Electricity Regulatory Cooperation Framework for Trans-Regional Grid Interconnections for Enhanced Energy Security and Climate Prosperity

Global Experience in Operating Cross-Border Interconnections

Key Ingredients and Requisites for Safe, Secure, and Reliable Design and Operation of Trans-Regional Grid Interconnections

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Gradual Evolution of Interconnected Systems..(1)

1. Early Power Systems (Late 19th Century)

- **1882**: First power station by **Thomas Edison** (Pearl Street Station, New York) – **DC system**.
- **1886**: First **AC system** (Great Barrington, USA) by **William Stanley** – enabled long-distance transmission.
- **1891**: First long-distance AC transmission line (175 km) in **Germany**.

2. Development of National Grids (Early 20th Century)

- **1920s–1930s**:
  - Regional power grids emerged.
  - Countries began connecting local grids into **national grids**.
  - **1926**: UK started its **National Grid**, completed by 1933.
- **1940s**: WWII accelerated grid interconnections for industrial use.

Gradual Evolution of Interconnected Systems..(2)

3. Post-War Expansion and Regional Interconnections (Mid-20th Century)

- **1950s–1960s**:
  - Industrial growth drove grid expansion.
  - **North America**: Formation of **Eastern**, **Western**, and **Texas (ERCOT)** Interconnections.
  - **1964**: Formation of **UCPTE** in Europe for cross-border coordination.
- **Key Development**: Adoption of **HVDC technology** for efficient long-distance transmission.

4. International Interconnections (Late 20th Century)

- **Key Milestones**:
  - **1965**: Canada–U.S. interconnection.
  - **1981**: First France–UK HVDC link under the **English Channel** (IFA 2000).
  - **1984**: **Skagerrak HVDC link** (Denmark–Norway).
- Increased cross-border grids in **Europe**, **Asia**, and **North America**.

Gradual Evolution of Interconnected Systems..(3)

5. Global Grid Integration (21st Century)

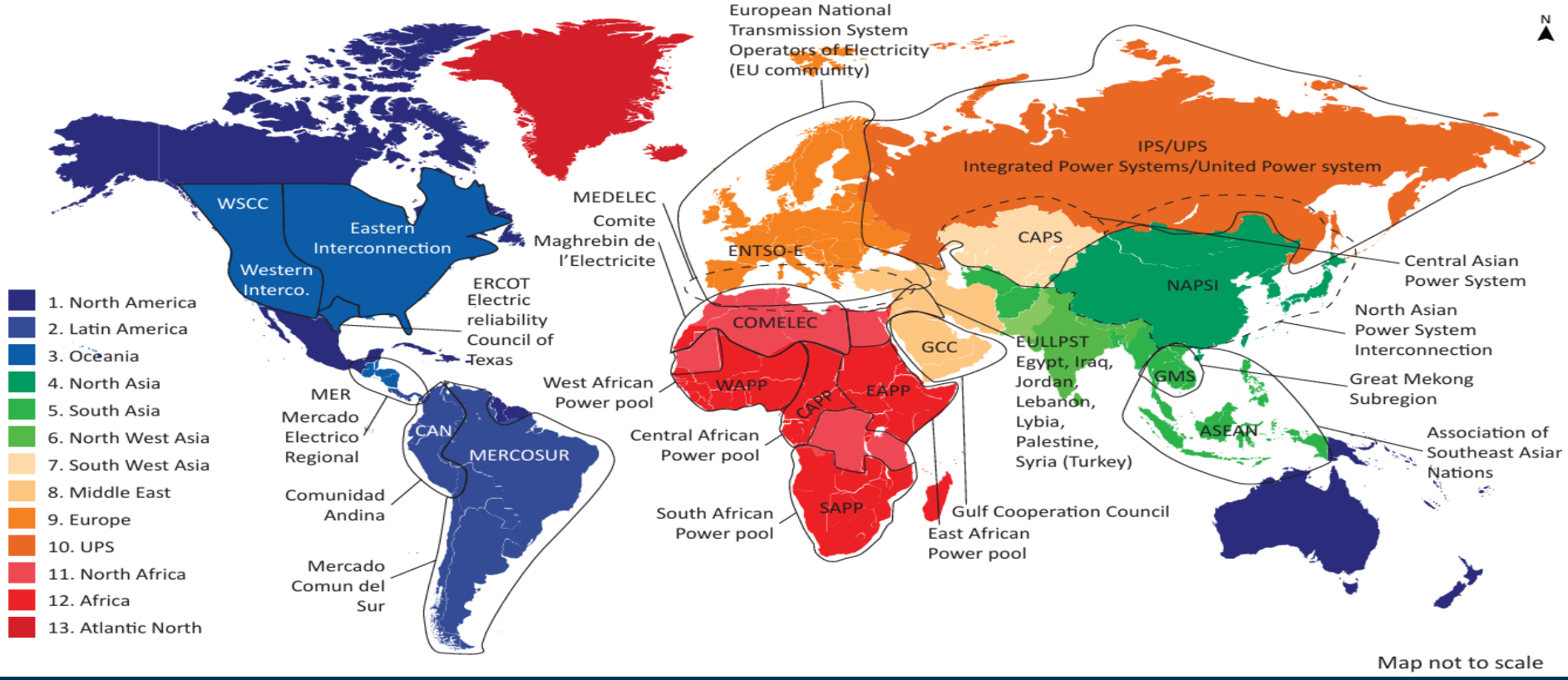
- **Focus on Renewables**: Integration of solar, wind, and hydropower using **HVDC** and **smart grid** technologies.
- **Key Regional Interconnections**:
  - **Europe**: **ENTSO-E** network (36 countries).
  - **Asia**: China's HVDC grids connect to neighbouring countries.
  - **Africa**: **SAPP** (Southern Africa) and **WAPP** (West Africa).
  - **Latin America**: **SIEPAC** (Central America).
- **2016–Present**: Vision for a **Global Energy Interconnection (GEI)** proposed by **GEIDCO** (China).

