Executive Summary: A holistic view of system services

The EPICS-ESIG Workshop, held on 30 October 2025, in Philadelphia, brought together members of the EPICS and ESIG communities, as well as international partners, for a dedicated System Services session to discuss the evolution of power system services in an inverter-based grid. Over 25 researchers and power system professionals from EPRI, ESIG, Imperial College London, Georgia Tech, NESO UK, Polaris Systems Optimisation, Resources for the Future and Telos Energy attended the workshop. The session was organised and led by Dr Agnes Nakiganda from Imperial College London and facilitated by Professor Ben Hobbs from Johns Hopkins University and Professor Mark O'Malley from Imperial College London.

System Operators (SO) have historically ensured that generators provide power system services through two main avenues: by mandate in grid codes governing generators, or as a "free" byproduct of large rotating synchronous machines. In some regions, the trend over the last decade has been to transition their procurement to market mechanisms. With the increase in inverter sources on the grid, services are now more complex, multidimensional, and "atomised", requiring a rethink in their design, quantification and acquisition.

Considering the holistic view of system services in Figure 1, the key issues discussed during the specialised session included the development of technology-agnostic metrics for quantifying system services, the interactions between evolving system needs during operation and their influence on service provision, and the implications for market mechanisms and grid code design required to acquire these services. SOs, service providers, and market operators must thoroughly examine the issues mentioned above to provide a holistic view of system services and, thus, ensure adequate service provision and grid reliability.

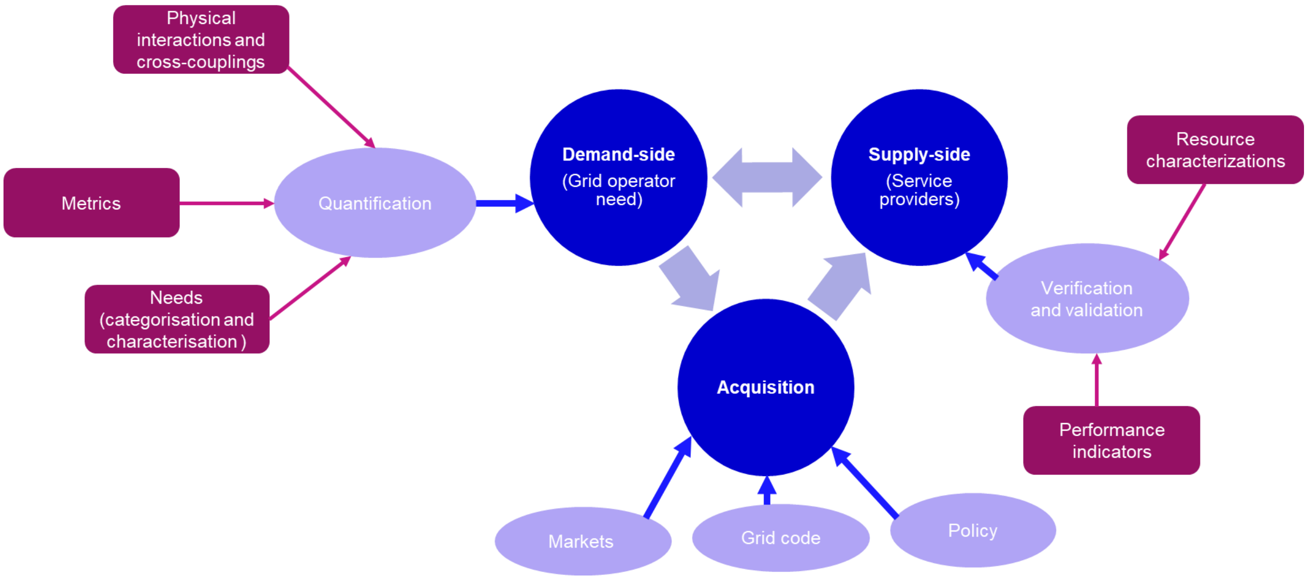

Figure 1. An integrated ecosystem for system services.

The Physics of System Services: Service Interactions

System services pose various complex interactions at different levels. Agnes Nakiganda from Imperial College London presented an overview of the 'physics side' of grid services and explained that the system needs can be categorised by the system operability areas (i.e., frequency, voltage, thermal, stability and restoration), by time frames, and spatial requirements, etc., making the needs highly intertwined, locational and dynamic. When assessing system needs, one must navigate the trade-off between comprehensive physical modelling and the development of simplified metrics feasible for planning and system operations.

