Technical Challenges of System Planning & Operation of Integrated Grid of SAARC Region

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By

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At

"Training Workshop on System Operation and Settlement Mechanism, Cross Border Trade/Regional Power Market in South Asia"

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About Power Planners International (PPI)

- Established in 2007 as a limited company registered in England and Wales (Regd. No.6363482
- In Pakistan: Registered with Pakistan Engineering Council under Registration No. Consult/1147 and Alternative Energy Development Board of Pakistan under registration No. 0038-2007
- PPI: Registered with Saudi Electricity Company (SEC) having a bidder ID of 0005010127
- It is a renowned company in power sector of South Asia and Middle-East in power system analysis and planning especially in the areas of
  a. Transmission and Generation
  b. Cross-Border Interconnection Studies
  c. Distribution Infrastructure Planning
  d. Regulatory Compliance and Reform
  e. Interconnection of Conventional and Renewable Power Projects
  f. Technical Consulting for Utilities
  g. Capacity Building and Training of personnel of entities relating to power sector
  h. Grid interconnection studies of all types of power plants e.g.
     - Thermal,
     - Hydels
     - Renewables such as wind, solar, bagasse and waste-to-energy etc.

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PPI's Role in SAARC Region

1. **Sri Lanka:** Study of Reactive Power Compensation and requirement of SVCs for grid stability of Ceylon Electricity Board
2. **Nepal**: Consultancy services to US donor agency, Millenium Challenge Corporation (MCC) on developing 400 kV network in Nepal (Ongoing)
3. **Afghanistan**: Consultancy to German donor GIZ for Energy Reliability in Afghanistan and how to improve it
4. **For SAARC Energy Center**:
   i. Study for Designing Management and Monitoring Framework for Regulatory Compliance by Power Transmission Utilities in the South Asian Countries and related workshop in Colombo, Sri Lanka in 2015
   ii. Training workshops for SAARC delegates
      a. on 'Power System Studies for Synchronization of Multiple Systems' at Kabul, Afghanistan in 2014,
      b. on "Application of on-grid Biogas Technologies" at Kabul, Afghanistan in 2016.
   iii. Presently conducting a series of video workshops on Power System Analysis to be telecasted in SAARC countries under joint venture of Virtual University, Pakistan and SAARC.

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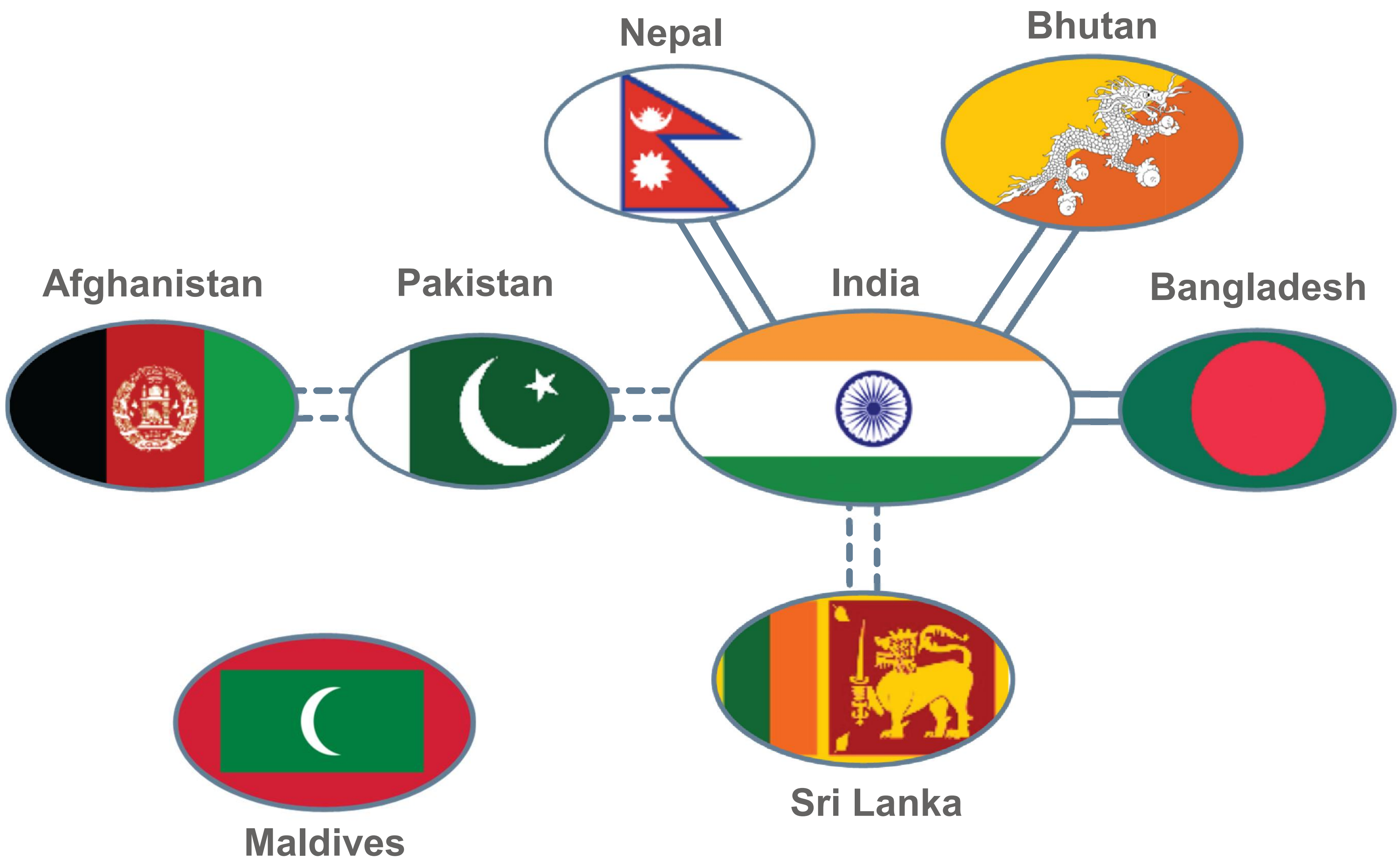
Agenda of the Presentation

