INTRODUCTION

Integration of Renewable Based Generation into Srilankan Grid 2018-2028

Dr. H.M Wijekoon
Chief Engineer (Transmission Planning)

Randika Wijekoon
Electrical Engineer (Generation Planning)

Generation and Transmission Planning Branch
Ceylon Electricity Board

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## Sri Lanka - Country Information

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>21.2 million</td>
</tr>
<tr>
<td>GDP per capita</td>
<td>3,835 USD (2016)</td>
</tr>
<tr>
<td>Area</td>
<td>65610 km²</td>
</tr>
<tr>
<td>Installed Capacity</td>
<td>4036 MW</td>
</tr>
<tr>
<td>Peak Demand</td>
<td>2523 MW</td>
</tr>
<tr>
<td>Annual Electricity Demand</td>
<td>14,620 GWh</td>
</tr>
<tr>
<td>Electrification Level</td>
<td>99%</td>
</tr>
<tr>
<td>Per Capita Electricity Consumption</td>
<td>603 kWh per yr</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>0.886 (metric tons per capita)</td>
</tr>
</tbody>
</table>
### Capacity Mix and Energy Mix

#### Capacity Mix (%) - 2017

- **CEB Hydro**: 34%
- **CEB Oil**: 15%
- **CEB Coal**: 20%
- **IPP Oil**: 17%
- **Other RE**: 14%

#### Energy Mix (%) - 2017

- **CEB Hydro**: 21%
- **CEB Coal**: 35%
- **IPP Oil**: 17%
- **Other RE**: 10%

### Capacity Mix and Energy Mix Details

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Capacity (MW)</th>
<th>Energy (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEB Hydro</td>
<td>1377</td>
<td>3014</td>
</tr>
<tr>
<td>CEB Thermal - Coal</td>
<td>810</td>
<td>5071</td>
</tr>
<tr>
<td>CEB Thermal - Oil</td>
<td>604</td>
<td>2560</td>
</tr>
<tr>
<td>IPP Thermal - Oil</td>
<td>687</td>
<td>2485</td>
</tr>
<tr>
<td>Other RE</td>
<td>558</td>
<td>1489</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4036</strong></td>
<td><strong>14620</strong></td>
</tr>
</tbody>
</table>
RE Development

Energy (GWh)

- Major Hydro
- Other RE
- Other Renewable Energy Share
- Total Renewable Energy Share

Installed Capacity (MW)

- Wind - 128 MW
- Solar Rooftop - 100 MW
- Solar Grid Scale - 50 MW
- Total VRE - 278 MW

Wind - 128 MW
Solar Rooftop - 100 MW
Solar Grid Scale - 50 MW
Total VRE - 278 MW
Network and Resource Locations

Transmission Network

Wind Resources

Solar Resources
VRE Development Challenges

- Infrastructure development for RE resources
- High Seasonality of RE resources
- Ensuring System Stability
- Constraints in existing network
- Daily Load Variation pattern
- Ensuring adequate Operational flexibility
- Impact of DG on distribution system
- Accurate system modelling
- National Policy on energy mix
Overall Study Methodology

Renewable Energy Resource Assessment
Major Hydro, Mini Hydro, Wind, Solar, Biomass

Renewable Energy Development Projection
Future capacity additions and energy contribution
Resource availability & quality, Infrastructure availability, Technology costs

Optimization of Long Term Planning
Optimized Generation Expansion plan, 20 year planning period, Multiple scenarios

Transmission Network Study
Steady State Analysis,
Dynamic Analysis
Short term frequency stability Analysis

Medium to Short term operational study
Medium term Hydro Thermal Optimization,
Economic Dispatch in 30min time steps
Operational Constraints, curtailments

Results and Analysis
• Energy and Capacity Contribution
• Stability and Curtailments
• Economic Analysis of Integration scenarios
RE Resource Assessment and modelling

Major Hydro

- 5486 GWh
- 4155 GWh
- 3233 GWh

Wind

- Wind Speed (m/s)
- Plant Output (MW)

