



Egypt  
Energy

# **Managing Grid Complexity in a Multi-Source Energy World**

**Mohamed Atia**

**Head of Energy Policies Committee – El-Adl**

# Introduction: The Evolving Energy Landscape

## From Past to Present

**Past:** One-way power flow from centralized plants

**Present:** Multi-source energy system with distributed generation

- Solar, wind, batteries, EVs, demand response
- Bidirectional power flows
- Power-electronics dominance (inverters)

## Key Challenges:

- ⚡ Variability & uncertainty (weather-driven)
- 🏠 Distributed generation across the network
- 🔌 Different technical characteristics
- ⚖️ Maintaining supply-demand balance

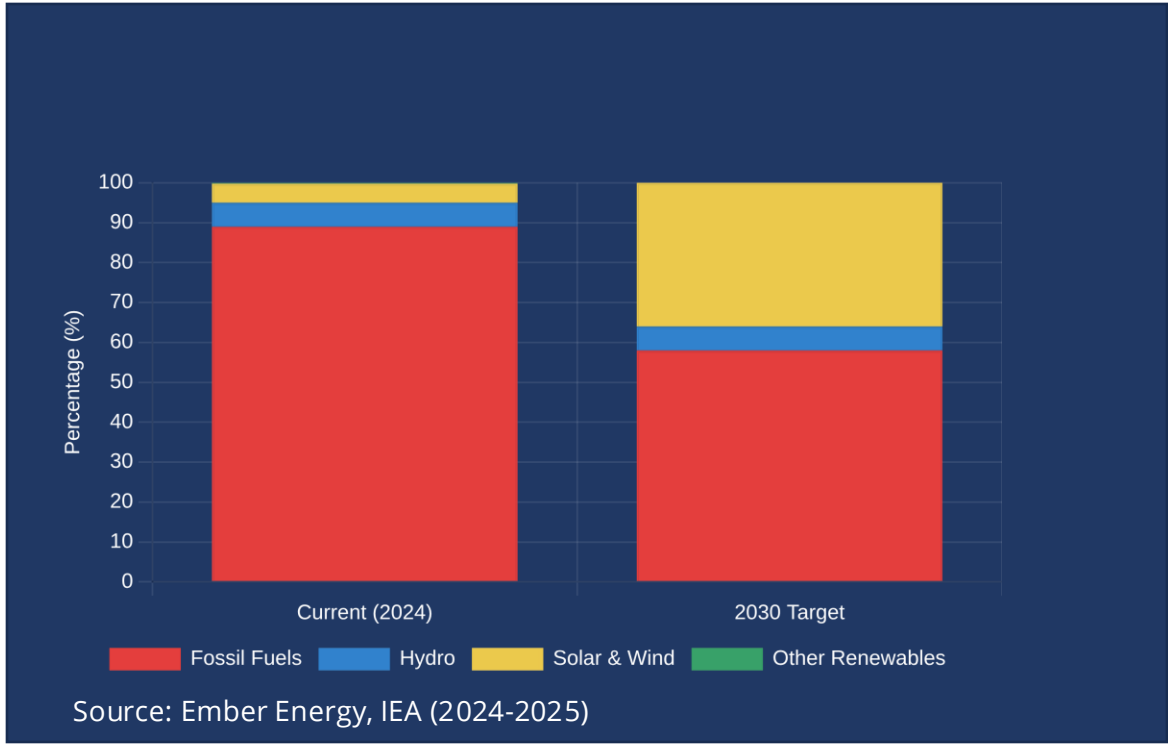


## Egypt's Context

- ☀️ Vast solar and wind potential
- 📈 Electricity demand tripled over past two decades
- 🎯 Target: 42% renewable electricity by 2030
- 💰 \$2.8B investment in grid infrastructure (FY 2025/26)

# Egypt's Energy Profile & Targets

## Current Energy Mix vs 2030 Target



## Regional Context & Benchmarks

### Regional Context & Benchmarks

#### Egypt's Position

- 🌐 24th largest country by electricity demand
- 🌿 11% clean electricity (global avg: 41%)
- ☀️ 4.8% solar & wind (global avg: 15%)
- 🏭 Emissions: 1.2 tCO<sub>2</sub> per capita (below global avg)

