Emerging Trends and Challenges Electric Power Systems

By

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## Evolution of Power Systems

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Late 1870s</td>
<td>Commercial use of electricity</td>
</tr>
</tbody>
</table>
| 1882 | First Electric power system (Gen., cable, fuse, load) by Thomas Edison at Pearl Street Station in NY.  
- DC system, 59 customers, 1.5 km in radius  
- 110 V load, underground cable, incandescent Lamps |
| 1884 | Motors were developed by Frank Sprague                              |
| 1886 | Limitation of DC become apparent                                   |
|      | - High losses and voltage drop.                                     |
|      | - Transformation of voltage required                                |
|      | Transformers and AC distribution (150 lamps) developed by William Stanley of Westinghouse |
| 1889 | First ac transmission system in USA between Willamette Falls and Portland, Oregon.  
- 1- phase, 4000 V, over 21 km |
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1888</td>
<td>N. Tesla developed poly-phase systems and had patents of gen., motors, transformers, trans. Lines. Westinghouse bought it.</td>
</tr>
<tr>
<td>1890s</td>
<td>Controversy on whether industry should standardize AC or DC. Edison advocated DC and Westinghouse AC. - Voltage increase, simpler &amp; cheaper gen. and motors</td>
</tr>
<tr>
<td>1893</td>
<td>First 3-phase line, 2300 V, 12 km in California. ac was chosen at Niagara Falls ( 30 km)</td>
</tr>
<tr>
<td>Year</td>
<td>Early Voltage (Highest)</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>1922</td>
<td>165 kV</td>
</tr>
<tr>
<td>1923</td>
<td>220 kV</td>
</tr>
<tr>
<td>1935</td>
<td>287 kV</td>
</tr>
<tr>
<td>1953</td>
<td>330 kV</td>
</tr>
<tr>
<td>1965</td>
<td>500 kV</td>
</tr>
<tr>
<td>1966</td>
<td>735 kV</td>
</tr>
<tr>
<td>1969</td>
<td>765 kV</td>
</tr>
<tr>
<td>1990s</td>
<td>1100 kV</td>
</tr>
</tbody>
</table>

Standards are 115, 138, 161, 230 kV – HV
345, 400, 500 kV - EHV
765, 1100 kV - UHV

Earlier Frequencies were
25, 50, 60, 125 and 133 Hz; USA - 60 Hz and some countries - 50 Hz
<table>
<thead>
<tr>
<th>1950s</th>
<th>HVDC Transmission System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mercury arc valve</td>
</tr>
<tr>
<td>1954</td>
<td>First HVDC transmission between Sweden and Got land island by cable</td>
</tr>
</tbody>
</table>

**Limitations of HVAC Transmission**

1. Reactive Power Loss
2. Stability
3. Current Carrying Capacity
4. Ferranti Effect
5. No smooth control of power flow
Indian Power System - Present

- Installed Capacity: 157GW
- Peak Demand – 110 GW
- Peak Deficit – 13.9%
- Energy Deficit – 9.6%
Indian Power System - Present

• Transmission Grid Comprises:
  – 765kV/400kV Lines - 77,500 ckt. km
  – 220/132kV Lines - 114,600 ckt. km
  – HVDC bipoles - 3 nos.
  – HVDC back-to-back - 7 nos.
  – FSC – 18 nos.; TCSC – 6 nos.

• NER, ER, NR & WR operating as single grid of 90,000MW

• Inter-regional capacity : 14,600 MW
Inter-regional links - At present

Inter-regional capacity: 14,600MW
Scenario by 2012

- Peak Demand: 157,000 MW (1.5 times of 2007)
- Installed Capacity: 212,000 MW (1.5 times of 2007)
- Hydro potential in NER and upper part of NR
- Coal reserves mainly in ER
- For optimal utilisation of resources – strong National Grid
Inter Regional Links by 2012 – 40,000 MW Capacity

Northern
- Agra
- Allahabad
- Sahupuri
- Gorakhpur
- Balia
- Fatehpur

Western
- Ujjain
- Malanpur
- Gwalior
- Vindhyachal
- Zerda
- Ponda
- Kolhapur

Southern
- Nagjhari
- Belgaum
- Ramagunda
- With Krishnapattanam UMPP

Eastern
- Jeypor
- Talcher
- Balimela

NER Pooling
- Salakat
- North-eastern

- Bongaigaon
- 3250 MW
- WR Pooling
- 3000MW
- 12650MW
- 7250 MW
- 2700 MW
- 5000 MW
- With Krishnapattanam UMPP

