SHURA ENERGY TRANSITION CENTER

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SHURA AGENDA

Transformation of the Distribution Grids

Electric power systems have traditionally been designed around centralized generation and unidirectional power flows. Electricity generated at large-scale power plants has been delivered to end-users through transmission and distribution grids.

However, the energy transition is fundamentally reshaping this structure. As distributed energy resources such as rooftop solar PV systems, battery energy storage technologies, electric vehicles (EVs), and heat pumps become more widespread, consumers are no longer merely using electricity. They are also generating, storing, and, when needed, feeding electricity back into the grid.

This transformation is turning distribution grids from passive infrastructure into the backbone of digital, flexible, and actively managed energy systems. The 16th issue of SHURA AGENDA examines the evolving role of distribution grids in the energy transition, the new challenges emerging from this transformation, and the priority areas for modernization in Türkiye.

"Distribution grids are evolving from passive infrastructure that merely delivers electricity to consumers into the backbone of digital, flexible, and actively managed energy systems capable of managing electricity flows in real time."

Why do distribution grids need to transform?

Achieving net-zero emissions by mid-century requires the rapid deployment of clean electrification and the integration of renewable energy resources into the electricity system. Distribution grids, which have traditionally been planned based on relatively predictable load profiles, must now adapt to increasingly variable and bidirectional power flows driven by the growing deployment of distributed renewable energy resources and electrification.

This transformation:

- makes voltage management more challenging,
- increases the need for grid flexibility, and
- makes real-time monitoring and control systems indispensable.

As a result, investments in the digitalization and modernization of existing distribution systems have become just as important as investments in new grid infrastructure. Distribution systems are increasingly evolving into platforms integrated with data, digital technologies, and smart systems. In this context, ensuring that these systems are actively managed and aligned with market mechanisms is becoming increasingly important.

From the conventional system to the new energy system

Conventional System	New Energy System
Unidirectional power flow	Bidirectional power flow
Passive consumer	Prosumer
Centralized generation	Distributed generation
Conventional operation	Digital operation
Fixed load	Flexible load

The role of distribution system operators is evolving

As distributed energy resources become more widespread, the role of distribution system operators (DSOs) is also changing significantly. Traditionally responsible for planning, operating, maintaining, and expanding distribution networks, DSOs are evolving into active system operators that enable the safe and efficient integration of distributed energy resources into the power system.

The evolving role of DSOs

Traditional Responsibilities	New Responsibilities
Operation of the distribution grid	Active management of grid constraints
Maintenance and investment planning	Coordination of distributed energy resources
Provision of new grid connections	Providing voltage and reactive power support to the transmission system

The success of this transformation depends not only on clearly defining these new responsibilities, but also on redesigning distribution systems with digitalization at their core. The transformation of the distribution system will play a critical role in enabling the effective integration of the distributed energy resources required for the transition to a net-zero economy.

Why is the modernization of the distribution system necessary?

Conventional distribution grids were largely designed based on predictable electricity consumption profiles. As a result, voltage management and reactive power compensation could be effectively planned through load-flow analyses, voltage profile simulations, and optimization studies.

However, the rapid deployment of electric vehicle (EV) charging infrastructure, rooftop and utility-scale solar PV systems, and renewable power plants connected at the distribution level is making voltage regulation far more dynamic.

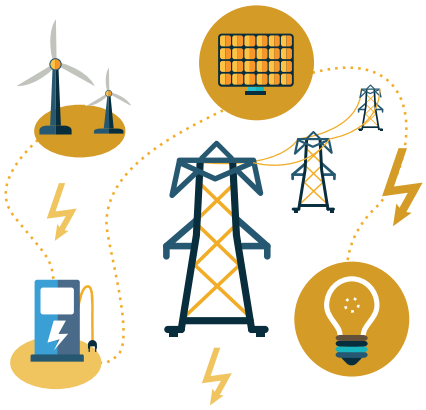
The main drivers of this change include:
- the variable generation characteristics of renewable energy sources,
- sudden fluctuations in active power output, and
- generation patterns that can lead to rapid voltage variations across the grid.

The growing share of inverter-based renewable energy capacity, together with increasing electrification, is also reshaping intraday electricity consumption profiles. As a result, the balance between electricity supply and demand is becoming increasingly bidirectional.

This new structure:
- creates more variable supply and demand profiles,
- increases the need for flexibility in grid operation, and
- requires stronger forecasting, monitoring, and control capabilities.

Consequently, the simultaneous expansion, modernization, and digitalization of distribution systems have become fundamental requirements for the energy transition.

New opportunities created by distributed generation



Distributed energy resources, inverter-based systems, energy storage technologies, electric vehicles, smart meters, and digitalization are creating not only new challenges but also significant opportunities for power systems.

In particular, the ability of inverters and synchronous generators used in distributed generation facilities to provide reactive power support to the distribution system while continuing to generate active power offers important operational advantages.

For distribution system operators (DSOs), making effective use of this capability can:

- reduce the need for additional capacitor and reactor investments,
- enable reactive power support from existing distributed generation resources,
- improve investment efficiency,
- reduce grid losses,
- increase the utilization of existing assets, and
- enhance grid flexibility.