Xiaoyao Zhou from the UK National Energy System Operator (NESO) highlighted that interactions can occur between one or more operability areas, e.g., between different frequency support services such as inertia and fast frequency response; on the other hand, interactions can occur between frequency support and voltage support services. In the spatial dimension, a global service such as frequency response can conflict with local needs; e.g., providing the service in one location might violate a local thermal or transmission constraint. From the grid perspective, when quantifying the need for different services, the challenge lies in understanding the 'knock-on effects' of one service on another. However, there is a need to focus on the strongest interactions, as modelling all this physics would be impractical in operation.

Furthermore, from a service provider's perspective, one might want to combine different services to maximise revenue, such as a battery delivering fast frequency response and inertia services. The challenge, however, lies in differentiating and quantifying the value of each service when offered simultaneously.

Looking at the holistic picture (see Figure 1) of the implications on the acquisition of these services, for example, through service markets, the interactions highlight the need to co-optimise markets for different ancillary services. This issue has been challenging for system operators in practice.

The Physics of System Services: Service Quantification

Deepak Ramasubramanian from the Electric Power Research Institute (EPRI) showcased the ESIG services framework for quantifying grid-stability services, a joint project undertaken by the ESIG services task force. The framework also provides mechanisms to verify service provision across different resources from both the grid perspective and the provider's perspective. It employs a risk assessment framework to determine reserve requirements and estimate each unit's risk contribution. The framework prompted discussions on how resource characterisation and subsequent contributions affect the interconnection queue. Moreover, the necessity of always ensuring service quantification, firmly grounded in system physics, was strongly emphasised.

A key challenge in quantifying system services is to apply technology-agnostic metrics that are easy to determine and straightforward to understand. Matthew Richwine from Telos Energy presented a technology-agnostic metric for measuring the fast active power service. The proposed metric utilised electric frequency (in the form of frequency ramps) to assess the system's inertia. With operational validation and verification ongoing, this metric has the potential to translate complex physics interactions into measurable outputs, allowing for seamless integration into the control room and operational timescales. The need to develop metrics for system services that bridge the gap between complex physics interactions and real-time applicability is key to reliable quantification of system services.

Incentives for Grid Services

Karen Palmer from Resources for the Future highlighted the importance of markets in promoting efficiency and innovation and stressed the need to include the demand side in service provision. However, it is not the case that system operators can or should acquire all grid services through competitive markets. Erik Ela from the Energy Systems Integration Group (ESIG), explained that grid services can be incentivised through competitive auctions and cost-recovery mechanisms, with some services requiring no compensation because they naturally occur within the system. While competition does encourage efficiency and innovation, SOs cannot procure certain services through competitive auctions due to factors such as limited competition in some regions, the complexity of designing the service—including software limitations and unintended consequences arising from interactions across multiple services—and location-specific requirements that can influence market power. Additionally, some services are inherently sufficient in the system, such as in a synchronous generation-based grid, where inertia or short-circuit power are naturally present and could be more than adequate. Practical considerations also play a role; for example, a feasible approach could be for grid codes to mandate that all resources provide specific services. Post-hoc analysis of the Iberian blackout, for example, could suggest that a mandate for generators with sufficient capacity to provide reactive power support could have mitigated the systemic incident. Finally, the costs and complexities of establishing a new service market may outweigh the expected financial benefits, making a competitive auction impractical.

The discussion further highlighted that a successful market design looks beyond MW capacity and also includes responsiveness, e.g., MW per Hertz, response speed, and the interaction of the service with other services. Moreover, how other markets, e.g. energy scheduling, are designed can impact the quantity of dispatch. An example of this is the shift from a 5-minute dispatch to a 1-minute dispatch, which eliminates the need for a reserve product and further highlights the risk for any resource participating in the given market.

In conclusion, the talks and discussions emphasised the importance of aligning market incentives with physical system needs and of avoiding unintended consequences when designing services markets effectively. Moreover, the difficulty of testing models against extreme "tail" scenarios or "unknown unknowns," such as the sudden rise in data centres, could introduce another dimension of complexity. Additionally, the group identified service interactions and their impacts on service provision as a research gap; understanding their linkages is vital when quantifying services and designing market models.