- 3650 MW
- 3250 MW
- 3650 MW
- 2700 MW
- 5000 MW
- 7250 MW
- 12650MW
- 3000MW
- 3250 MW
- 3650 MW
- 2700 MW
- 5000 MW
- 7250 MW
<table>
<thead>
<tr>
<th>Year</th>
<th>400 kV</th>
<th>±800 kV HVDC</th>
<th>1200 kV UHVAC</th>
<th>±500 kV HVDC</th>
<th>765 kV AC</th>
<th>400 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
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<tr>
<td>2000</td>
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<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
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<tr>
<td>2012/13</td>
<td></td>
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</tbody>
</table>
### Line Parameters

- **Line parameters of 1200kV/765kV/400kV Transmission System**

<table>
<thead>
<tr>
<th></th>
<th>1200 kV</th>
<th>765kV</th>
<th>400kV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nominal Voltage (kV)</strong></td>
<td>1150</td>
<td>765</td>
<td>400</td>
</tr>
<tr>
<td><strong>Highest voltage (kV)</strong></td>
<td>1200</td>
<td>800</td>
<td>420</td>
</tr>
<tr>
<td><strong>Resistance (pu/km)</strong></td>
<td>4.338 x10^{-7}</td>
<td>1.951x10^{-6}</td>
<td>1.862x10^{-5}</td>
</tr>
<tr>
<td><strong>Reactance (pu/km)</strong></td>
<td>1.772 x10^{-5}</td>
<td>4.475x10^{-5}</td>
<td>2.075x10^{-4}</td>
</tr>
<tr>
<td><strong>Susceptance (pu/km)</strong></td>
<td>6.447 x10^{-2}</td>
<td>2.4x10^{-2}</td>
<td>5.55x10^{-3}</td>
</tr>
<tr>
<td><strong>Surge Impedance Loading (MW)</strong></td>
<td>6030</td>
<td>2315</td>
<td>515</td>
</tr>
</tbody>
</table>

*Base kV : 1200kV/765kV/400kV; Base MVA : 100 MVA*
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Less than 200MW</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>200/210MW</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>500MW</td>
<td></td>
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</tr>
<tr>
<td>660/800/1000MW</td>
<td></td>
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</tr>
</tbody>
</table>
Likely power transfer requirement between various regions by 2022 & beyond

**North-eastern Region**
- IC = 80 GW
- Despatch = 60 GW
- Demand = 10 GW
- Surplus = 50 GW

**Western Region**
- IC = 135 GW
- Despatch = 100 GW
- Demand = 130 GW
- Deficit = 30 GW

**Southern Region**
- IC = 135 GW
- Despatch = 100 GW
- Demand = 130 GW
- Deficit = 30, GW

**Eastern Region**
- IC = 106 GW
- Despatch = 80 GW
- Demand = 40 GW
- Surplus = 40 GW

**ALL INDIA**
- IC = 600 GW
- Demand = 450 GW

**Northern Region**
- IC = 145 GW
- Despatch = 110 GW
- Demand = 140 GW
- Deficit = 30 GW

**Additional Power Transfer**
- 18 GW from North-eastern to Northern Region
- 27 GW from Northern Region to Western Region
- 12 GW from Western Region to Southern Region
- 23 GW from Southern Region to Eastern Region
- 20 GW from Eastern Region to Northern Region
- 15 GW from Northern Region to ALL INDIA
- 15 GW from Eastern Region to ALL INDIA
Transmission System through Narrow Area

• Requirement of Power Flow between NER & ER/WR/NR: 50 GW
• Required Transmission Capacity : 57.5 GW (15% redundancy)
• Existing & planned Capacity : 9.5 GW
• Additional Trans. Capacity to be planned : 48 GW
  Options :  
  1. ±800kV HVDC : 8nos.
  2. ±800kV HVDC : 5nos.; 765kV EHVAC : 6nos.
  3. ±800kV HVDC : 4nos.; 1200kV UHVAC : 2nos.
• Selection of Next Level Transmission Voltage i.e. 1200kV UHVAC in view of :
  – Loading lines upto **Thermal Capacity (10000 MW)** compared to **SIL (6000 MW)**
  – Saving **Right of Way**
New Transmission Technologies

• **High Voltage Overhead Transmission**
  – Voltage up to 1100 kV
  – High EM radiation and noise
  – High corona loss
  – More ROW clearance

• **Gas Insulated Cables/Transmission lines**

• **HVDC-Light**

• **Flexible AC Transmission Systems (FACTS)**
Gas insulated Transmission Lines

- Benefits of GITL
  - Low resistive losses (reduced by factor 4)
  - Low capacitive losses and less charging current
  - No external electromagnetic fields
  - No correction of phase angle is necessary even for long distance transmission
  - No cooling needed
  - No danger of fire
  - Short repair time
  - No aging
  - Lower total life cycle costs.
HVDC-Light

• Classical HVDC technology
  – Mostly used for long distance point-to-point transmission
  – Requires fast communication channels between two stations
  – Large reactive power support at both stations
  – Thyristor valves are used.
  – Line or phase commutated converters are used.

