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Coordinated Frequency and Voltage Support from Distributed Energy Resources in Hierarchical Power Systems

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Abstract

The rapid expansion of distributed energy resources (DERs) is transforming power systems from centralised, one-way networks into complex, multi-layer, bidirectional infrastructures. In these systems, frequency and voltage support need to be coordinated across transmission and distribution levels and across various time scales. This paper reviews the fundamental principles, system architectures, and control mechanisms that enable coordinated frequency and Volt/VAR support from inverter-connected DERs within hierarchical power systems. It first establishes a hierarchical framework to clarify control objectives, interfaces, and decision-making timeframes. It then discusses how DERs contribute to frequency stability through inertial response, synthetic inertia, and droop-based primary and secondary controls. Next, the paper examines voltage regulation and Volt/VAR control strategies, including feeder-level aggregation and reactive-power support roles under cross-layer objectives. Building on these insights, it compares centralised and distributed coordination models, summarises necessary information and communication protocols for secure and scalable operation, and explores optimisation approaches for joint frequency and VAR management. Finally, the paper considers stability, controllability, and cyber-physical security issues under high DER penetration, highlights open challenges such as standardised interfaces, robust measurement-to-control mapping, and scalable real-time coordination, and suggests that data-driven and machine learning methods are promising for future hierarchical DER orchestration.

Keywords: Distributed Energy Resources (DERs), Hierarchical control architecture, Frequency support, Voltage regulation, Inverter-based resources, Coordinated Volt/VAR control

1. Introduction

The increasing use of distributed energy resources (DERs) is transforming traditional power systems, shifting from unidirectional, top-down models to bidirectional power flow with daily demand forecasting, greater DER flexibility, and multi-agent cooperation across various time and spatial scales. Regulatory focus has moved from cost minimisation to multiple criteria, including operational costs, energy constraints, system stability, renewable energy, equipment lifespan, and emissions. Providing actionable control signals requires specifying high-level control goals and low-level electrical characteristics to agents for operational purposes. Hierarchical power system frameworks help model and design frequency and voltage control, especially with frequency-voltage-derivative (freq-VAR) control in multi-agent systems. Traditional multi-agent control with numerous decisions and agents poses challenges, making high-efficiency agent design critical, especially within a federated learning framework for DERS in low- and medium-voltage networks. Dense agent layouts and graph-based simulation ensure security under day-ahead scheduling, with cyclic POD-freq-VAR optimisation. Control agents using empirical-closure techniques offer flexibility across different control types, making them suitable for high-density LV and multi-scheduling problems. Coarse-grained simultaneity is modelled with bi-objective and uni-objective approaches. The numerous advantages and benefits of coordinated frequency and voltage damping supported by DERs illustrate the features, methodologies, developments, and applications of this approach, which are elaborately evaluated and described. The basic principles of the synchronous machine are first introduced, and the distributed frequency support provided by DERs in parallel with microgrids and their service implementation are widely assessed and discussed. The synchronised voltage at the AC bus of the microgrid is first described in terms of its orderly regulation, followed by a detailed introduction to the microgrid's autonomous real-time operation. (Lu et al.2021)

2. The Hierarchical Power System Framework

A hierarchical power system framework effectively delineates grid levels and critical control-layer interfaces, carefully framing the necessary conditions and objectives for both frequency and reactive-power support through distributed energy resources (DERs). Power grids comprise diverse, intricately integrated domains ranging from generation to transmission, distribution, and communication, each characterised by distinct physical constraints, services, and operating timescales. These distinct grid domains allocate operational responsibilities across various time hierarchies, which are essential for maintaining system stability. Within this sophisticated framework, highly coordinated synchronous grids specify requirements for wide-area primary-frequency control, extending them to all generator units, while also implementing secondary-frequency restoration for large generators. This overall structure is bolstered by advanced monitoring techniques and predictive analytics, which help establish connections at critical transmission-distribution boundaries, ensuring the entire system operates smoothly and efficiently. (Wang et al., 2021)

Distributed networks primarily deliver localised assignments that are intricately connected to extensive customer load support and essential voltage regulation. By implementing a structured, tiered organisation akin to that found in expansive synchronous grids, it becomes possible to harness additional advantages in frequency and reactive power from decentralised generation coupled with controllable inverters. The objectives of control clearly validate the necessity of these services within the layered architecture, and the timeframes for decision-making play a critical role in determining suitable strategies tailored to the distinct control layers where Distributed Energy Resources (DER) are located. (Duan et al., 2021)