- SAARC Integrated Grid: Existing & Proposed
- Generation Planning for SAARC Integrated Grid
  - Generation Planning Methodology & Criteria
  - Private Power Sector in Integrated Generation Planning
  - Role of Renewables in Generation Planning
- Transmission Planning of Integrated SAARC System
- Issues of System Operation of Integrated SAARC Grid
  - Frequency Control and Active Spinning Reserve
  - Voltage Control and Reactive Power Reserves
  - System Stability/Dynamic Conditions
- Penetration of Renewables (Wind & Solar): Issues and Challenges in System Operation
- Voltage Stability/Voltage Collapse/System Collapse
- Smart Grid Solutions at SAARC Integrated Grid Level
- Regulatory Framework of SAARC Integrated Grid

SAARC Integrated Grid: Existing & Proposed



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SAARC Integrated Grid Existing/Ongoing

- **India and Bangladesh (Import)**
  - B-B HVDC 500 MW to be extended to 1000 MW & more
- **India and Nepal (Export/Import)**
  - Dhalkebar-Muzaffarpur 400 kV D/C: capacity 1200 MW
  - New Butwal- Ghorakhpur 400 kV D/C: capacity 1800 MW (Nepali part ongoing under MCC funding)
- **India and Bhutan: Bhutan exporting to India**
  - 220 kV Chukha-Malbase-Birpara S/C
  - 220 kV Chukha-Pling-Birpara D/C
  - 400 kV Tala-Khogla-Binnaguri/New Silliguri D/C
  - 400 kV Tala-Pagli/Malbase-Binnaguri/New Silliguri D/C
  - Two D/C of 400 kV and one S/C of 400 kV underconstruction
- **Pakistan-Afghanistan: Import (Ongoing Project)**
  - CASA 1000
  - 1300 MW from Kyrghizisan on Multi-Term HVDC with 300 MW mid-terminal at Afghanistan (near Kabul) and 1000 MW at Peshawar (Pakistan)

SAARC Integrated Grid: Proposed/Prospective

- India-Pakistan
  - 500 kV either HVDC or HVAC Amritsar-Lahore
- India-Sri-Lanka
  - HVDC Submarine Link of 2x500 MW or More
- India-Bhutan: India has agreed to develop and import 10,000 MW from Bhutan through a combination of 400 kV and 765 kV lines from different Hydrpower Plants to be constructed in Bhutan in near future.
- Bhutan-Bangladesh wheeled through India
- Nepal – Bangladesh wheeled through India

Generation Planning for SAARC Integrated Grid

- Generation Planning for two or more systems are connected through Interties for
  - Reserve sharing (emergency exchange)
  - Economy interchange
  - Fix power exchange
- Multi-Area Analysis in EGEAS (and other software) provides modeling the effects of all

➢ Reserve Sharing:

- Interconnection model is used in determining reserve margins and loss of load probabilities.