• HVDC-Light
  – Power transmission through HVDC utilizing voltage source converters with insulated gate bipolar transistors (IGBT) which extinguishes the current more faster and with less energy loss than GTOs.
HVDC-Light

- It is economical even in low power range.
- Real and reactive power is controlled independently in two HVDC light converters.
- Controls AC voltage rapidly.
- There is possibility to connect passive loads.
- No contribution to short circuit current.
- No need to have fast communication between two converter stations.
- Operates in all four quadrants.
- PWM scheme is used.
- Opportunity to transmit any amount of current of power over long distance via cables.
HVDC-Light

- Low complexity-thanks to fewer components
- Small and compact
- Useful in windmills
- Offers asynchronous operation.

- **First HVDC-Light pilot transmission for 3 MW, ±10kV in March, 1997 (Sweden)**
- **First commercial project 50 MW, 70 kV, 72 km, in 1999.**
• Transmission system limitations:
  – **System Stability**
    • Transient stability
    • Voltage stability
    • Dynamic Stability
    • Steady state stability
    • Frequency collapse
    • Sub-synchronous resonance
  – **Loop flows**
  – **Voltage limits**
  – **Thermal limits of lines**
  – **High short-circuit limits**

**FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)**
Flexible AC Transmission Systems (FACTS) are the name given to the application of power electronics devices to control the power flows and other quantities in power systems.
• Benefits of FACTS Technology
  – To increase the power transfer capability of transmission networks and
  – To provide direct control of power flow over designated transmission routes.

• However it offers following opportunities
  – Control of power flow as ordered so that it follows on the prescribed transmission corridors.
  – The use of control of the power flow may be to follow a contract, meet the utilities’ own needs, ensure optimum power flow, ride through emergency conditions, or a combination thereof.
  – Increase the loading capability of lines to their thermal capabilities, including short-term and seasonal.
  – Increase the system security through raising the transient stability limit, limiting short-circuit currents and overloads, managing cascading blackouts and damping electromechanical oscillations of power systems and machines.
- Provide secure tie line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides.
- Allow secure loading of transmission line to a level closer to the thermal limits, while avoiding overloading and reduce the generation margin by having the ability to transfer more power between the controlled areas.
- Damping of power oscillation,
- Preventing cascading outages by limiting the impacts of faults and equipment failures.
- Provide greater flexibility in sitting new generation.
- Upgrade of lines.
- Reduce reactive power flows, thus allowing the lines to carry more active power.
- Reduce loop flows.
- Increase utilization of lowest cost generation.
• Whether HVDC or FACTS?
  – Both are complementary technologies.
  – The role of HVDC is to interconnect ac systems where a reliable ac interconnection would be too expensive.
    • Independent frequency and control
    • Lower line cost
    • Power control, voltage control and stability control possible.
  – The large market potential for FACTS is within AC system on a value added basis where
    • The existing steady-state phase angle between bus nodes is reasonable.
    • The cost of FACTS solution is lower than the HVDC cost and
    • The required FACTS controller capacity is lesser than the transmission rating.
FACTS technology is concerned with development of following two areas

- High rating Power electronic switching devices and Pulse Width Modulated converters.
- Control methods using digital signal processing and Microprocessors.
- Devices: IGBT $\rightarrow$ Insulated gate bipolar transistors, GTO $\rightarrow$ gate turn off thyristor, MCT $\rightarrow$ Metal oxide thyristor (MOS) controlled transistor

<table>
<thead>
<tr>
<th>Throughput</th>
<th>HVDC 2 terminal</th>
<th>FACTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 MW</td>
<td>$40-50$ M</td>
<td>$5-10$ M</td>
</tr>
<tr>
<td>500 MW</td>
<td>75-100 M</td>
<td>10-20 M</td>
</tr>
<tr>
<td>1000 MW</td>
<td>120-170 M</td>
<td>20-30 M</td>
</tr>
<tr>
<td>2000 MW</td>
<td>200-300 M</td>
<td>30-50 M</td>
</tr>
</tbody>
</table>
### Table: Comparison of power semiconductor devices