As a result, long-term investment planning can become more efficient while improving the operational performance and sustainability of distribution systems. At the same time, this approach can help DSOs develop investment strategies that are more innovative, cost-effective, and environmentally sustainable.

As the energy transition progresses, distribution grids are increasingly evolving to resemble small-scale transmission systems. Voltage management is no longer a centrally managed process but is becoming a more dynamic function delivered through the coordinated contribution of distributed resources across the grid.

Investments and applications that can accelerate the transformation of distribution grids

Expanding the deployment of smart meters to increase digitalization and support the implementation of smart grids.
Increasing grid observability, controllability, and outage management capabilities through the wider adoption of digital technologies such as Supervisory Control and Data Acquisition (SCADA), Distribution Management Systems (DMS), Outage Management Systems (OMS), smart sensors, and integrated measurement systems.
Modernizing distribution infrastructure through advanced grid technologies, including power electronics-based Static Synchronous Compensators (STATCOM), Static VAR Compensators (SVC), On-Load Tap Changer (OLTC) distribution transformers, and Dynamic Line Rating (DLR) systems to enhance grid flexibility, provide dynamic voltage support, and reduce operational constraints.
Using advanced forecasting and predictive tools to effectively manage sudden increases and decreases in electricity generation and improve grid flexibility.
Strengthening cybersecurity measures, including advanced software solutions, to address the growing cyber risks associated with increasingly digitalized distribution systems.
Leveraging innovative technologies such as artificial intelligence (AI), blockchain, and the Internet of Things (IoT) to enhance the contribution of prosumers and aggregators to grid flexibility through greater demand-side participation.
Expanding the deployment of energy storage technologies, such as battery energy storage systems, to increase grid flexibility.

Regional planning is becoming increasingly important

To enable the effective transformation of distribution systems, distribution system operators (DSOs) need to anticipate future investment requirements. This, in turn, depends on establishing regional deployment targets for renewable and distributed energy resources in advance.

With clearly defined regional targets, DSOs can:

- develop more accurate demand forecasts using advanced data analytics,
- identify priority investment areas, and
- plan infrastructure investments more effectively.

This approach will help optimize investment costs while supporting a more structured and efficient development of the electricity grid.

Stronger coordination between transmission and distribution systems is needed

As the energy transition accelerates, the interaction between transmission and distribution systems is becoming increasingly important. Ensuring that this transformation is managed in a stable, reliable, and cost-effective manner requires stronger and more continuous coordination between transmission and distribution system operators.

At the same time, adapting to the evolving energy system also requires the roles, responsibilities, and mandates of relevant institutions to be updated in line with emerging needs.

The growing importance of distribution grids in the COP31 process

As electrification and renewable energy targets continue to gain momentum, electricity grids are becoming one of the most critical components of the energy transition. Consequently, grid development has become an increasingly prominent priority in the global energy agenda over the past three COP conferences.

The commitment adopted at COP28 to triple global renewable energy capacity by 2030 requires the secure integration of increasingly variable renewable energy resources into electricity systems. Expanding and modernizing electricity grids is therefore recognized as an indispensable component of the energy transition.

COP29 reinforced this ambition by introducing, for the first time, a dedicated global target for electricity grids. Countries agreed to refurbish or build 25 million kilometres of electricity grids by 2030. In addition, the Green Energy Zones and Corridors Pledge highlighted the importance of strengthening regional interconnections, expanding cross-border transmission infrastructure, and developing large-scale green energy corridors.

Building on these commitments, Türkiye as the host country and President of COP31, has called for a global initiative to increase the share of electricity in final energy consumption from around 20% today to 35% by 2035. Achieving this objective will require significantly higher levels of electrification, particularly across the transport, industry, and buildings sectors. As a natural consequence, the demand placed on electricity distribution systems is expected to increase substantially.

The global agenda is increasingly focused on electricity grids

Key commitment	
COP28	Triple global renewable energy capacity by 2030
COP29	Refurbish or build 25 million km of electricity grids by 2030
COP31	Increase the share of electricity in final energy consumption to 35% by 2035

In this context, the priority will be to strengthen financing mechanisms, mobilize greater investment, and enhance system integration in order to accelerate the implementation of these global commitments.

Priorities for Türkiye

As the energy transition accelerates, distribution system operators in Türkiye need to evolve from passive network operators into active system operators. The growing integration of distributed energy resources at the distribution level, together with changing load profiles and bidirectional electricity flows, makes real-time monitoring and more active management of distribution systems increasingly essential.

To accelerate this transformation, the following actions should be prioritized in the near term.

Accelerate the deployment of smart meters.
Expand the implementation of digital grid applications.
Strengthen grid automation systems.
Enhance coordination between transmission and distribution system operators.
Develop tariff structures and market mechanisms that promote flexibility.
Reinforce cybersecurity infrastructure.

When considered together, the electrification targets highlighted under the COP31 process and the renewable energy and grid commitments adopted at previous COP conferences clearly demonstrate that the modernization of distribution grids has become one of the fundamental priorities of the energy transition.

Looking ahead, developing distribution systems that are more digital, more flexible, and smarter will play a crucial role not only in accelerating Türkiye's energy transition but also in supporting the achievement of global climate goals.