Generation Planning for SAARC Integrated Grid

Fixed Power Exchange

- The contracted power either way is modeled as fixed/committed generation or must run (depending on term sof agreement)
- Modeling can be performed with annually or seasonally, depending upon the cost/tariff agreed in different seasons
- Affects only the production cost and unserved energy, the reserve margin and LOLP are unaffected.

Generation Planning for SAARC Integrated Grid

- Economy Exchange:
  - Dispatcher's hour-by-hour decisions in real time are replaced by simulated interchanges based on a probabilistic determination of the availability and cost of economy interchanges.
  - Modeling, which can be performed with annually or seasonally, affects only the production cost and unserved energy, the reserve margin and LOLP are unaffected.

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Generation Planning for SAARC Integrated Grid

- Tie-line limitations are specified in terms of a capacity (MW) and a capacity factor (percent).
- Analysis is not performed on an hourly basis, a capacity constraint is imposed where the limiting value is the product of the capacity, capacity factor, and the number of hours in the time period.
- If the energy transfer is only in one direction during a time period, then the energy constraint is modeled exactly.

- If there are transfers in both directions, however, some of the transfers may cancel each other and the constraint is modeled only approximately.
- Tie-line limits can be specified for each system and different limits can be applied for sales and purchases; the limits can vary from year to year.

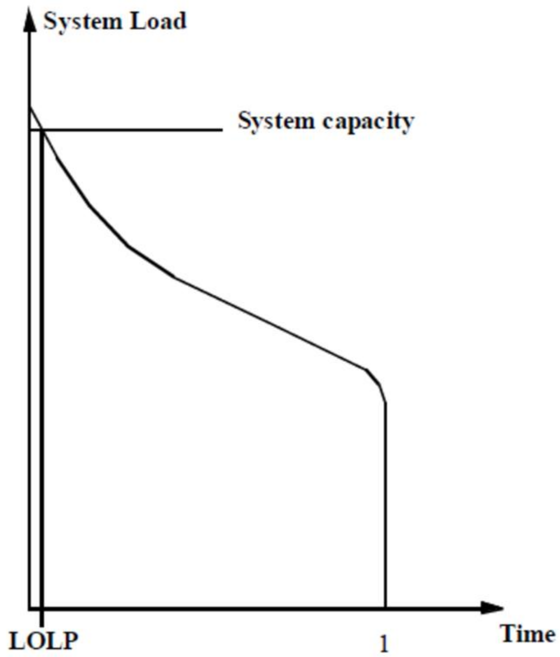
Generation Planning Reliability Criteria

- **Deterministic Approach**
  - Reserve Margins consisting
    - Hot Active Spinning Reserve (ASR) for unscheduled outages
    - Maintenance Reserves for scheduled outages
    - Planning Reserves to address uncertainties in demand forecasts
  - Total Reserves Margin from 10-15 % of Planned Generation

Generation Planning Reliability Criteria

➢ **Probabilistic Approach**

- **Loss of Load Probability (LOLP) or Loss of Load Expectancy (LOLE)**
- It is defined as the probability (fraction of time) that the system demand is not fully satisfied, or in other words, that the system demand exceeds the available capacity
- Usually 0.2 days/year (4.8 hrs/year (0.1 to 0.6 is an acceptable range)



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Generation Planning Reliability Criteria

- **Expected Energy Not Served (EENS)**
  - Unserved energy, expressed in GWH,
  - is calculated using operating capacities and represents the portion of the initial system energy expected not to be met by the system's generating units.
  - If desired, you can assign a cost to this energy in terms of dollars per MWH.