<table>
<thead>
<tr>
<th></th>
<th>Thyristor</th>
<th>GTO</th>
<th>IGBT</th>
<th>SI* thyristor</th>
<th>MCT</th>
<th>MOSFET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max. voltage rating (V)</strong></td>
<td>8000</td>
<td>6000</td>
<td>1700</td>
<td>2500</td>
<td>3000</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Max. current rating (A)</strong></td>
<td>4000</td>
<td>6000</td>
<td>800</td>
<td>800</td>
<td>400</td>
<td>100</td>
</tr>
<tr>
<td><strong>Gating</strong></td>
<td>Pulse</td>
<td>Current</td>
<td>Voltage</td>
<td>Current</td>
<td>Voltage</td>
<td>Voltage</td>
</tr>
<tr>
<td><strong>Conduction drop (V)</strong></td>
<td>1.2</td>
<td>2.5</td>
<td>3</td>
<td>4</td>
<td>1.2</td>
<td>Resistive</td>
</tr>
<tr>
<td><strong>Switching frequency (kHz)</strong></td>
<td>1</td>
<td>5</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td><strong>Development target max. voltage rating (kV)</strong></td>
<td>10</td>
<td>10</td>
<td>3.5</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Development target max. current rating (kA)</strong></td>
<td>8</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* SI: Static induction thyristor, MOSFET: MOS field effect transistor
• **Developments in Generation side**
  – Powerformer Energy System
  – Distributed Generations
    • Wind Power
    • Fuel Cells
    • Biomass etc.
  – Combined Cycle Power Plants
Powerformer™ Benefits

- Higher performance (availability, overload)
- Environmental improvement
- Lower weight
- Less total space requirement
- Lower cost for Civil Works
- Less maintenance
- Reduced losses
- Lower investment
- Lower LCC
Electrical Field Distribution

Bar

E-field non-uniform

3kV/mm

6-9kV/mm

Cable

E-field uniform

E (kV/mm)
Conductor (1), Inner semi-conducting layer (2), Insulation (3) and an outer semi-conducting layer (4).
Opportunities/Challenges

- ...
- ...
- Fault Analysis including Internal Fault
- Faulty Synchronization
- Model for Double Winding Generator
- ....
- ....
Distributed Generation/Dispersed Generation

- DG includes the application of small generations in the range of **15 to 10,000 kW**, scattered throughout a power system.
- DG includes all use of small electric power generators whether located on the utility system at the site of a utility customer, or at an isolated site not connected to the power grid.
- By contrast, **dispersed generation** (capacity ranges from **10 to 250 kW**), a subset of distributed generation, refers to generation that is located at customer facilities or off the utility system.
DG includes traditional -- diesel, combustion turbine, combined cycle turbine, low-head hydro, or other rotating machinery and renewable -- wind, solar, or low-head hydro generation.

The plant efficiency of most existing large central generation units is in the range of 28 to 35%, converting between 28 to 35% of the energy in their fuel into useful electric power.

By contrast, efficiencies of 40 to 55% are attributed to small fuel cells and to various hi-tech gas turbine and combined cycle units suitable for DG application.

Part of this comparison is unfair. Modern DG utilize prefect hi-tech materials and incorporating advanced designs that minimize wear and required maintenance and include extensive computerized control that reduces operating labor.
DG “Wins” Not Because It is Efficient, But Because It Avoids T&D Costs

Proximity is often more important than efficiency

- Why use DG units, if they are not most efficient or the lowest cost?
  - The reason is that they are closer to the customer. They only have to be more economical than the central station generation and its associated T&D system. A T&D system represents a significant cost in initial capital and continuing O&M.
  - By avoiding T&D costs and those reliability problems, DG can provide better service at lower cost, at least in some cases. For example, in situations where an existing distribution system is near capacity, so that it must be reinforced in order to serve new or additional electrical demand, the capital cost/kW for T&D expansion alone can exceed that for DG units.
Operational Changes
Intelligent Grid - WAMS

Leader not a follower
• Power System Restructuring (Privatization or Deregulation)
  – But not only Privatization

• Deregulation is also known as
  – Competitive power market
  – Re-regulated market
  – Open Power Market
  – Vertically unbundled power system
  – Open access
• Why Restructuring of Electric Supply Industries?
  – Better experience of other restructured market such as communication, banking, oil and gas, airlines, etc.
  – Competition among energy suppliers and wide choice for electric customers.