6. Modern Trends and Future Vision

- **Super grids**: Plans for intercontinental connections (e.g., Asia–Europe, Africa–Europe, OSOWOG).
- **Smart Grids**: Use of AI, IoT, and real-time data for grid efficiency.
- **Global Grid**: Aim to connect renewable energy worldwide for sustainable development. (e.g., International Solar Alliance).

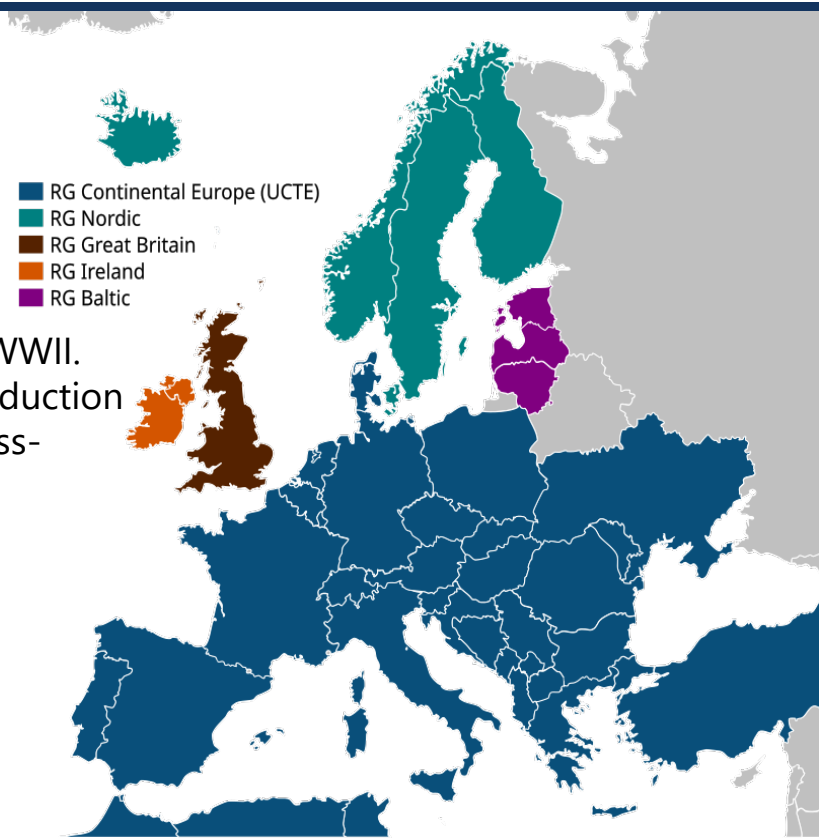
Global & Trans-Regional Grid Interconnections

Existing and ongoing regional interconnection initiatives



ENTSO-E (European Network of Transmission System Operators for Electricity)

- Founded in 2009 to ensure secure, efficient, and sustainable operation of Europe's interconnected electricity grid.
- **Members:** 39 Transmission System Operators (TSOs) from 36 European countries.



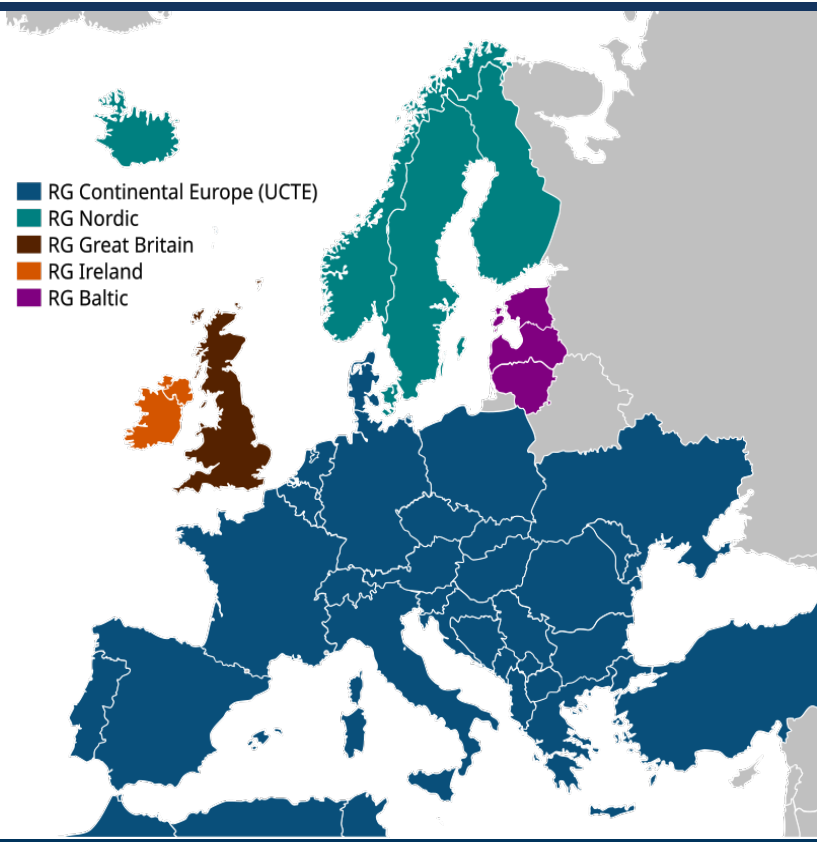
Development of the European Power Interconnection