#### Key Initiatives

- ⚡ 12 GW renewable energy addition by 2026
- 🏗️ Middle East's first country-wide smart grid
- 🔌 Egypt-Saudi Arabia HVDC Interconnection (\$1.8B)
- 🧪 Green hydrogen production leadership
- 🏠 First utility-scale solar-plus-storage facility (2025)

Total Installed Capacity  
**59 GW**  
End of 2024

Renewable Capacity  
**11%**  
of total generation

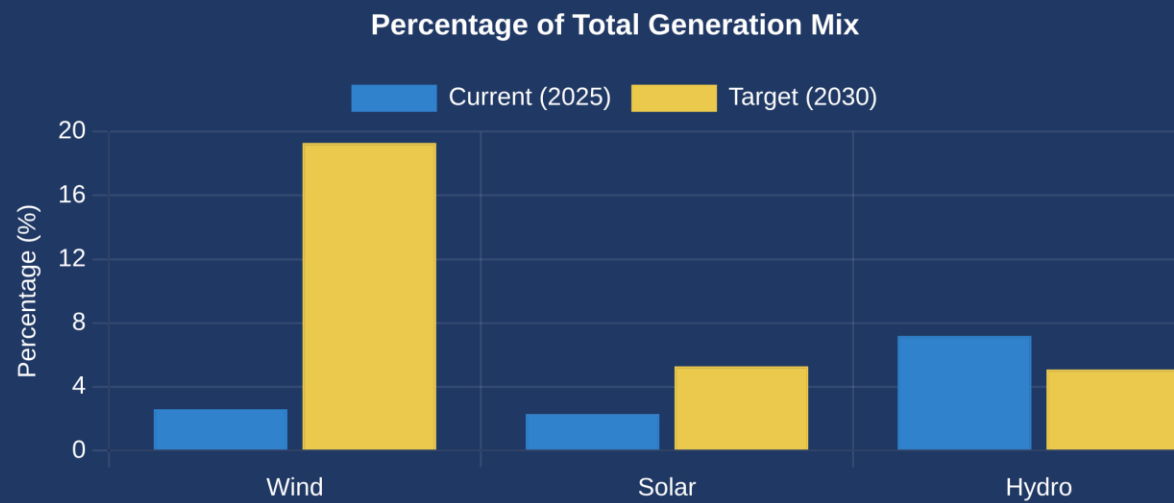
Peak Load Forecast  
**85 GW**  
by 2035

Grid Investment  
**\$2.8B**  
FY 2025/26



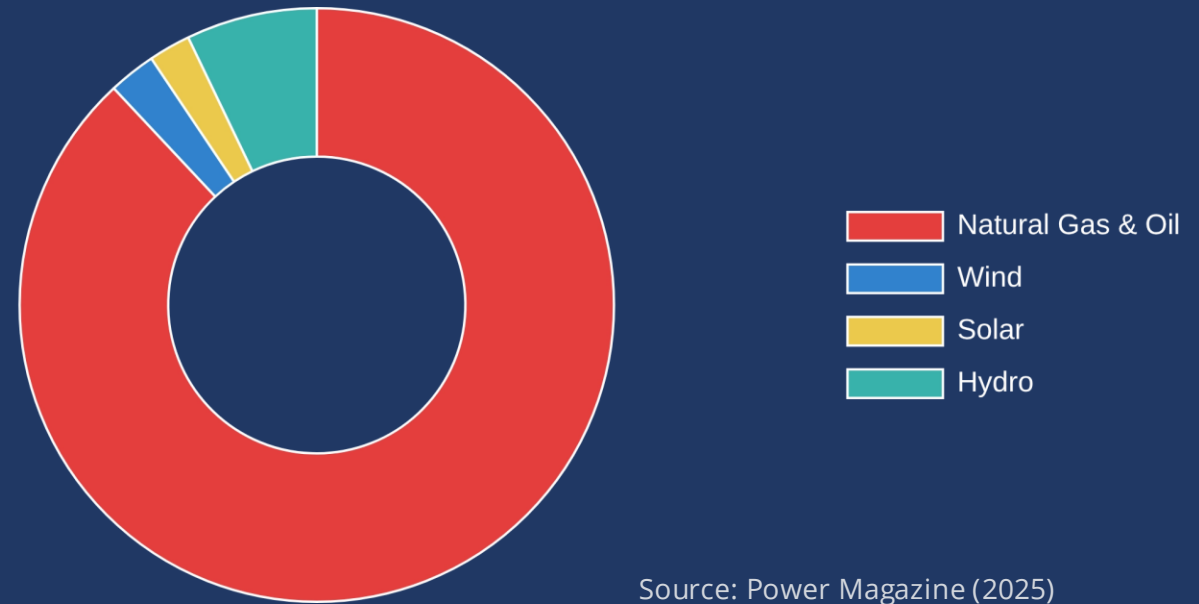
# Egypt Renewable Energy & Grid Stability