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Private Power Sector in Integrated Generation Planning

- From being cost-minimization to profit-maximization
  - Private-Public Mix
  - Private Market
- Regulator is a bridge between Independent Power Producer (IPP), the utility and the consumers
- Comprehensive Generation Plan has to consider
  - Basket Price affordable by the consumer
  - Tariff for an IPP ensuring attractive profits

Private Power Sector in Integrated Generation Planning

- Bid-Based Market
- Marginal pricing within bid-based pools with the unit dispatch based on bid prices.
- The revenue earned by each generating unit is calculated and compared against its cost to develop the net margin for the unit.
- A negative net margin would indicate that the unit is a likely retirement candidate
- Unit revenues are based on the market clearing price concept

Generation Planning in Private Power Market

- These revenues are calculated during production costing, based on bid prices and the number of hours each generating unit is the marginal unit.
- The bid price for each unit is the marginal operating cost multiplied by the user-specified bid multiplier.
- The marginal operating cost, in dollars per megawatt hours, includes the following components:

Generation Planning in Private Power Market

- Fuel
- Variable operating and maintenance cost
- Detailed costs modeled as variable O&M
- Emission allowance costs, if emission adjusters are used to modify the dispatch order
- Dispatch modifier, if modeled
- EGEAS sets the dispatch order based on the bid prices.
- For multiple-block units, EGEAS uses a levelized cost for each of the blocks

Generation Planning in Private Power Market

- Must-run blocks are treated as having a marginal cost of zero
- Higher blocks of must-run units use the actual, rather than levelized, cost.
- For hours where there is insufficient capacity (loss of load hours), EGEAS uses the cost of unserved energy as the marginal price.

Role of Renewables in Generation Planning

- Variability in the net load (Residual Load) increases due to variable generation of Renewables i.e. wind and solar
- Following are to be considered for Generation Planning Model:
  - Bankable Wind Data of wind farms to reduce deviation in forecasted generation
  - 4 hour ahead forecast rather than day-ahead forecasting
  - Increasing spinning reserve in conventional generators

Role of Renewables in Generation Planning

- Use of improvised battery storage to mitigate intermittency
- Offer-based economic dispatch.
- Convolve daily load curves with Solar Plants' duty cycle and evolve flexibility with conventional hydel and thermal power plant's dispatch order
- Wind and demand correlation
- WASP and EGEAS may be used by modifying Load Duration Curves to represent Residual Load (NET Load) as the load to be met