- **1950s**: Regional grids in Europe began interconnecting post-WWII.
- **1964**: Formation of **UCPTE** (Union for the Coordination of Production and Transmission of Electricity) to manage and coordinate cross-border electricity flows.
- **1990s**: Expansion to include Eastern and Southern European countries after the fall of the Soviet Union.
- **2009**: UCPTE transformed into **ENTSO-E** under the EU's **Third Energy Package**, promoting:
  - Grid integration.
  - Energy market liberalization.
  - Renewable energy transition.

ENTSO-E (European Network of Transmission System Operators for Electricity)

Key Statistics:

- ❑ **Number of Countries Represented**: **35**
- ❑ **Number of TSOs Represented**: **39**
- ❑ **Generating Capacity**: Approximately 1,000 GW
- ❑ **Annual Electricity Demand**: Approximately 3,300 TWh
- ❑ **Population Served**: Approximately 532 million people



ENTSO-E Network Codes :The backbone for European interconnection

- Network codes are a set of rules drafted by ENTSO-E, with guidance from the Agency for the Cooperation of **Energy Regulators ACER**, to facilitate the harmonization, integration and efficiency of the European electricity market.
- Each network code is an integral part of the drive towards completion of the internal energy market, and achieving the European Union's energy objectives of:
  - **At least 55% cut in greenhouse gas emissions** compared to 1990 levels.
  - **At least a 32% share of renewable energy consumption**.
  - At least **32.5% energy savings** compared with the business-as-usual scenario.
- ENTSO-E Network codes [Ref. EU Regulation 714/2009]

Connection Code
- Demand Connection Code
- High Voltage Direct Current Connections
- Requirements for Generators

Operations Code
- Emergency and Restoration
- System Operations

Market Code
- Capacity Allocation & Congestion Management
- Electricity Balancing
- Forward Capacity Allocation

Cybersecurity Code
- Network Code on Cybersecurity

Source: https://www.entsoe.eu/network_codes/

Evolution of pan-European Interconnection

1948
Organization for European Economic Co-operation (OEEC), which was established

1951
Union for the Coordination of Production & Transmission of Electricity (UCPTE) founded in Paris

1964
Spain and Portugal achieved synchronous interconnection with UCPTE

1974
Yugoslavia connected with UCPTE

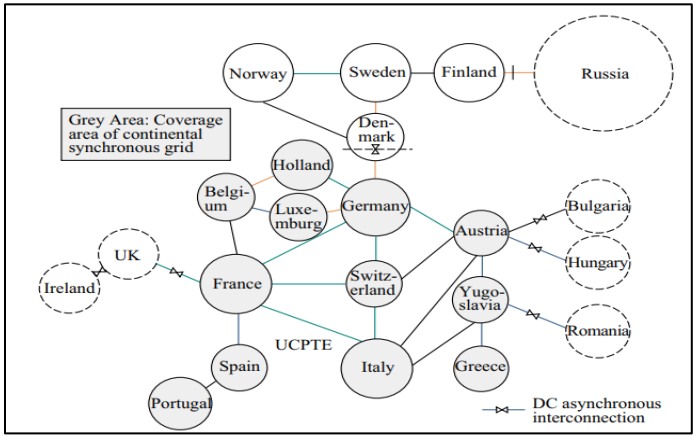
1977
Greek power grid was connected with Yugolavia

Late 1980s
12 European countries got interconnected

End of 20th Century
All European countries except those of Iceland and Cyprus, were interconnected and gradually formed five major synchronous grids