3. Distributed Energy Resources as Resources for Frequency Support

Driven by increased variable renewable energy and the need for accurate frequency monitoring in smart

grids, distributed energy resources (DERs), such as solar panels and batteries, have become more common in distribution networks. Their dynamics can extend time outside the normal frequency range, delay restoration, provide ride-through to reduce dips, and participate in active frequency control. Improving utilisation is crucial as inverter-based DERs replace synchronous generators during disturbances or gradual imbalances. Transmission-level primary control reacts immediately to restore frequency; secondary adjusts set points; tertiary enables environment-driven dispatch (Gao et al., 2024; Makinde et al., 2021). In hierarchical systems, DERs support primary and secondary control by reacting at different times and following varied sequences. During secondary control, DERs can quickly return the system to the set frequency at minimal cost. Utility-scale DERs can also provide frequency-restoration service via load-frequency control schemes that track droop-adjusted frequency without explicit communication, enabling participation in control sequences (Smith et al., 2024). Coordinated scheduling and control across transmission and distribution are increasingly important, especially as distribution systems incorporate high levels of variable DERs, controllable demand, and storage for ancillary services traditionally limited to transmission. Conventional forecast-based pre-dispatch and post-dispatch flow adjustments, along with contracted flexible resources, are practical for pre-disturbance control. Transparent pre-dispatch allocation from the transmission side is essential to effectively utilise detailed distribution models (Gui et al., 2024; Tang et al., 2023).

3.1. Inertial Response and Synthetic Inertia

Distributed Energy Resources (DERs) can support grid frequency by providing inertial, synthetic, and controllable capabilities. As more generation technologies emerge, DERs such as synchronous machines, wind, solar, and storage provide inertial support. Power electronic converters enable rapid control of electrical variables by injecting or absorbing power in response to frequency deviations (Hoke et al., 2021). Inertial response and synthetic inertia help inverter-based DERs stabilise frequency, replacing lost inertia from the retirement of synchronous generators and improving system stability. Inertial response, a mechanical reaction to frequency changes caused by turbine and rotor imbalances, is typical in synchronous machines, hydro, oil, microturbines, and wind turbines with significant rotational mass (Duan et al., 2021). Since modern power systems are asymmetrical, inertial response mainly occurs during frequency drops, often with limited active-power recovery, thus not fully meeting inertia standards. Therefore, the industry emphasises synthetic inertia, which involves a timely increase in power during frequency drops to meet specifications. Inverter-based DERs with ride-through capability, however, generally must defer participation in frequency support for several seconds during transient overvoltage events. The services are enabled only after the ride-through duration has expired and may be temporarily revoked if inverter power operation continues in the disturbance direction. In an extensive transmission system, local disturbances can affect only a fraction of the grid, requiring a more extended observation period. The proportion of controllable DERs in the distribution grid, a critical fixture of transmission–distribution–substation power–frequency coordination, remains inadequate. Consequently, primary-frequency support is still predicated on inertia and various degrees of synthetic inertia, supplemented by request-based secondary-frequency assistance.

3.2. Primary and Secondary Frequency Control with DER

Distributed Energy Resources (DERs) offer frequency services to improve power system dynamics and support various frequency levels. Conventional units naturally respond to frequency deviations, which DERS can emulate by enabling droop-based primary-frequency restoration and synthetic inertia (Duan et al., 2021). During wide-area disturbances, systems may split into islands; a you-are-here logic can trigger procedures for restoration. Managing power-frequency relations is crucial for security and for higher

renewable integration, as it can impair frequency support (Jan Liu, 2017). Two frequency-support services use schedule-based info from transmission and distribution systems. A transmission-level algorithm coordinates DERs to mitigate disturbances, activating specific DERs based on scheduled data. A frequency-restoration process sequences resources, adjusting DER activation and reserve levels for recovery.