• Why was the electric utility industry regulated?
  – Regulation originally reduced risk, as it was perceived by both business and government.
  – Several important benefits:
    • It legitimizied the electric utility business.
• It gave utilities recognition and limited support from the local Govt. in approving ROW and easements.
• It assured a return on the investment, regulated as that might be.
• It established a local monopoly in building the system and quality of supply without competitors.
• Simplified buying process for consumers.
• Electricity of new and confusing to deal with the conflicting claims, standards and offerings of different power companies.
• Least cost operation.
• Meeting social obligations
• Hugh investments with high risk
• Forces behind the Restructuring are
  – High tariffs and over staffing
  – Global economic crisis
  – Regulatory failure
  – Political and ideological changes
  – Managerial inefficiency
  – Lack of public resources for the future development
  – Technological advancement
  – Rise of environmentalism
  – Pressure of Financial institutions
  – Rise in public awareness
  – Some more ………. 
### Reasons why deregulation is appealing

<table>
<thead>
<tr>
<th>No longer necessary</th>
<th>The primary reason for regulation, to foster the development of ESI infrastructure, had been achieved.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Price may drop</td>
<td>Expected to drop due to innovation and competition.</td>
</tr>
<tr>
<td>Customer focus will improve</td>
<td>Expected to result in wider customer choice and more attention to improve service</td>
</tr>
<tr>
<td>Encourage innovation</td>
<td>Rewards to risk takers and encourage new technology and business approaches,</td>
</tr>
<tr>
<td>Augments privatization</td>
<td>In the countries where Govt. wishes to sell state-owned utilities, deregulation may provide potential buyers and new producers.</td>
</tr>
</tbody>
</table>
• What will be the transformation?

– Vertically integrated => vertically unbundled
– Regulated cost-based ==> Unregulated price-based
– Monopoly ==> Competition
– service ==> commodity
– consumer ==> customer
– privilege ==> choice
– Engineers ➔ Lawyer/Manager
• A number of questions to be answered
  – Is a Restructuring good for our society?
  – What are the key issues in moving towards the restructuring?
  – What are the implications for current industry participants?
  – What type of new participants will be seen and why?
  – What should be structure of market and operation?
  – What might an electricity transaction of future look like?
• What will be the Potential Problems?
  – Congestion and Market power
  – Obligation to serve
  – Some suppliers at disadvantages
  – Price volatility
  – Non-performance obligation
  – Loss operating flexibility
  – Pricing of energy and transmission services
  – ATC calculations
  – Ancillary services Management
    • Reserves
    • Black start capability
    • Voltage and frequency control
    • System security and stability
    • Transmission reserves
  – Market Settlements and disputes
Milestones of Restructuring

- 1982 Chile
- 1990 UK
- 1992 Argentina, Sweden & Norway
- 1993 Bolivia & Colombia
- 1994 Australia
- 1996 New Zeeland
- 1997 Panama, El Salvador, Guatemala, Nicaragua, Costa Rica and Honduras
- 1998 California, USA and several others.
- 2000 Several EU and American States
• Markets are defined by the commodity traded
  – Energy
  – Transmission system
  – Ancillary services
• Markets defined by the time-frame of trade
  – Day-ahead
  – Hour-ahead
  – Real-time
• Based on auction - single-sided or double sided
• Based on type of bids --> block or linear bid
• Based on generation settlement - uniform price (MCP) or pay-as-bid
Market Clearing Price

<table>
<thead>
<tr>
<th>Gen.</th>
<th>Price ($)</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen-1</td>
<td>2.5</td>
<td>20</td>
</tr>
<tr>
<td>Gen-2</td>
<td>2.0</td>
<td>10</td>
</tr>
<tr>
<td>Gen-3</td>
<td>2.4</td>
<td>15</td>
</tr>
<tr>
<td>Gen-4</td>
<td>2.3</td>
<td>45</td>
</tr>
<tr>
<td>Gen-5</td>
<td>2.2</td>
<td>30</td>
</tr>
</tbody>
</table>

Demand = 80 MW
• **Electricity Market is very risky**
  – Electricity is not storable in bulk quantity
  – End user demand is typically constant
  – Trading is directly related to the reliability of the grid
  – Demand and supply should be exact
  – Electricity prices are directly related with other volatile market participants.
  – Cost of continuity is more than cost of electric.
Thank You ?