## Current vs. Target Renewable Energy Mix



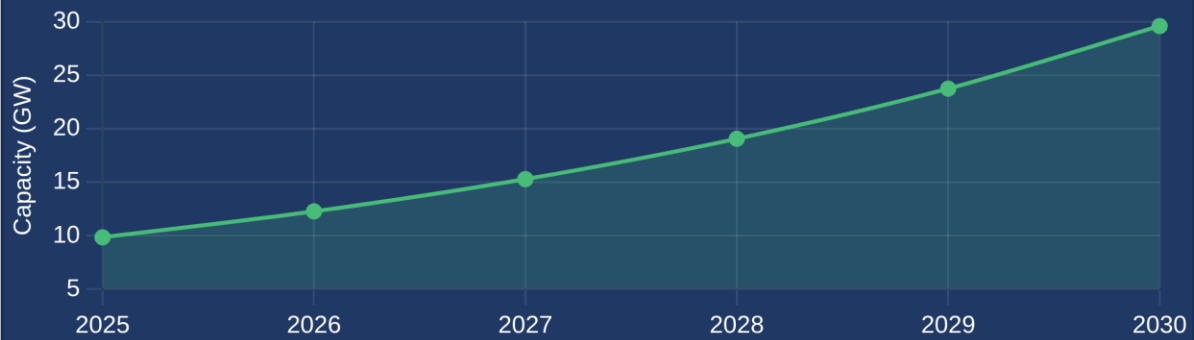
Source: IMF Report, Ministry of Electricity (2025)

## Current Power Generation Mix (2025)



Source: Power Magazine (2025)

## Renewable Capacity Growth Projection



Source: Mordor Intelligence (2025)

**RE Target**  
**29.7%**  
By 2030

**Growth Rate**  
**24.6%**  
CAGR

**BESS Target**  
**3.3 GW**  
By 2030

# Grid Flexibility & Stability Challenges

## Key Concepts

### Flexibility

The grid's ability to adjust supply/consumption across different time scales (seconds to days)

### Stability

The grid's ability to maintain voltage and frequency within safe limits after disturbances

### Why They Matter

- ⇒ Renewables fluctuate rapidly
- ⇌ Inverters don't provide natural inertia
- ▲ System collapse risk without proper controls

## Flexibility

### Flexibility Tools

- ⚡ Fast-ramping generation
- 💡 Demand response
- ⚙️ Renewable curtailment
- 🌐 Regional interconnection
- 🔋 Energy storage systems

### Stability Tools

- 🧠 Primary frequency control
- ⚙️ Automatic generation control
- 🔌 Reactive power control
- ⌚ Synchronous condensers
- 🔌 Grid-forming inverters

### Egypt's Challenges

- 📈 Tripling electricity demand over two decades
- ⚙️ Integrating 42% renewables by 2030
- 🏗️ Transitioning from gas-dominated grid
- 🔧 Upgrading aging grid infrastructure