3.3. Frequency Containment and Restoration Algorithms

Systems with high penetration of renewable generation face increasingly stringent frequency and voltage regulatory requirements. Coordinated frequency (sustained and shake-off) and voltage (steady and dynamic) support is performed across hierarchical levels, whereas distributed energy resources (DERs) typically support these variables at contiguous lower levels. By broadening frequency and voltage support roles to all DERs, additional measures can be taken without imposing extra constraints on one or more already-overcommitted DERs. Frequency support is addressed first, followed by voltage support. Three frequency-containment and restoration algorithms that leverage the participation of low-voltage DERs within existing power plays and their inherent capabilities are then outlined. These approaches complement existing methods by specifying control actions decentralised in both time and space, internally maximising the shake-off recovery achievable from low-voltage and other DERs while concurrently optimising the service provided across multiple duties outside the recovery window. The algorithms exploit known “you-are-here” triggers and restoration sequencing to simplify operation.

4. Coordination for Voltage Support via DER

Voltage is regulated in distribution networks by operating transformers with multiple tap positions that keep the voltage within limits at key points in the system. Local voltage controllers make tap change decisions based on measurements of the transformer secondary voltage. There is coordination of the operation of multiple transformers or capacitors along a feeder to minimise losses. Coordinated voltage regulation with local controllers can optimise tap-change frequency and ensure operation within tap-change limits. Coordination resolves conflicts when local decisions provide conflicting control signals. Participation of distributed energy resources (DERs) in Volt/VAR control, in combination or segregation, ensures reactive power support without violating local operational constraints. Aggregation coordinates multiple DERs on the same feeder and yields control signals consistent with each DER's local authority. Aggregation can also address the unbalanced-capacitor-matching problem in DER aggregation control for a microgrid. Volt/VAR control of a given feeder minimises the overall loss of that feeder. The tap-changing, capacitor-switching, and outage-control sequences for transformers, generators, and switches are usually long-term decisions.

4.1. Voltage Regulation in Distribution Networks

While traditional grid-level scalar volt/VAR control has been dominant, growing attention focuses on coordinated Volt/VAR control with DER resources. Within distribution networks, such coordination can exploit aggregation approaches in which DERs execute specific setpoints, offering functions such as tap-changer scheduling, Volt/VAR control with aggregations, and reactive-power support for multi-layer coordination. The distribution substation-tier coordination problem maximises the welfare associated with tap changes, thereby improving the voltage profile and reducing losses. Such coordination differs from existing approaches by its welfare-focused objective, which is differentiated from the Volt/VAR problem, is suited to both centralised and distributed solutions, and operates faster than market timescales. Voltage-regulation challenges within the distribution network, exacerbated by DER proliferation and rising demand, have attracted significant scrutiny. Conventional solutions, such as transformer tap-changing and line-voltage-reducing/reactive-power-injecting devices, remain insufficient due to slower time constants and ineffective adjustments to favourable voltage margins. Consequently, alternative techniques have emerged,

including coordinated tap-change control formulated as optimal-dispatch problems for voltage improvement and loss minimisation, implemented via distributed methods across practical communication pathways.

4.2. Volt/VAR Control with DER Aggregations

Owing to the extensive deployment of Distributed Energy Resources (DERs) and growing power quality challenges, voltage support has emerged as a critical concern, notably at the distribution level. Consequently, the imperative arises to scrutinise coordinated Volt/VAR control across complex power-system hierarchies, emphasising the allocation of neighbouring measurements to DER aggregations. In the steady-state regime, Volt/VAR control primarily aims to maintain target voltage levels and optimise active power losses in distribution systems. With DERs engaged, coordination can flourish among multiple aggregation points (Zhu & Jan Liu, 2015). Feeder-level coordination facilitates the integration of voltage set-point modulation, further minimising distribution losses (Baker et al., 2017). The dynamic operation of inverters also permits the realisation of Volt/VAR control at faster time scales (Singhal & Ajjarapu, 2018). Volt/VAR control with DER aggregations involves coordinating large numbers of resources to regulate the voltage at substations or distribution transformers. Aggregation strategies allow some DERs to offer Volt/VAR capability even when other services have priority, thereby fostering greater participation in the coordination scheme.

4.3. Reactive Power Support in Hierarchical Coordination

Distributed Energy Resources (DERs) can provide ancillary services to help maintain system frequency and are often interfaced with power systems in an automated manner. Support for ancillary services from aggregated DERs is of substantial interest in practical operations, especially in systems with a large share of inverter-based generation. However, DER participation in grid frequency support may also adversely affect other system qualities, such as voltage, and the provision of other ancillary services. Such a situation particularly manifests in a hierarchical coordination framework in which the operating variables are decentralised and coordinated across different layers. A comprehensive study on aggregated DERs that simultaneously offer frequency and voltage support is therefore desired. It is necessary to properly define the role of reactive power resources in a multi-institutional power system. Many conventional power systems take the presence of synchronous generators for granted, which shall not hold for ungated AC power networks. In distribution systems, while providing useful reactive power reserves for transmission systems, the remaining volatile active power can also be used to implement limited frequency control. All these issues constitute and conclude the reactive power reserves for the various layers of a hierarchical system.

