Infrastructure:** Substations are being upgraded to support the increasing demand for EV charging stations, without compromising stability. The transition to electric mobility is one of the strategies to decarbonize the transport sector, and the grid has to adapt and be flexible enough to support the load of EVs when they are charging.
- **Internet of Things (IoT) in Grid Management:** IoT facilitates real-time monitoring of the grid with the help of sensors deployed across T&D network to capture real-time voltage, current, and other parameters. IoT data is transmitted in real-time to monitor grid health, detect abnormalities, and proactively address network issues with predictive maintenance. IoT sensors help in implementing demand response programs for efficient grid management, optimize energy consumption, monitor grid disturbances, reduce peak loads and support grid decarbonization.

## Conclusion

The technologies discussed above are critical for creating future smart T&D grid infrastructure, which are safe and reliable, and adaptive to variable RE connections without compromising grid stability and quality of supply. Enabled by technology research and innovations, the future grid ecosystem must aim to achieve the KPI-driven outcomes, namely:

- **Enhanced Grid Reliability:** Reduction in outages and improved response times to disturbances, with real-time monitoring, control and protection.
- **Increased Grid Flexibility:** Increased capacity of adding RE sources and increased grid flexibility to accommodate variable RE connections, promoting grid decarbonization and sustainability.
- **Improved Operational Efficiency:** Optimized asset utilization and cost savings, with better network observability and automated controls. EI

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