Nominal Frequency

**50 Hz**

Egypt & MENA Region

Safe RoCoF Limit

**0.5 Hz/s**

International standard

Frequency Deadband

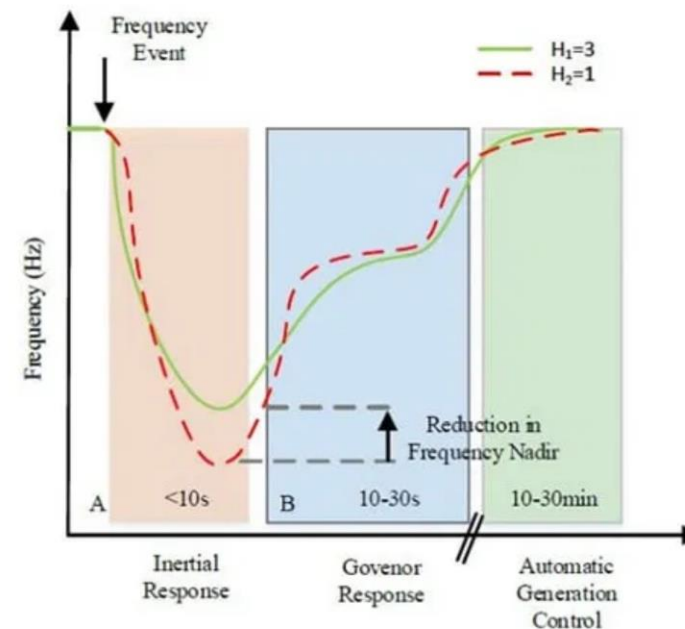
**±0.2 Hz**

Typical operating range

Response Time

**<10s**

Primary frequency control



# Advanced Grid Infrastructure



## Advanced Power Flow Control

### FACTS (Flexible AC Transmission Systems)

Control power flows, enhance capacity

### HVDC Links

Connect asynchronous grids

### Synchronous Condensers

Provide inertia and stability

### Grid-Forming vs Grid-Following

#### Grid-Following

- Operate as current sources
- Need stable grid reference
- Most common today

#### Grid-Forming

- Operate as voltage sources
- Create grid reference
- Essential for high renewables

### Egypt's Smart Grid Initiative

Egypt is developing the Middle East's first country-wide smart grid with \$2.8B investment in FY 2025/26.

## Key Components



### Sensors & PMUs

Time-synchronized measurements



### SCADA + EMS

Control and management systems



### Communication

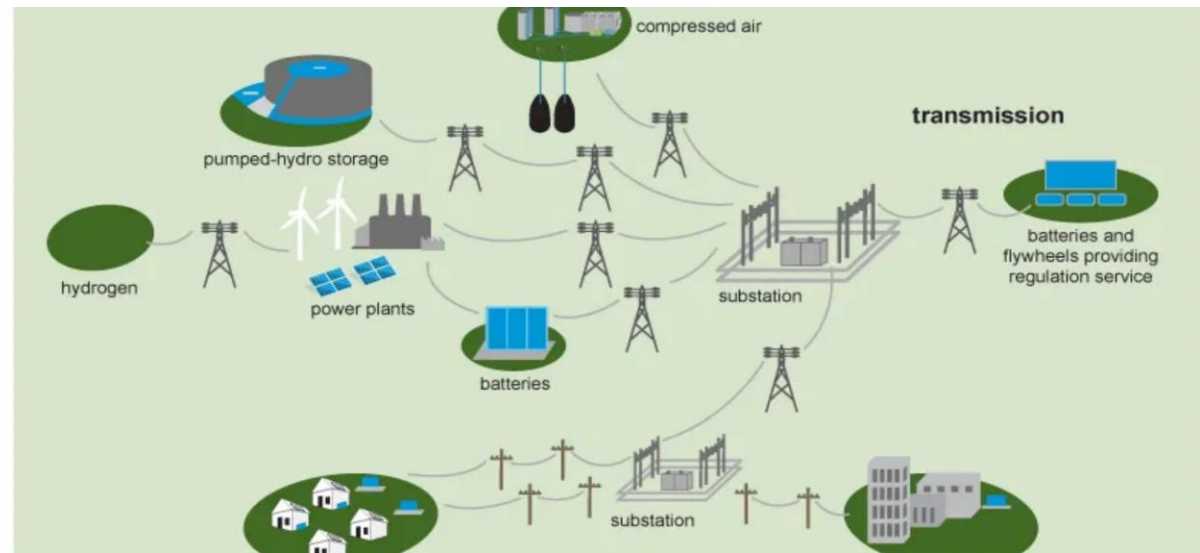
Low-latency, secure networks



### Edge Computing

Local controllers for microgrids

# Energy Storage Systems



## Storage Technologies

### Batteries

Fast response (ms-s), high efficiency

### Pumped Hydro

Long duration, mature technology

### Thermal Storage

Heat/cold storage applications

### Hydrogen

Long-term/seasonal storage

## Key Applications

- ⚡ Fast Frequency Response
- ⏸ Peak Shaving & Load Shifting
- ⚙ Renewable Firming
- 🔌 Black Start Capability