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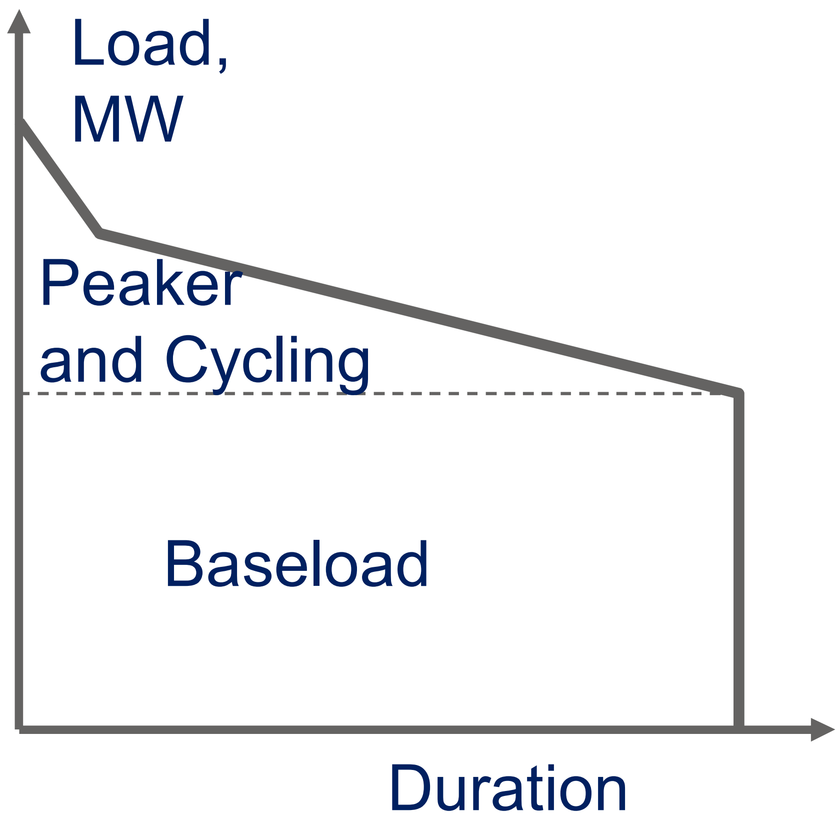
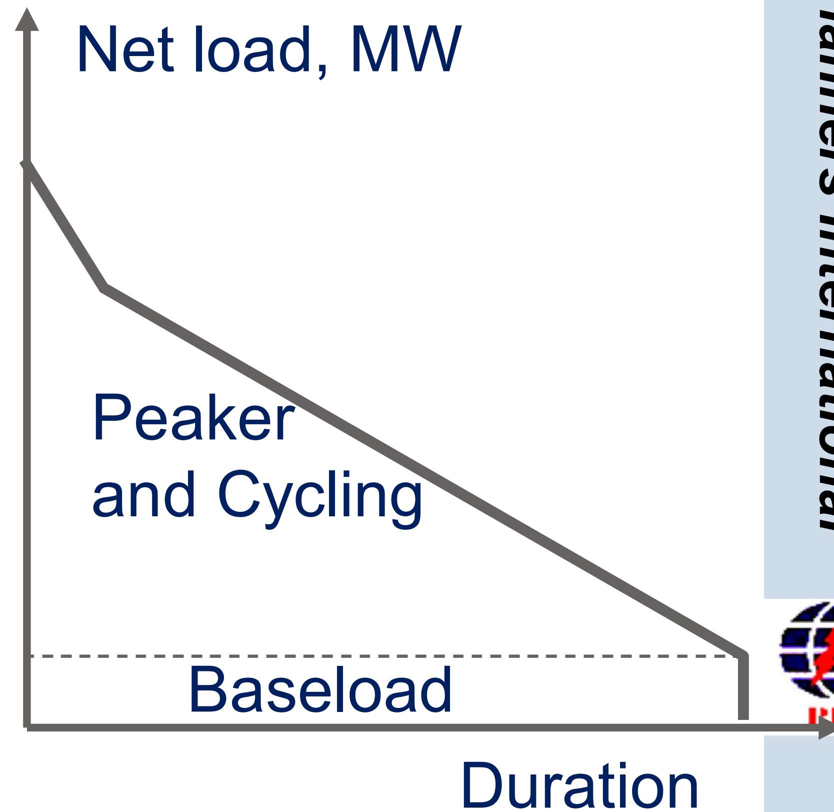
Role of Renewables in Generation Planning

Load-duration without wind.



Net Load-duration with wind.
Net load = load minus wind.