Solar PV

- Solar Irradiance (W/m²)

Mini Hydro

- Per Unit Monthly Average Capacity
- Jan: 0.23
- Feb: 0.16
- Mar: 0.18
- Apr: 0.29
- May: 0.37
- Jun: 0.45
- Jul: 0.46
- Aug: 0.42
- Sep: 0.45
- Oct: 0.49
- Nov: 0.51
- Dec: 0.41
Transmission Network Study

Power System Stability Studies - VRE Variability

Power output variation in a day of 10 MW Hambantota plant

Enlarged view of time period 10.30 hrs to 13.00 hrs

Aggregated output off Wind Turbines
Power System Stability Studies

Short term frequency stability analysis
100 seconds duration

Defined ramp event

Study Scenarios

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenarios</th>
</tr>
</thead>
</table>
| 2018 | Case 1: Only swing machine is used for free governor  
      | Case 2: Swing machine + GT7 used for free governor  
      | Case 3: Swing machine + KCCP used for free governor  
      | Case 4: With All Hydro Governor (Victoria, Kotmale, Upper Kotmale, N’Lax)  
      | Case 5: Swing machine + KCCP + GT7 + 2x35MW GTs used for free governor |
| 2020 | Case 1: With All Hydro Governor (Victoria, Kotmale, Upper Kotmale, N’Lax) used for free governor  
      | Case 2: Swing machine + KCCP + GT7 used for free governor  
      | Case 3: Swing machine + KCCP + GT7 + LNG used for free governor  
      | Case 4: Swing machine + KCCP + GT7 + LNG + 2x35MW GTs used for free governor |
| 2020, 2025, 2028 | LNG + GTs + Hydro (Victoria, Kothmale, Upper Kothmale) |

Ramp Rate defined for 540 kW Solar PV Plant
Power System Stability Studies

Short term frequency stability analysis

**Different Solar Penetration Levels**

**Different Regulating scenarios**

Studied years-2018, 2020, 2022, 2025, 2028
# Short term frequency stability - Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>State</th>
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<tbody>
<tr>
<td>Hydro Maximum Day Peak – DH</td>
<td>System Stable with Load Shedding</td>
</tr>
<tr>
<td>Thermal Maximum Day Peak - DT</td>
<td>System Stable with Load Shedding</td>
</tr>
<tr>
<td>Minimum ORE Day Peak – ORE_Dp</td>
<td>System Stable</td>
</tr>
<tr>
<td>Hydro Maximum Night Peak - NH</td>
<td>System Stable with Load Shedding</td>
</tr>
<tr>
<td>Thermal Maximum Night Peak - NT</td>
<td>System Stable</td>
</tr>
<tr>
<td>Minimum ORE Night Peak – ORE_NP</td>
<td>System Stable</td>
</tr>
<tr>
<td>Hydro Maximum Off Peak - HMOP</td>
<td>System Stable with Load Shedding</td>
</tr>
<tr>
<td>Thermal Maximum Off Peak - TMOP</td>
<td>System Stable</td>
</tr>
</tbody>
</table>
System Operation Study

- Medium term hydro thermal optimization and operational analysis with the tool SDDP
- Short term economic dispatch and operational analysis with the tool NCP

- Time series demand data
- Hydrological Inflow Data
- Hydro/ Thermal plant technical parameters
- Hydro/ Thermal plant operational constraints
- Hydro inflow forecasting methodology
- Fuel Prices and O&M cost of thermal plants
- Annual power plant additions/retirements
- Plant maintenance and outages
- Annual Renewable capacity development
- Time Series RE resource profiles
- operating reserve requirements
- System operational constraints
OPERATIONAL STUDY (Dispatch Results 2025 - High wind season)
## Variable Renewable Energy Curtailment