5. Control Architectures for Cross-Layer Coordination

Coordination across control layers affects architectures, trade-offs, and information structures. Centralised coordination streamlines optimisation and offers a global view, but needs scalability, low latency, and security. Distributed coordination allows individual agency and partial observability but complicates joint management. Control protocols use system identification to simplify optimisation, such as interlayer linearization. Reduced-order models link dynamics for frequency and temperature regulation. Coordinated control requires consistent information and models reflecting the system. Frequent updates require integrity monitoring and fault detection, especially in the face of cyber threats. Dynamic consistency addresses noise, jitter, and delays and promotes control reusability and rapid reconvergence. Cross-layer optimisation balances control actions to support frequency and voltage within ramp-rate limits. Defining multiple system states from measurements enables independent control actions. These conditions empower distribution entities with more authority based on performance (Duan et al., 2021).

5.1. Centralised versus Distributed Coordination

The distinction between centralised and distributed coordination is critical for the successful integration of large-scale renewable energy while maintaining system reliability. Synchronous machine generation with a large inertia remains the most effective and cost-efficient strategy to ensure system stability. The task of balancing generation and load while securing a minimum level of inertia has remained solely at the Transmission Organisation layer during the formation of Power Systems 2.0. As new technologies such as wind turbines and battery energy storage systems are installed at the Distribution organisation layer, it is imperative to determine whether their inertial response can support the inertia requirement in these grids. A central question is whether these generation sources and load-control strategies can be harvested and coordinated to assist in frequency control. One option is to form a fully centralised coordination, with Transmission Organisation responsibility and all participants directly communicating with the Transmission Organisation's control centre (Andrew Robbins, 2011). Such a configuration introduces scalability, latency, and robustness challenges specific to the control layer of an emerging hierarchical Power Systems 2.0. It raises questions surrounding data confidentiality, privacy for non-residential loads, user collaboration levels, and control objectives. A comprehensive analysis of whether the problem formulation provides a concrete formulation of top-level and mid-level Power System objectives is essential (Duan et al., 2021).

5.2. Communication and Information Models

Distributed Energy Resources (DERs) engaged in frequency and reactive power control constitute key entities for the seamless transition towards more decentralised and digitalised power supply systems. In line with the philosophy of proactively shaping future energy systems, recently proposed cross-layer coordination schemes for Direct Current transmission, Distribution, and Sub-Transmission operating in voltage- and dockless-system configurations are expanded to ensure coordinated Frequency and Volt-Ampere-Reactive (F-VAR) support by distribution-connected and generation-participating DERs. The hierarchical and cross-layer design concept is retained but applied to an electrified Transmission-Distribution-Substation architecture. The educational pedagogical objective is to point to the imperative of a coordinated frequency- and voltage-orchestrating approach to the increasingly ubiquitous energy Transformation, superimposed by evolving generation designs in Local Area Power Supply Systems (LAPSS) as well as by the growing importance of Flexibility and Network activities. Cross-layering the coordinated framework details its information models of Data and Communication flows pertinent to integrating the all-important energy or “supply” security vector into Master-Master and Master-Resource-centric Control proposals that are showing accelerated proliferation and practice (Jan Liu, 2017).

5.3. Optimisation Frameworks for Joint Freq-VAR Management

Coordination of frequency and voltage with distributed energy resources in hierarchical power systems; emphasise evidence-based arguments, formal structure, and objective analysis. Optimisation frameworks for joint frequency and voltage management arise at the interface between transmission and distribution system operators in hierarchical arrangements. Under decentralised control, transmission operators may direct the provision of frequency regulation services from dispatchable resources and ambient frequency or frequency-rate signals from inverter-based resources. Aggregated voltage control and enhancement functions in the distribution domain can also be implemented independently while accounting for transmission-level objectives (Meliopoulos et al., 2019). The framework simultaneously determines distribution-level ΔP and ΔP-VAR setpoints for a selected set of resources, extending the spatial coordination presented earlier (Xu et al., 2017). These setpoints govern the aggregated frequency response of distribution-level resources. Coverage of both objectives addresses the interdependence and supports two-tier collaborative participation through distinct objective functions. Three solution methods are applied: a two-block alternating direction method of multipliers algorithm, a sequential linear programming strategy,

and an iterative path-following scheme. All approaches yield equivalent solutions despite differences in implementation.