2008
Formation of ENTSO-E

Illustration of the power interconnection in Europe in the late 1980s



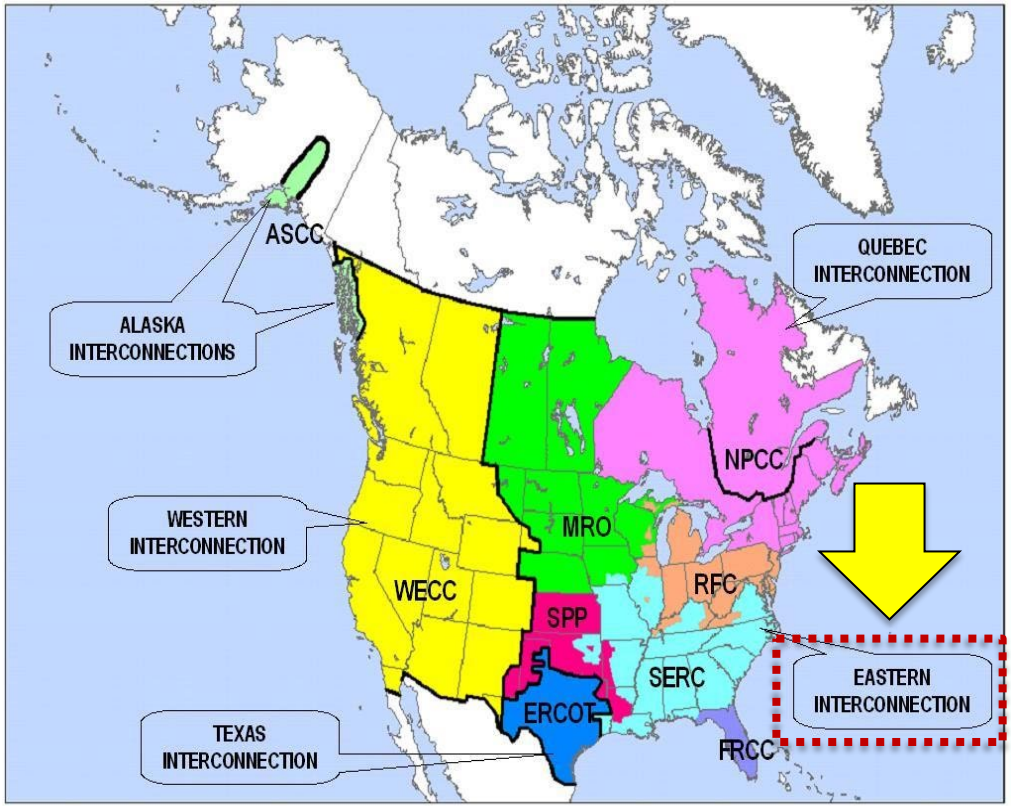
Source: https://www.sciencedirect.com/science/article/pii/S2096511720300451

Eastern Interconnection

One of North America's major synchronously connected (AC) electrical grids—encompasses the eastern two-thirds of the United States and parts of Canada.

Key Statistics:

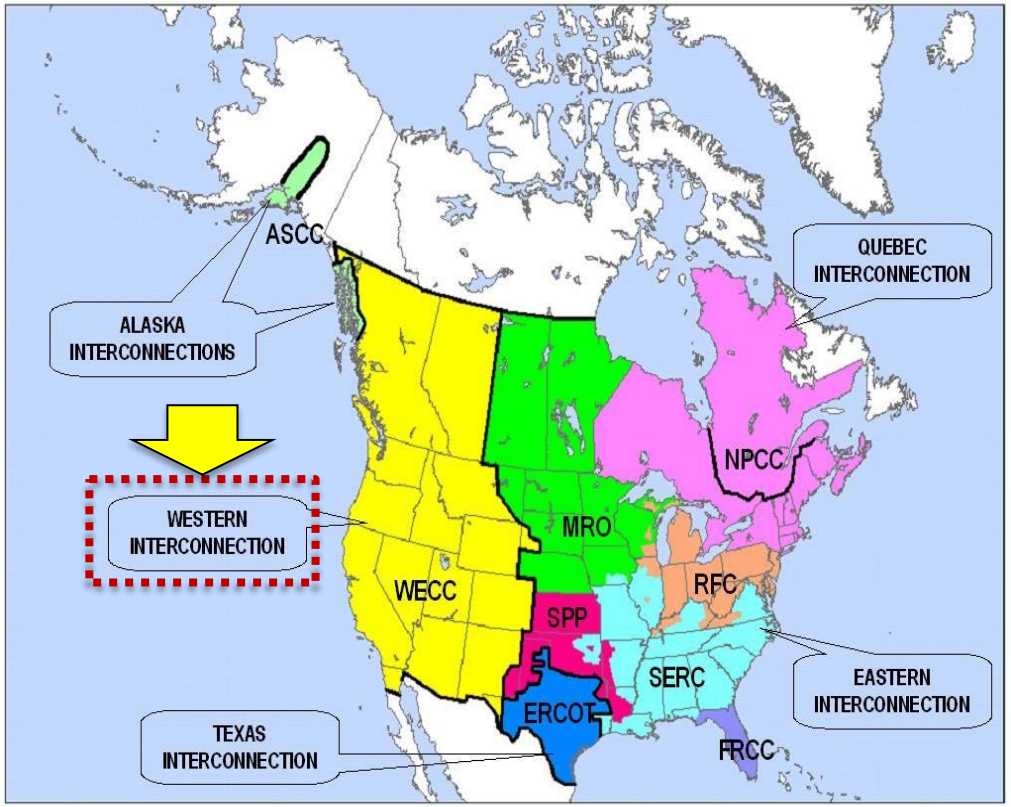
- **Number of Countries Represented**: 2 (United States and Canada)
- **Number of Balancing Authorities**: 36 (31 in the U.S. and 5 in Canada)
- **Generating Capacity**: Approximately 700 GW
- **Annual Electricity Demand**: Approximately 3,000 TWh
- **Population Served**: Approximately 240 million people



Western Interconnection

Key Statistics:

- **Number of Countries Represented**: 3 (United States, Canada, and Mexico)
- **Number of Balancing Authorities**: 37 (34 in the U.S., 2 in Canada, 1 in Mexico)
- **Generating Capacity**: Approximately 307 GW
- **Annual Electricity Demand**: Approximately 1,000 TWh
- **Population Served**: Approximately 80 million people