Future Generation Planning: Residual Load Curve

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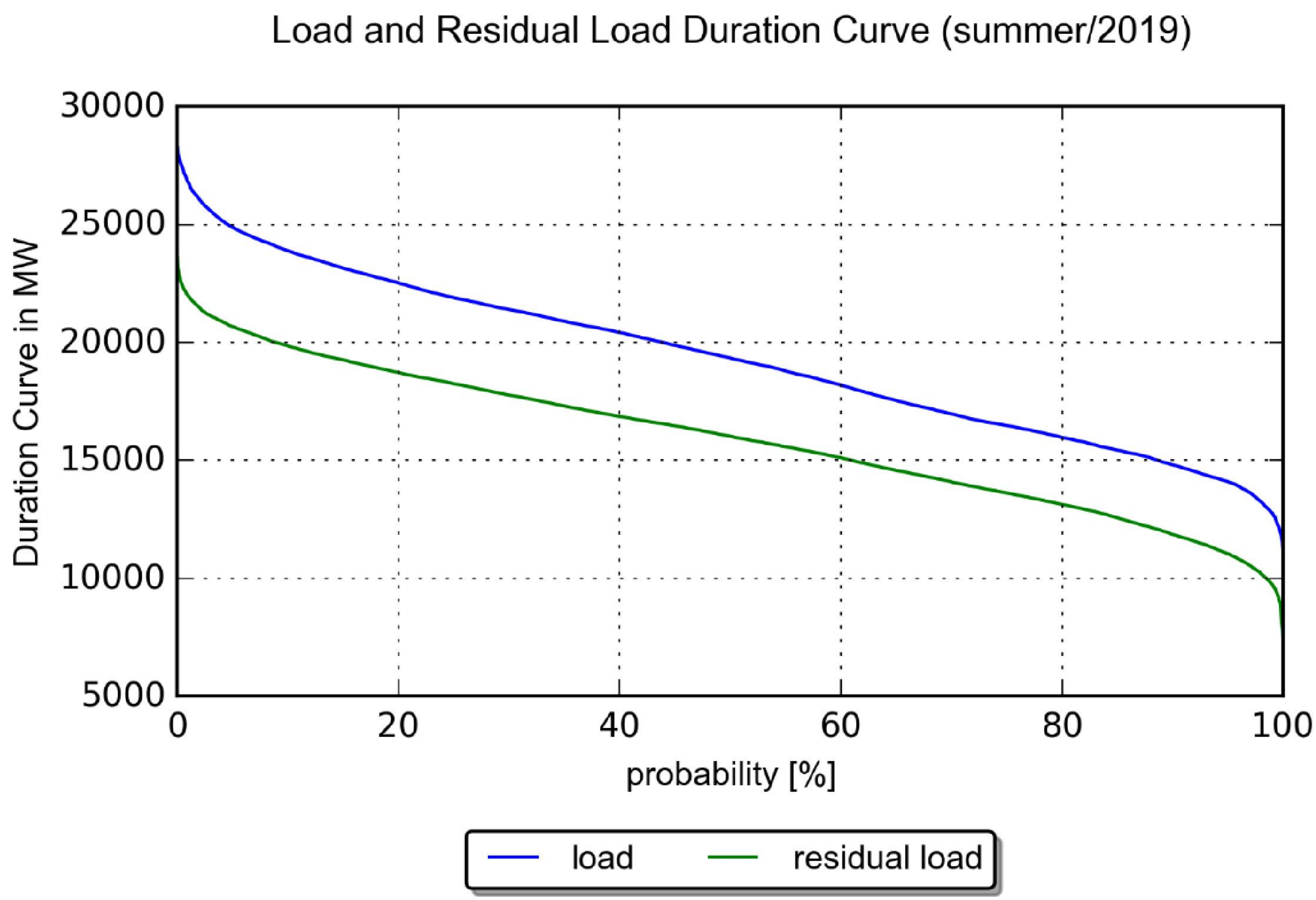
Residual Load=Actual Load minus power generated by wind and PV plants



Transmission Planning of Integrated SAARC System

- Determination of Tie Lines Capacities
  - Depends on the type of exchange: Reserve Sharing, Fixed Power Exchange or Economy exchange
- Adequate Redundancy (at least N-1, preferably N-2)
- Adequate capacity/reliability in the rear transmission system to pump power for export
- Adequate capacity/reliability in the rear transmission system to absorb the import

Issues of System Operation of Integrated SAARC Grid

- Frequency Control and Active Spinning Reserve
- Voltage Control and Reactive Power Reserves
- System Stability/Dynamic Conditions
  - Rotor Angle Stability (Large Signal Stability)
  - Small Signal Stability (Oscillatory Stability)
  - Voltage Stability
  - Avoidance of voltage collapse/system collapse.

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Frequency Control and Active Spinning Reserve

1. Allocation of primary reserve is dominated by potential ***outages of large conventional generation unit***, meaning it can easily cope with these rapid variations
2. For Cross Border Synchronized Systems
   - Partial Loss of Intertie/s
   - Full Loss of Intertie/s
3. Corrective Measures for Importing Conditions
   - Mix of
     - Active Spinning Reserve
     - Automatic Loadshedding (UFLS Relyas) of specified loads
     - Stages can be determined for the level of loadshedding wrt. The amount of sudden loasss of Generation in the importing system
4. Corrective Measures for Exporting Countries
   - For a bigger system, like India, would be manageable through governor action
   - For smaller countries, outages of generators on over-frequency may lead to system collapse
   - Dedicated radial transmission from Plant to cross-border

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Voltage Control and Reactive Power Capacity

- Adequate Local Reactive Power Capacity in every subsystem (country)
  - To generate/provide VARs to counter voltage sag
  - To absorb VARS to counter voltage bulge
- Sources
  - Generators (lagging/leading PF)
  - Shunt capacitors/Reactors
  - Static VAR Compensators (SVC)
  - FACTS e.g. STATCOM, TCSC etc.