## Global Energy Storage Growth



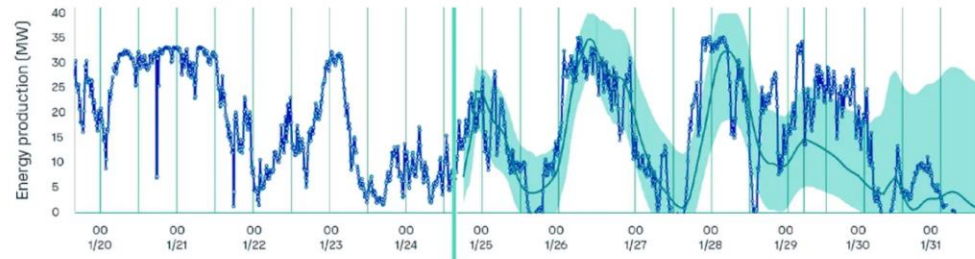
Source: BNEF, Global Energy Storage Monitor (2024-2025)

## Egypt's Storage Initiatives

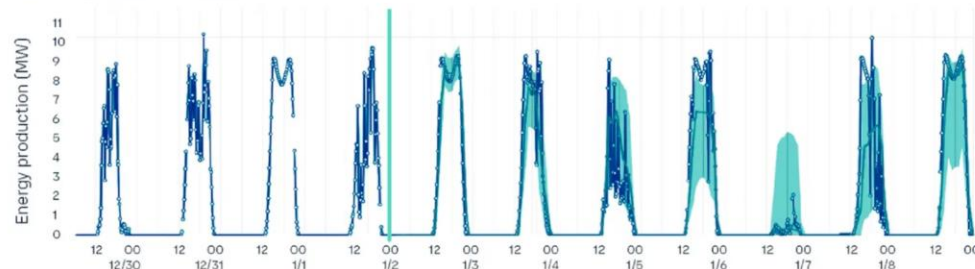
- ✅ First utility-scale solar-plus-storage facility (2025)
- ✅ Part of \$3.5B renewable energy investment

# Energy Storage Systems

Wind energy production forecast versus observations



Solar energy production forecast versus observations



## Forecasting: Making Uncertainty Manageable

### What We Forecast

- ⚡ Load (demand)
- ☀️ Solar generation
- 🌬️ Wind generation

### Techniques

- 📊 Statistical models
- 🧠 Machine learning
- ☁️ Weather models

## Demand-Side Management Tools

### Price Signals

- 🕒 Time-of-use tariffs
- ⚠️ Critical peak pricing

### Direct Control

- 🌡️ HVAC systems
- 🔌 EV charging

## Virtual Power Plants (VPPs)

Aggregation of distributed energy resources that can be dispatched like a conventional power plant.