NERC Reliability Standards :The backbone for European interconnection

- These standards are enforceable in **all interconnected jurisdictions in North America**: the continental United States; the Canadian provinces of Alberta, British Columbia, Manitoba, New Brunswick, Nova Scotia, Ontario, Quebec, and Saskatchewan; and the Mexican state of Baja California Norte.
- NERC files the standard with the appropriate authority **in each jurisdiction**
- Standards are broadly classified into following types: (currently 92 active Standards)

(BAL) Resource and Demand Balancing (8)	(CIP)Critical Infrastructure Protection (15)	(COM) Communications (2)	(EOP) Emergency Preparedness & Operations(7)	(FAC) Facilities Design, Connections, and Maintenance (7)	(INT) Interchange Scheduling and Coordination (2)
(IRO) Interconnection Reliability Operations & Coordination (12)	(MOD) Modeling, Data, and Analysis (6)	(NUC) Nuclear (1)	(PER) Personnel Performance, Training & Qualifications (3)	(PRC) Protection and Control (18)	(TOP) Transmission Operations (6)
		(TPL) Transmission Planning (2)	(VAR) Voltage and Reactive (3)		

Source: https://www.nerc.com/pa/Stand/pages/reliabilitystandards.aspx/

Evolution of United States Interconnected Grid

1880s–1920s: Early Electrification
- Thomas Edison establishes the first commercial power plant

1910s–1920s:
- Expansion of small, local grids. However, grids are still largely isolated and unregulated.

1930s: Federal Intervention and Rural Electrification
- **1935:** The Federal Power Act creates the Federal Power Commission (now FERC).
- **1936:** The Rural Electrification Act provides funding to extend electricity to rural areas.

1940s–1960s: Growth of Interconnected Networks
- **1940s:** Demand for electricity during World War II drives grid expansion and interconnection for reliability.

1965: The Northeast Blackout highlights the need for better coordination and reliability standards. This leads to the establishment of the NERC.

1970s–1990s: Consolidation and Regulation
- **1970s:** Formation of the Eastern Interconnection, Western Interconnection, and Texas (ERCOT).
- **1977:** The Department of Energy (DOE) is established.

1990s:

Deregulation and restructuring of the electricity market allow competition among power producers, further integrating grids.

2000s–Present: Modernization and Integration
- **2003:** The Northeast Blackout underscores the importance of advanced grid technologies and operational standards.
- **2010s:** Growth of renewable energy and smart grid technologies.
- **2020s:** Efforts to expand and modernize the grid.

Source: https://grid-sentry.com/history-and-evolution-of-us-power-grid/

Some Notable Trans-Regional Grid Interconnections

Central American Electrical Interconnection System (SIEPAC)

Key Statistics:

- **Number of Countries Represented**: 6 (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama)
- **Number of Transmission System Operators (TSOs) Represented**: 6 (one per country)
- **Population Served**: Approximately 50 million people

Southern Common Market (MERCOSUR)

Key Statistics:

- **Number of Countries Represented**: 4
- **Member Countries**: Argentina, Brazil, Paraguay, Uruguay
- **Total Installed Generating Capacity**: Approximately 250 GW
- **Annual Electricity Generation**: Approximately 1,200 TWh
- **Population Served**: Approximately 295 million people

Southern African Power Pool (SAPP)

Key Statistics:

- **Number of Countries Represented**: 12 (Angola, Botswana, Democratic Republic of Congo, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia, Zimbabwe)
- **Number of Transmission System Operators (TSOs) Represented**: 16
- **Generating Capacity**: Approximately 80 GW
- **Peak Demand**: Approximately 57 GW
- **Available Capacity**: Approximately 48 GW
- **Population Served**: Approximately 360 million people

West African Power Pool (SAPP)

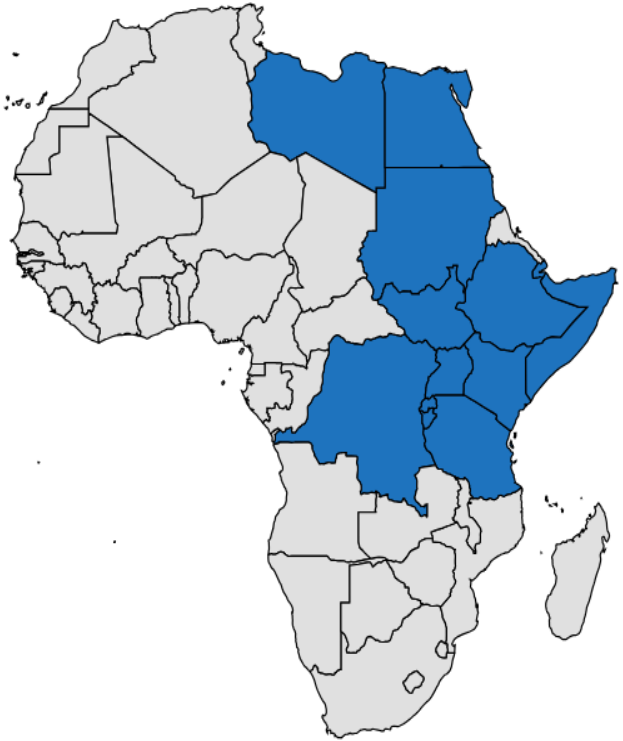
Key Statistics:

- **Number of Countries Represented**: 14 (Benin, Burkina Faso, Côte d'Ivoire, Ghana, The Gambia, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo)
- **Number of Transmission System Operators (TSOs) Represented**: 26
- **Generating Capacity**: Approximately 15.49 GW
- **Planned Additional Capacity (2019-2033)**: Approximately 15.49 GW
- **Transmission Lines Planned (2019-2033)**: Approximately 22,932 km
- **Population Served**: Approximately 400 million people

East African Power Pool (SAPP)

Key Statistics:

- **Number of Countries Represented**: 14 (Burundi, DRC, Egypt, Ethiopia, Libya, Kenya, Rwanda, Sudan, SINELAC of DRC – Rwanda – Burundi, TANESCO of Tanzania, UETCL of Uganda, EDD of Djibouti and the newly joined SSEC of South Sudan and Electricity utilities of Somalia.)
- **No of Transmission System Operators (TSOs) Represented**: 26
- **Generating Capacity**: Approximately 15.49 GW
- **Planned Additional Capacity (2019-2033)**: Approximately 15.49 GW
- **Transmission Lines Planned (2019-2033)**: Approximately 22,932 km
- **Population Served**: Approximately 400 million people



Mediterranean Electricity Interconnection (MED-TSO)

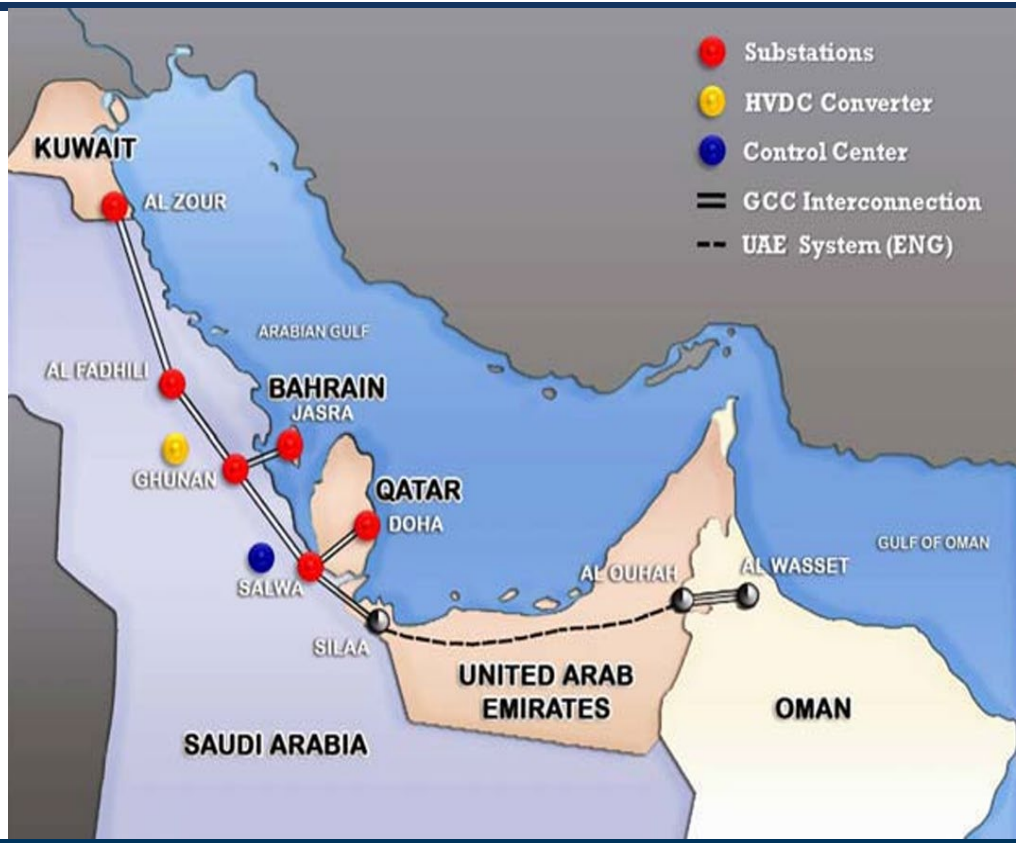
Key Statistics:

- **Number of Countries Represented**: 19
- **Member Countries**: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Jordan, Libya, Malta, Montenegro, Morocco, Slovenia, Spain, Tunisia, Turkey
- **Total Installed Generating Capacity**: Approximately 600 GW
- **Annual Electricity Generation**: Approximately 2,500 TWh
- **Population Served**: Approximately 500 million people

Gulf Cooperation Council Interconnection Authority (GCCIA)

Key Statistics:

- **Number of Countries Represented**: 6 (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates)
- **Number of Transmission System Operators (TSOs) Represented**: 6 (one per country)
- **Generating Capacity**: Approximately 148 GW
- **Annual Electricity Demand**: Approximately 500 TWh
- **Population Served**: Approximately 57 million people



Association of Southeast Asian Nations (ASEAN)

Key Statistics:

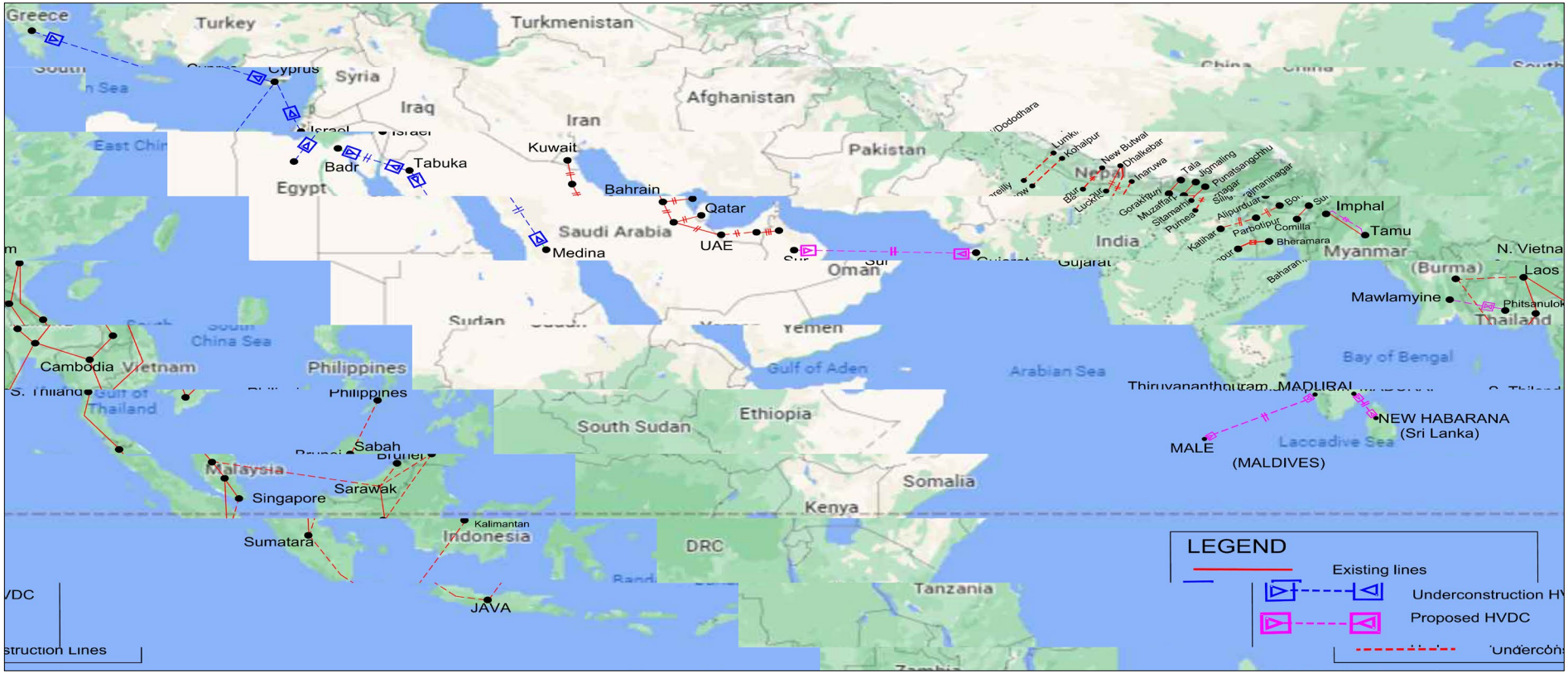
- **Number of Countries Represented**: 10
- **Member Countries**: Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, Viet Nam
- **Total Installed Generating Capacity**: Approximately 300 GW
- **Annual Electricity Generation**: Approximately 1,300 TWh
- **Population Served**: Approximately 680 million people

South Asian Association for Regional Cooperation (SAARC)

Key Statistics:

- **Number of Countries Represented**: 8
- **Member Countries**: Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
- **Total Installed Generating Capacity**: Approximately 500 GW
- **Annual Electricity Generation**: Approximately 1,800 TWh
- **Population Served**: Approximately 1.9 billion people

Proposed Cross Border Interconnections under OSOWOG



Key Ingredients and Requisites for Safe, Secure, and Reliable Design and Operation of Trans-Regional Grid Interconnections

I. Technical Requisites

- **Grid Synchronization**:
  - Ensure frequency and voltage stability across interconnected regions.
  - Use of **synchronous and asynchronous interconnections** (HVDC links) to stabilize power flows.
- **Advanced Transmission Technology**:
  - High-Voltage Direct Current (HVDC) systems for long-distance, efficient power transfer, STATCOM, SVCs
- **System Protection and Control**:
  - Wide-Area Monitoring Systems (WAMS) and Phasor Measurement Units (PMUs).
  - Robust **relay protection schemes** to detect and isolate faults quickly.
- **Energy Storage Solutions**:
  - Integration of large-scale **battery energy storage systems (BESS)** for grid balancing.
  - Use of pumped hydro storage for managing intermittent renewable power.
- **Resilient Infrastructure**:
  - Strong and reliable **transmission lines**, substations, and transformers designed to withstand natural disasters and cyber threats.

2. Operational Requisites

- **Coordinated Grid Operations:**
  - Establishment of Regional Security Coordinators (RSCs) to oversee operations.
  - Unified grid codes and operational standards across regions.
- **Real-Time Monitoring and Communication:**
  - Implementation of SCADA (Supervisory Control and Data Acquisition) systems for live monitoring.
  - Use of secure, fast communication networks between operators.
- **Load Flow Management:**
  - Advanced energy flow forecasting tools to predict and manage power transfers.
  - Dynamic load balancing to avoid congestion and overloads.
- **Black Start Capability:**
  - Design of black start systems to quickly restore power during regional grid failures.