6. Stability, Controllability, and Security Considerations

The introduction of a large proportion of distributed energy resources (DERs) equipped with power-electronics interfaces significantly alters power system dynamics and may also prevent frequency and voltage control. In the event of a tripping fault, system dynamics gradually evolve from a human- and mechanical-response time frame to an electronic time constant. Impacts on system damping, disturbance frequency-domain response, and failure modes differ, leading to critical frequency-tuning groupings. Time constant differences can lead to adverse interactions, magnifying disturbances or hiding system information (Duan et al., 2021). New cyber-communication and data acquisition threats emerge. The significant increase in DERs requires new solutions to maintain acceptable operation with high system receptivity and user flexibility. Most DERs respond to economic signals, while conventional resources are solely controlled via real power and voltage or reactive power. Support for the transmission system, therefore, depends on economic signals from distribution networks rather than on schedules from the transmission system. Scenarios that require control solutions for auxiliary services under high DER penetration and extensive energy storage remain: microgrids with a very high proportion of DERs, improving conventional supply during extreme weather events, and distribution system operation without a transmission infrastructure (Jan Liu, 2017).

6.1. Dynamic Stability under DER Participation

Inclusion of distributed energy resources (DER) in resource participation for frequency and reactive power support introduces a wide range of interaction time scales across various control types. Frequency-support participation directly addresses contingencies and disturbances at the second time scale. It has implications at the minute time scale, while the reactive power role is associated with voltages and actions at the time scale of essentially a fraction of a second. Hence, coordination that can encompass these time-scale interactions becomes necessary, as the real-time frequency and duration of active power can otherwise be significantly impaired during energy shortages at the minute time scale. Damping the oscillatory mode at the second time scale has also been found to enhance the stabilisation of an aggregated active-power-frequency-maintenance control loop using DERs. Appropriate damping measures for these oscillatory modes are an important consideration (Wang et al., 2021).

6.2. Cyber-Physical Security of DER-Enabled Services: Resilience to Component Failures

The ongoing expansion of distributed energy resources (DERs), like renewables and batteries, introduces new control challenges and increases the interdependence between transmission and distribution systems. As these systems become more complex and coordinated in frequency–voltage support, cybersecurity concerns also intensify, because malicious actors target control functions or undermine situational awareness. Manipulating these DER-enabled services can reveal significant vulnerabilities in the system (Zografopoulos et al., 2021). Such cyberattacks threaten large renewable-based transmission networks and can severely hinder the technical operation, control, and coordination of frequency–voltage support provided by DERs. Operators can implement measures such as advanced attack detection or control laws that remain effective even during active attack scenarios (Linnartz et al., 2022). Even without direct countermeasures, strategic indirect protections can help defend against larger threats. For example, frequent surge events such as faults or sudden fluctuations in generation or load may cause transmission and distribution systems to disconnect. This disconnection prevents the exchange of active and reactive power during disturbances. However, the operational procedures, control strategies, and backup plans of

connected transmission and distribution segments generally do not require significant changes. Still, efforts should be made to prevent disconnection, and fallback controls should be in place if disconnection cannot be avoided, to limit system impacts (Duan et al., 2021; Wang et al., 2021).

7. Case Studies and Simulation Insights

Hierarchical power system architecture, comprising transmission, distribution, and grid-forming generation levels, governs how authority cascades downward via distinct interfaces where knowledge and cognition decrease. Stable interconnected operation mandates coordinated management, yet increasingly decentralised generation due to renewables affects system inertia, reinforcing the need for global frequency control in the transmission sector. To alleviate frequency excursions, cross-layer arrangements promoting support from distributed energy resources (DERs) are gaining attention. A simulation study investigates the distinctive choreography of frequency and voltage control from boundaries where DERs connect to low-inertia systems. Combinations of various DER capabilities are assessed under two schemes for real-time coordination: one maintains a high-level frequency-target trajectory via setpoint adjustment, and the other shares a common responsibility-deviation signal. High DER penetration exacerbates generation degradation, and fine-tuning the coordination scheme is critical for effective management. The analysis also examines weather and contingency scenarios that shape performance, pinpointing conditions likely to strain frequency-Volt/VAR support when weather veers off established patterns (Duan et al., 2021) ; (Wang et al., 2021).