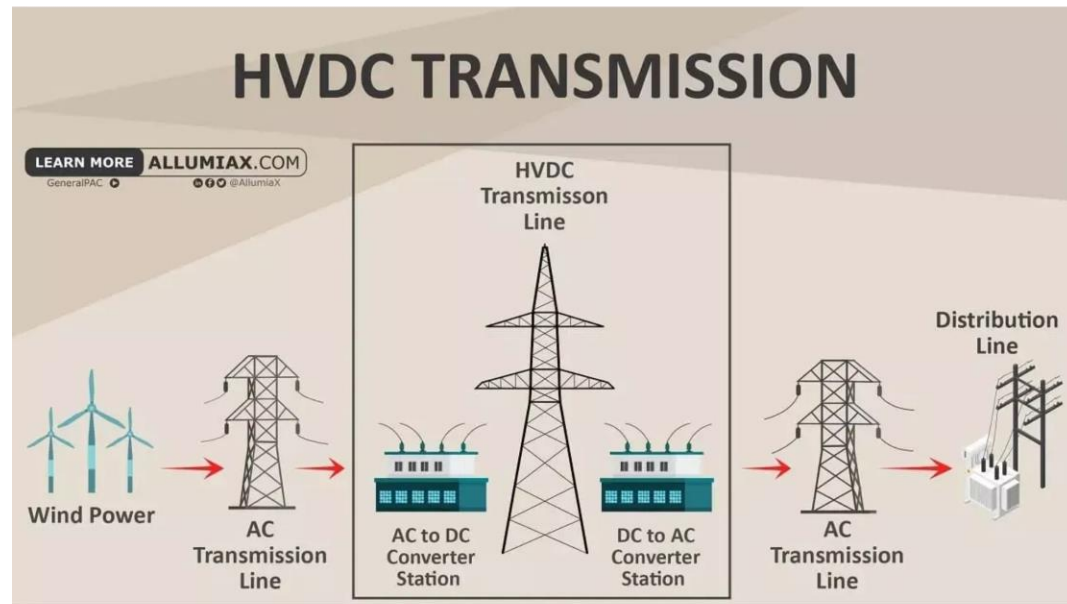
### Case Study: South Australia Tesla VPP

- ✅ \$800 million project value
- 🏠 Networks residential Powerwalls

## Benefits for Egypt

- ☀️ Better integration of solar resources
- ⚡ Reduced peak demand (currently ~35 GW)
- 🛡️ Enhanced grid resilience

# Integration & Interconnection



## Technical Integration Requirements

### Inverter Settings

- Grid-forming capabilities
- Fault ride-through
- Frequency response

### Protection Systems

- Anti-islanding protection
- Adaptive relaying
- Fault current contribution


### Grid Codes

- Harmonized standards
- Voltage control requirements
- Power quality limits

### Communication

- SCADA integration
- Real-time monitoring
- Secure protocols

## Regional Interconnection Projects

 **Egypt-Saudi Arabia HVDC:**  
\$1.8B, 1,300 km, 3,000 MW capacity

 **Sea Interconnection:**  
Linking Cyprus, Greece, and Israel

 **IMEC Corridor:**  
India-Middle East-Europe energy pathway

 **Pan-Arab Electricity Market:**  
Regional power trading

## Benefits & Challenges

### Benefits

- Smoothing renewable variability
- Shared reserve capacity
- Enhanced energy security
- Reduced overall system costs
- Optimized resource allocation

### Challenges

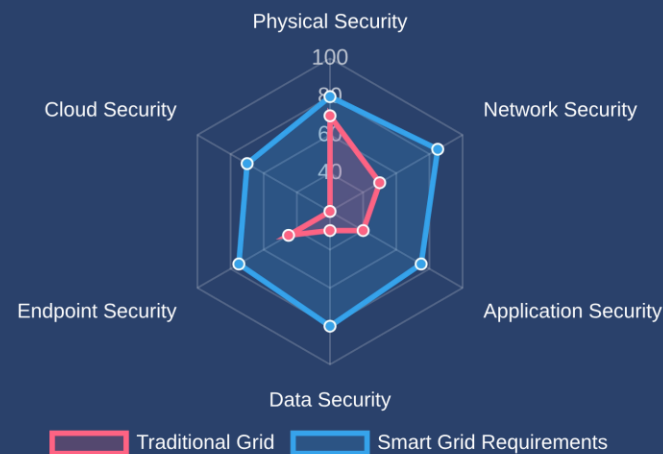
- Complex permitting processes
- High infrastructure costs
- Cross-border regulations
- Technical standards alignment
- Cybersecurity concerns

# Cybersecurity & Reliability

## Threats in a Digital Grid

- ⚙️ **Cyberattacks:** Ransomware, denial-of-service
- 🔌 **Supply Chain:** Compromised components
- 🗄️ **Data Integrity:** Falsified sensor data

## Defense-in-Depth Strategy



Source: Industry cybersecurity frameworks (NIST, IEC 62443)

## Defensive Strategies

### Network Segmentation

Separate OT from IT networks

### Zero Trust

Verify all connections

### Encryption

Secure communications

### Monitoring

Detect anomalies

## Reliability Engineering

🛡️ **N-1 Contingency:** System withstands loss of any component

⚡ **LOLE:** Loss of Load Expectation metric

⚡ **EENS:** Expected Energy Not Served

### Egypt's Context

As Egypt develops the Middle East's first country-wide smart grid, cybersecurity standards must evolve in parallel with digital transformation.