3. Regulatory and Policy Framework

- **Harmonized Grid Codes**:
  - Development of standardized rules and regulations for grid operation and maintenance.
- **Cross-Border Agreements**:
  - Bilateral and multilateral power trade agreements to ensure equitable power sharing.
- **Market Integration**:
  - Establishment of regional electricity markets to facilitate competitive energy trading.
  - Example: European Single Electricity Market under **ENTSO-E**.
- **Clear Governance and Oversight**:
  - Setting up independent regulatory authorities for grid operations and dispute resolution.

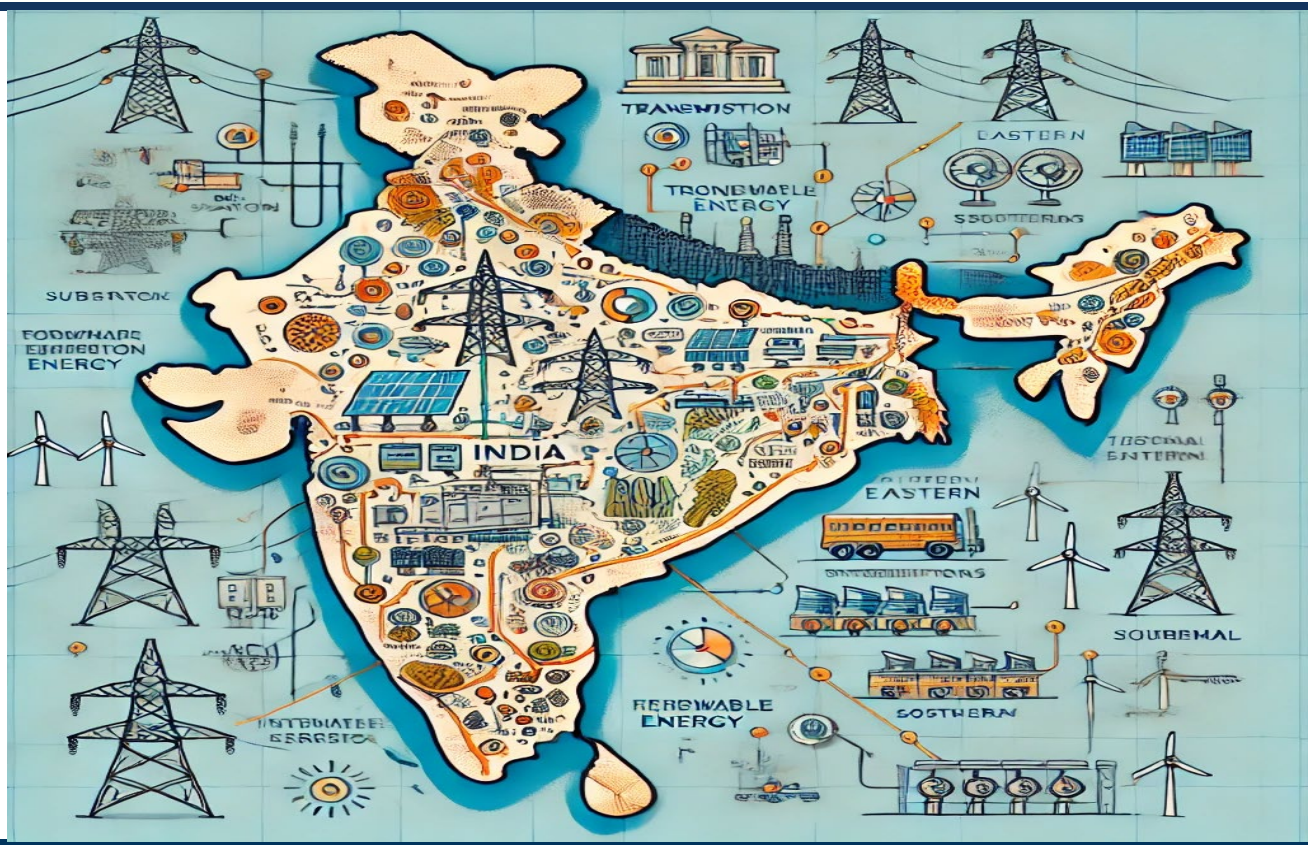
4. Financial and Economic Considerations

- **Investment in Infrastructure**:
  - Public-private partnerships (PPPs) to finance large-scale interconnection projects.
  - Example: SIEPAC and GCCIA models.
- **Cost Sharing Mechanisms**:
  - Transparent allocation of infrastructure costs among participating countries.
- **Economic Benefits**:
  - Lower operational costs and shared reserve capacity among regions.
  - Facilitation of renewable energy integration, reducing reliance on fossil fuels.

6. Cybersecurity and Resilience

- **Cybersecurity Measures**:
  - Deploy robust security frameworks to protect grid infrastructure from cyberattacks.
  - Real-time threat detection systems and secure communication protocols.
- **Disaster Resilience**:
  - Design grids to withstand natural disasters, including earthquakes, hurricanes, and floods.
  - Redundancy and backup systems for critical infrastructure.

Thank You...



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