7.1. Scenarios of Transmission-Distribution Interface in Distributed Energy Resources

Distributed Energy Resources (DERs) were examined across multiple transmission-distribution interfaces to evaluate how aggregation and different control actions affect frequency-voltage support. The study analysed primary-frequency response (PFR) at three interfaces and coordinated voltage control across two transmission-distribution schemes. When PFR was limited at an interface far from the disturbance, DERs shifted to primary-action manoeuvres, eventually becoming dominant. Different approaches were also considered while maintaining a layered hierarchy. In such scenarios, the electrical inertia of generation significantly stabilises both primary-frequency control and subsequent recovery (Wang et al., 2021). DERS are spread throughout the distribution network (Wang et al., 2021), and depending on load behaviour and connections, they may need to provide additional inertia or primary frequency reserves. In environments with high DER penetration, DERs on distant feeders might not effectively support frequency control during transmission-level generation shortages, requiring control coordination among the DSO, TSO, and DERs.

7.3. Weather and Contingency Scenarios

Weather and contingency scenarios influence the availability and operation of Distributed Energy Resources (DERs) capable of providing synchronised frequency–voltage reactive power support. Due to these uncertainties, interventions at the Transmission Distribution Interface (TDI) are necessary to ensure coordinated frequency–voltage support. Weather conditions also impact the status of grid-connected loads and their ability to participate in these activities (Duan et al., 2021). These scenarios involve changes driven mainly by meteorological and geographical factors. For example, increases in temperature, rainfall, and snow location affect the capacity of natural resources like photovoltaic and micro-hydro generators. The specific weather scenario determines the resource harvesting rate and, consequently, the grid's capacity. When sunlight is scarce, cooperation across TDI levels becomes essential to maintain frequency-voltage support. Overall, weather scenarios underscore the importance of targeted TDI interventions to sustain frequency–voltage stability in a hierarchical power system with minimal generation disruptions (Meliopoulos et al., 2019).

8. Open Challenges and Future Directions

As more Distributed Energy Resources (DERs) are integrated into the electricity network, challenges such as reduced system inertia and concerns about frequency stability emerge (Duan et al., 2021). The distribution system is becoming increasingly interconnected with the transmission layer, requiring urgent coordination. A framework is needed to address integration challenges and guide the development of distributed frequency and voltage support within the hierarchical power system. Simulation parameters are also adjusted to test disturbances under various weather scenarios. Several unresolved challenges and issues related to the future development of coordinated frequency-voltage support can be identified. The research community lacks standardised interfaces and communication protocols, which may impede the advancement of coordinated control strategies. It is therefore advisable to standardise the associated specification documents and communication standards for control strategy workshops at electrical engineering institutes, similar to widely used protocols like IEEE 2030.5 for distributed energy resources. Given the complexity of power and communication cyber systems, simplifying the modelling of DER participation for real-time coordinated frequency-voltage support becomes crucial. The emergence of machine learning and data-driven modelling techniques offers potential to accelerate this modelling process and enhance this aspect. Additionally, Time-frame coordination introduces a new perspective on frequency-voltage support, allowing more control variables to be explored from DERS within the two-time coordinated scheme. Meanwhile, further study on measurement-set pointing can help optimise measurement selection schemes.

9. Conclusion

The evolution of power systems towards hierarchical structures introduces cross-layer coordination of distributed energy resources (DERs) for frequency and voltage support. Coordinated frequency–VAR control maximises the contribution from generation and consumption at all grid levels, extending operational time and reducing supply loss. Coordination ensures that triggers or recovery strategies at one layer do not compromise objectives at another layer, and prioritises services based on system-level requirements. A comprehensive framework for freq–VAR coordination in multi-layered power systems has been delineated. Six hierarchical layers define distinct objectives and information exchanges. The objectives of each layer align with the global system requirements, enabling seamless coordination of support across the transmission, distribution, and grid-forming DER tiers. Coordination strategies for frequency support have been detailed, including DER participation and interactions with voltage-related services. Coordination principles have been specified for voltage support with DERs, identifying the requirements to maintain compatibility with broader grid objectives at other layers.

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