# Egypt's Grid development Projects

## National Smart Grid Transformation

**Scale:** \$287.5 million project by EEHC with Schneider Electric

- ✔ Four advanced control centers with ADMS
- ✔ 12,000+ smart grid main units nationwide
- ✔ EcoStruxure Grid IoT-compatible platform
- ✔ Real-time fault detection & auto-reconfiguration
- ✔ Intelligent sensors for predictive maintenance

## Rural Energy Transition Initiatives

**Context** Rural Egypt hosts 2/3 of population & building stock

- ✔ Energy-use benchmarking (2.5-92.3 kWh/m<sup>2</sup> for non-residential)
- ✔ Correlation analysis: electricity use & built environment
- ✔ Rooftop solar PV installations in rural communities
- ✔ 17% energy consumption reduction target by 2030
- ✔ 37% GHG emissions reduction target in electricity sector

## Egypt-Saudi Arabia HVDC Interconnection

**Scale:** \$1.8 billion project spanning 1,300 kilometers

- ✔ 3,000 MW capacity at 500 kV multi-terminal HVDC
- ✔ Three converter stations (Medina, Tabuk, Badr)
- ✔ Multi-directional power flow capability
- ✔ 20.4 km submarine cable crossing Gulf of Aqaba
- ✔ Benefits 20+ million people across both countries

## Grid Modernization Under NWFE Program

**Investment:** Part of \$2 billion program by EETC

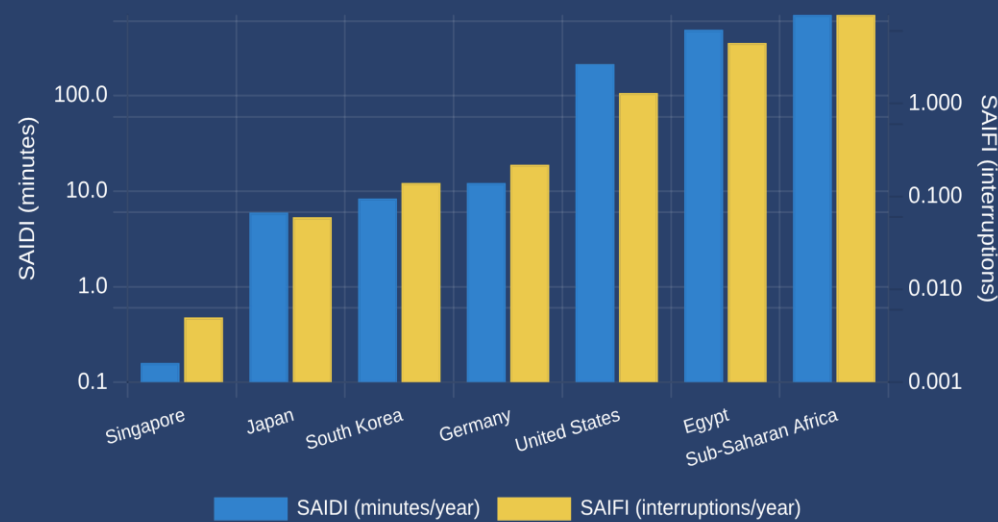
- ✔ Grid reinforcement for renewable integration
- ✔ Upgraded transmission for variable renewables
- ✔ Advanced monitoring and control systems
- ✔ First country-wide smart grid in Middle East
- ✔ Significant reduction in maintenance costs