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System Stability/Dynamic Conditions

- Rotor Angle Stability (Large Signal Stability)
- Severe faults in any subsystem (country) leading to big power swings may cause generators to :
  - Go out of step and loose synchronism
  - Trip by out-of-step relay or power swing relay
- Two or more interconnected systems should be robust enough (enough inertia) to withstand this jolt
- System Stability Studies to be carried out for all eventualities before interconnecting the systems

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Small Signal Stability (Oscillatory Stability)

- Common issue in Big Interconnected Systems
- Inter-Area Oscillations
- Gets into Smaller System when connected with bigger system
- India (especially) and Pakistan have this inherent problem
- Analysis Required
  - Eigenvalue Analysis
  - Modal Analysis
  - Prony Analysis using PSS/E plots
- Solutions : Power System Stablisers, well tuned and at appropriate power plants

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Voltage Stability/Voltage Collapse/System Collapse

- Increase of Dynamic (motor) Loads in the system
- Requires huge Instantaneous Injection of VARS in case of transient voltage instability
- Main symptoms of voltage collapse are:
  - Low voltage profiles
  - Heavy reactive power flows
  - Inadequate reactive support
  - Heavily loaded systems

Voltage Collapse

- **Definition**

  Voltage collapse is a process in which a voltage unstable system experiences an uncontrolled reduction in system voltage

  - **Prevention**

- Dynamic reactive reserves
  - Generators, SVCs, STATCOMS etc.
- Voltage control zones
- Load shedding (operate UVLS in specified stages)

Voltage Control Zones

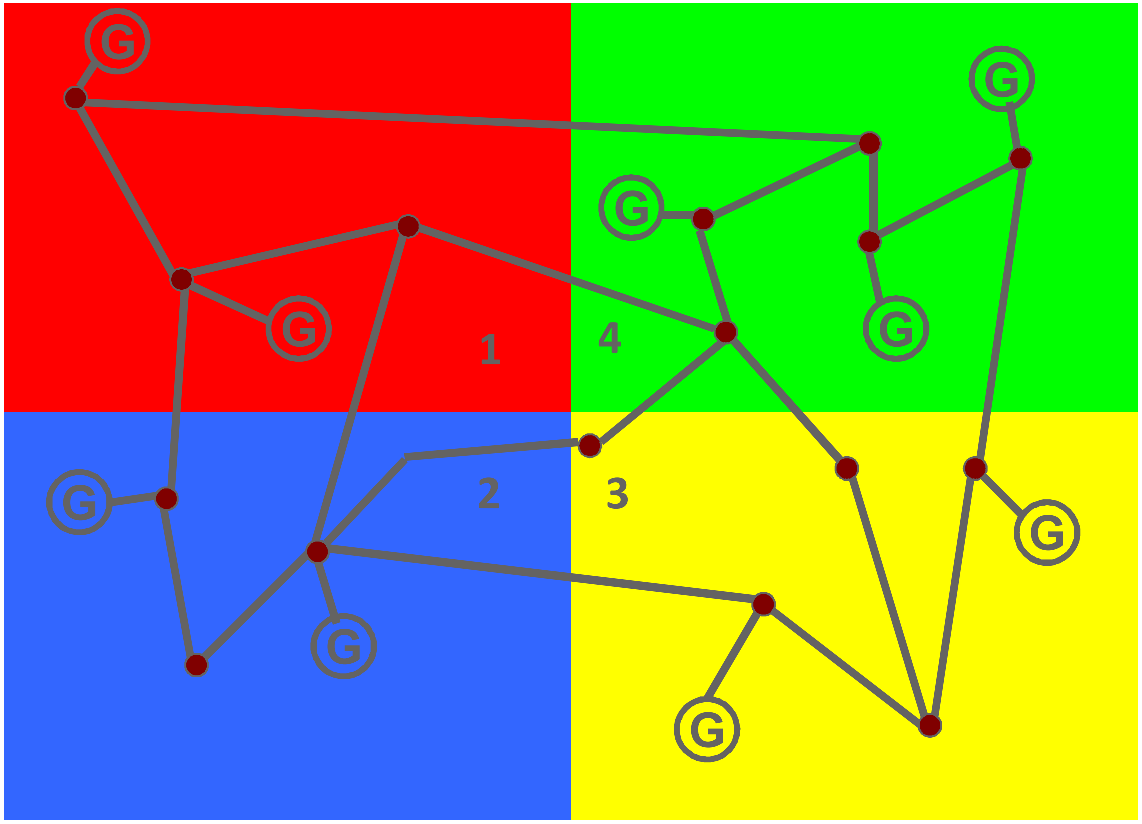
Minimum Reserves:

Zone #1 = 1000 Mvar

Zone #2 = 2500 Mvar

Zone #3 = 2000 Mvar

Zone #4 = 1500 Mvar



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Note:

As long as minimum levels of reactive reserves are held in each zone the likelihood of a voltage collapse is minimized within each zone

Penetration of Renewables (Wind & Solar): Issues and Challenges in System Operation

- Intermittency
- Requirement of Higher Active Spinning Reserve
- Weak in
  - Reactive Power Capability
  - Voltage Control
  - Frequency Control
  - Islanded Operation
- Power Quality Issues

Intermittency : Solutions

Improving Forecasting for Wind & Solar Radiance

- A dedicated task to be carried out by software and bankable data-bank with following inputs:
  - Historical wind/solar-radiation data
    - From Wind Masts/Wind Farms already in operation in wind corridors
    - Solar radiation levels collected from different regions
  - From Satellite Maps (both wind & solar)
  - Forecast from Meteorological Departments
  - From Satellite Maps of International Agencies

Intermittency : Solutions

- Hyberidization
  - Wind and Solar in wind corridor
  - Solar and small hydels in canal areas with small hydel potential
  - Solar and biomass/bagasse
- Treating RE Generation as Must-Run: Deduct this from overall Generation Curve and adopt dispatch policy taking the remaining load as Residual load
- Active Spinning Reserve in an interconnected SAARC system would not be a problem

Technology Improvements in WTGs

- New WTGs Type-3(DFIG) and Type-4 (FC) provide
  - Limited spinning reserve (Pseudo Governor Action)
  - Voltage control by Converters’ supplying VARS
  - Power Factors upto 0.9 Lagging (to supply VARs)
  - LVRT and HVRT Provision
- Installation of Switched Shunts or SVCs or STATCOMs at wind and solar parks

Storage Devices

1. **Mechanical Energy Storage**
   a) **Compressed Air Energy Storage (CAES)**
   b) **Flywheel Energy Storage (FES)**
   c) **Pumped Hydro Storage (PHS)**
2. **Electrical Energy Storage**
   a) **Battery Energy Storage (BES)**
   - **Lead Acid Battery**
     - **Nickel Battery**
     - **Sodium-Sulfur Battery**
     - **Lithium Battery**
     - **Metal Air Battery**

   a) **Flow Battery Energy Storage (FBS)**
   b) **Superconducting Magnetic Energy Storage (SMES)**
   c) **Super capacitor Energy Storage (SCES)**
3. **Storage Batteries**
   - Now available in 4 MW size pack or more (though costly)

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Smart Grid Solutions at SAARC Integrated Grid Level

- **Smartness at System Operation Level**
  - Fault detection self-healing of the network without the intervention of technicians. This will ensure more reliable supply of electricity, and reduced vulnerability to natural disasters or system faults.
  - Compliance to Grid Code
  - Automatic on-line load flows to take actions prior to an event
  - Demand-side management
  - Load adjustment/Load balancing: Using mathematical prediction algorithms predict how many standby generators need to be used, to reach a certain failure rate.

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Smartness at SAARC Integrated Grid Level

- In the traditional grid, the failure rate can only be reduced at the cost of more standby generators. In a smart grid, the load reduction by even a small portion of the clients may eliminate the problem.
- Peak curtailment/leveling and time of use pricing
- Permits greater penetration of highly variable renewable energy sources such as solar power and wind power, even without the addition of energy storage
- Demand response support: Demand response support allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes

Regulatory Frameworks of SAARC Integrated Grid

- Indian Experience
- NERC (North American Electricity Regulation Commission)
- ENTSO-E (European Network Of Transmission System Operators For Electricity: Represents 43 TSOs from 36 countries of Europe)
  - The Guideline on “Capacity Allocation and Congestion Management”
  - Sets out the methods for calculating how much space can market participants use on cross border lines without endangering system security.
  - It also harmonizes how cross border markets operate in Europe to increase competitiveness but renewables’ integration.
  - CACM is the cornerstone of a European single market for electricity.
- NORDEL (for electricity market of Nordic countries)

Thank You

For Your Kind Attention