



The Strategic Role of Advanced Volt/Var Optimization (VVO) in Modern Power Systems

Pharoes Advisory
July 2025

PUBLIC

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Introduction

As electricity grids evolve to accommodate a higher share of variable renewable energy sources, increasingly electrified end uses, and more distributed energy resources (DERs), the task of managing voltage and reactive power becomes significantly more complex. Both transmission and distribution system operators (TSOs and DSOs) are facing new operational challenges that cannot be addressed with traditional, rule-based voltage control schemes alone.

Advanced Volt/Var Optimization (VVO) offers a systematic, optimization-driven approach to managing voltage profiles and reactive power flows throughout the power system. By doing so, it enables enhanced operational efficiency, greater system resilience, better utilization of assets, and an increase in renewable hosting capacity.

Why VVO is Critical for Grid Operators

1. Voltage Compliance and Grid Stability

For TSOs, voltage stability is a critical component of overall system security. Long transmission lines and heavy load centers create voltage regulation challenges, especially under contingency conditions or fluctuating demand. Meanwhile, DSOs are facing highly localized voltage issues due to high penetration of rooftop solar PV, electric vehicle charging stations, and behind-the-meter battery systems.

VVO ensures that voltages stay within operational limits (typically $\pm 5\%$ of nominal voltage) through coordinated control of network assets such as:

- On-load tap changers (OLTCs)
- Shunt capacitors and reactors
- Voltage regulators
- Smart inverter-based DERs

This real-time coordination helps avoid conditions that could lead to voltage collapse or equipment damage, especially under changing grid conditions.

2. Minimizing Losses and Improving Efficiency

Reactive power flows do not perform useful work but still consume capacity on the grid. Poor Var management can lead to high circulating reactive currents, which result in thermal losses and reduced power quality.

By minimizing these unnecessary flows and optimizing voltage profiles, VVO contributes directly to:

- Lower system losses
- Reduced fuel consumption (for thermal plants)
- Deferred capital expenditures on reinforcement
- Lower electricity bills in deregulated markets

These efficiency gains are particularly important as electricity demand becomes more dynamic and cost sensitive.

3. Facilitating Renewable Integration

In both distribution and transmission systems, the integration of solar, wind, and storage introduces intermittency and bidirectional flows. Without proper reactive power support, these changes can destabilize voltage profiles, causing either overvoltage (e.g., on low-load, high-generation days) or undervoltage (e.g., during cloudy peaks or fast ramps).

VVO mitigates these effects by:

- Dispatching Var support from inverter-based renewables
- Coordinating with voltage-regulating devices
- Ensuring compliance with dynamic voltage requirements from grid codes

This active management improves the grid's renewable hosting capacity, delaying or eliminating the need for reinforcement while avoiding curtailment.

4. Extending Asset Life and Enhancing Reliability

Excessive voltage fluctuations can cause thermal and dielectric stress on transformers, lines, and power electronics. Repeated tap changes or capacitor switching, if not optimized, accelerates wear and leads to expensive maintenance or early failure.

VVO helps preserve the condition of grid equipment by:

- Reducing the frequency of switching operations
- Maintaining stable operating voltages
- Avoiding voltage excursions that shorten insulation life

In effect, it contributes to both preventive maintenance and asset management strategies, enhancing overall system reliability and cost-effectiveness.

5. Tangible Financial Benefits at Scale

For a large transmission operator, which transmits approximately 80 TWh of electricity annually, even modest loss reductions enabled by VVO translate into significant savings:

- A 1% reduction in transmission losses equates to 800 GWh/year saved. At an average energy value of ~\$0.05/kWh, this results in approximately \$40 million in annual savings.

- Additional savings from deferred infrastructure, improved renewable utilization, and reduced maintenance could raise total value to \$50–60 million/year.

These figures highlight how VVO is not just a technical enhancement but a strategic investment with measurable returns.

A Modern Solution for Advanced Volt/Var Optimization

Developed by Pharoos, **Kairos** is a cutting-edge cloud-based economic dispatch platform that seamlessly integrates Advanced Volt/Var Optimization into its core optimization engine. Designed to meet the demands of 21st-century power system operation, Kairos empowers system operators with a flexible, high-performance environment for optimal voltage and reactive power control.

1. Accurate Power Flow Representation

Kairos supports both **power flow models, covering active and reactive power flows**, using both **linearized approaches** as well as **Second-Order Cone Programming (SOCP)**, enabling more accurate modeling of **reactive power, voltage magnitude, and AC flow limits**. This is critical for transmission grids, where both voltage stability and line limits need to be respected under real power flow conditions.

For **distribution systems**, **Kairos** can model **radial and meshed topologies** with voltage drops, incorporating **inverter control logic** and real-world DER behavior.

2. Holistic Co-Optimization of Real and Reactive Power

Unlike siloed tools that treat voltage control separately, Kairos enables **co-optimization of real and reactive power**, factoring in:

- Generator dispatch costs and **heat rate curves**
- **Ramping constraints** and startup costs
- **Reactive power capability curves** and voltage support limits
- **Priority dispatch** for renewable generation

This integrated approach leads to **economically and technically optimal dispatch plans**, reducing system losses while ensuring voltage security and maximizing renewable usage.

3. High Scalability and Computational Performance

Thanks to its microservices base architecture, Kairos can launch **a large number of processes simultaneously**, each solving complex VVO problems across different regions or time intervals. This makes it well-suited for:

- Real-time dispatch support
- Hour-ahead and day-ahead planning
- Monte Carlo simulations for security assessment
- Scenario-based policy testing (e.g., curtailment vs. Var support)

This scalability ensures that grid operators can run VVO analyses quickly and reliably even under demanding workloads.

4. Seamless Integration and Low Barriers to Adoption

Kairos offers **open APIs** and **JSON-based data exchange**, making it easy to integrate with existing SCADA, EMS, DMS, or DERMS platforms.

This delivery model is ideal for utilities and operators looking for **low-friction digital transformation** in their grid control systems.

Conclusions

Advanced Volt/Var Optimization is becoming indispensable for both TSOs and DSOs in the face of a more dynamic, decentralized, and decarbonized power system. It helps operators achieve multiple strategic goals:

- Maintaining voltage compliance and avoiding equipment failures
- Minimizing losses and improving efficiency
- Enabling greater integration of renewable energy sources
- Preserving the integrity and longevity of grid assets

Kairos, with its advanced optimization engine, scalable architecture, and deep integration capabilities, provides an ideal platform for implementing VVO in real-world operational settings. It empowers operators to proactively manage their networks, reduce costs, improve reliability, and accelerate the clean energy transition.

About the authors

This article was written by Diego Luca de Tena, Managing Director of Pharoos, who is based in Madrid. The author wants to thank the following institutions and programs, which have funded this technology:



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