## Key Takeaways

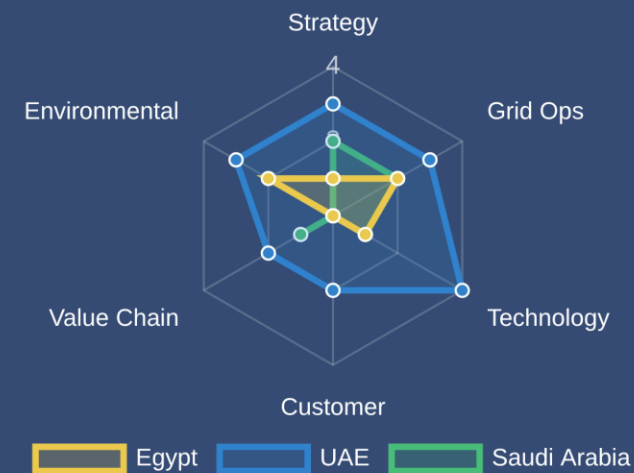
Egypt is implementing a comprehensive approach to grid complexity management through technological innovation, international interconnection, rural energy transition, and significant infrastructure investments.

# Global & Regional Grid Complexity Benchmarking

## Global Grid Reliability Comparison



## MENA Region Grid Maturity Comparison



## Smart Grid Maturity Model (SGMM)

Standardized framework measuring grid modernization across 8 domains:

- ✓ Strategy & Management
- ✓ Organization & Structure
- ✓ Grid Operations
- ✓ Work & Asset Management
- ✓ Technology
- ✓ Customer
- ✓ Value Chain Integration
- ✓ Societal & Environmental

Maturity Levels: 1-Initial, 2-Functional, 3-Integrating, 4-Optimizing, 5-Pioneering

## Technical Complexity Metrics

Metric	Egypt	Global Leaders
System Non-synchronous Penetration	15-20%	65-75%
Grid Inertia	Traditional levels	Low-inertia systems
Fault Levels	Managing changes	Advanced control
Voltage Control	Expanding with FACTS	Distributed control
Frequency Response	Implementing requirements	Fast frequency response

# Egypt's Grid development Projects

## Advanced Grid Architecture

- ✔ Layered control architectures
- ✔ Bidirectional power flow design

**Egypt:** Strengthen transmission backbone between renewable-rich areas and load centers

## Flexibility & Demand Management

- ✔ Portfolio of flexibility resources
- ✔ Virtual power plants (VPPs)

**Egypt:** Target large industrial consumers first

## Monitoring & Control Systems

- ✔ High-resolution PMU monitoring
- ✔ Hierarchical control architectures

**Egypt:** Prioritize SCADA/EMS upgrades at transmission level

## Integration & Interoperability

- ✔ IEEE 1547-2018 for advanced inverters
- ✔ Common information models (CIM)

**Egypt:** Ensure compatibility with GCC interconnection standards

## Forecasting & Planning Tools

- ✔ Ensemble forecasting methods
- ✔ Digital twins for system simulation

**Egypt:** Develop Egypt-specific weather forecasting models

## Resilience & Cybersecurity

- ✔ Defense-in-depth strategies
- ✔ Cellular grid structures

**Egypt:** Design thermal resilience for extreme desert temperatures

### Implementation Priorities for Egypt

#### Short-term (1-3 years)

Complete national smart grid control centers; develop grid codes for renewables

#### Medium-term (3-5 years)

Deploy advanced energy management systems; implement demand response programs

#### Long-term (5-10 years)

Achieve full visibility of distribution networks; establish regional energy hub

# The Way Forward



## Key Recommendations for Egypt

- 📈 Accelerate grid modernization to support 42% renewable target by 2030
- 🔋 Expand energy storage deployment for grid stability
- 🔌 Strengthen regional interconnections for flexibility
- 🛡️ Prioritize cybersecurity in parallel with digitalization

## Success Factors

### ⚙️ Technology

Advanced grid infrastructure, storage systems, and smart controls

### 🌐 Infrastructure

Robust transmission, distribution networks, and interconnections

### 🏛️ Markets

Effective pricing, incentives, and regulatory frameworks

### 🔒 Security

Comprehensive cybersecurity and physical protection

## The Future Grid

- ✅ Cleaner energy mix with lower emissions
- ✅ More resilient and adaptive to disruptions
- ✅ Digitally enabled with advanced analytics
- ✅ Consumer participation through demand response



**Thanks..**