<table>
<thead>
<tr>
<th>Year</th>
<th>Dry Period</th>
<th>High Wind Period</th>
<th>Wet Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekday</td>
<td>Weekend</td>
<td>Weekday</td>
</tr>
<tr>
<td></td>
<td>-Offpeak -Daytime</td>
<td>-Offpeak -Daytime</td>
<td>-Offpeak -Daytime</td>
</tr>
<tr>
<td>2020</td>
<td>None</td>
<td>None</td>
<td>150MW</td>
</tr>
<tr>
<td>2022</td>
<td>None</td>
<td>None</td>
<td>220MW</td>
</tr>
<tr>
<td>2025</td>
<td>None</td>
<td>None</td>
<td>380MW</td>
</tr>
<tr>
<td>2028</td>
<td>-</td>
<td>-</td>
<td>70MW</td>
</tr>
</tbody>
</table>

**Case 1: With Future Coal Power, LNG and Pump Storage Development**

- **2020**: None, None, 150MW, 80 MW, 170MW, 140MW
- **2022**: None, None, 220MW, 140MW, None, None
- **2025**: None, None, 380MW, 330MW, 70MW, 20MW
- **2028**: - , - , 70MW, 30MW, - , -

**Case 2: With No Future Pump Storage and Coal Power Development**

1. **With new combined cycle minimum load operation constraint at 50%**
   - **2025**: None, None, 445MW, 380MW, None, None
   - **2028**: None, None, 80MW, 200MW, None, None

1. **With new combined cycle minimum load operation constraint at 30%**
   - **2025**: None, None, 215MW, 175MW, None, None

**Case 3: LNG Development Restricted to Western Province only**

- **2028**: - , - , 70MW, 60MW, - , -
The study enabled the Average Annual Absorption of Other Renewables to be nearly four times higher than the past.
Ongoing Work

Understanding System Flexibility

**Flexibility Requirement**
- Flexibility Reserve
- Ramp characteristics

**Sources of Flexibility**
- Dispatchable Generation
- Storage
- Demand Side activities
- Interconnections

**Minimizing Flexibility**
- Geographical Spread
Assessing Flexibility Reserve Requirement with VRE

Regulating Reserve Estimation for VRE development

10 minute variability
Year 2016 Actual data - Filtered for Outages

-250 -200 -150 -100 -50 0 50 100 150 200 MW

-250 -200 -150 -100 -50 0 50 100 150 200 MW

20% VRE Share
15% VRE Share
10% VRE Share
Load

Regulating reserve (% of Peak)

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028

Load

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028
Evaluating Flexibility requirement

Main attributes of the flexibility requirement

- Magnitude of the ramp
- Ramp duration
- Ramp rate
- Frequency of occurrence

Analytical techniques

- Impact of Plant minimum operating level

Production simulation

- Ramp Magnitude
- Ramp Duration
- Ramp rate

Ramp Events of Net Load

Load (MW)

Ramp Event Magnitude (MW)

x 10 minutes
Assessing Flexibility requirement

Ramp events in VRE development scenarios

Duration curves of Ramp Rate Requirement

Ramp up Events of Net Load - 2025

Ramp duration (minutes)

Ramp Magnitude (MW)

Upward (MW/min)

- 30% VRE Share
- 20% VRE Share
- 10% VRE Share
- Load

Downward (MW/min)
Flexibility of Generating Units

Flexible contribution of future regulating units

Aggregated Regulation Response Availability

Reserve Magnitude and Duration

Ramp Rate of Reserve
With Coal, Combined Cycle and Pumped Hydro units

With only combined cycle units
Impact of Pumped Storage Hydro Plant Operation

VRE Curtailment

Baseload Plant Cycling
Assessing the Variability of Distributed Solar PV

Temporal Variability

Spatial Variability and Aggregated effect
Analyzing Demand Side activities

Impact of EV charging load on the flexibility Requirement

Upward Regulating Reserve Requirement

- Original Load
- Scenario 1 (EV trend) - Dump Charging
- Scenario 1 (EV trend) - ToU Charging
- Scenario 2 (20% of New Additions) - Dump Charging
- Scenario 2 (20% of New Additions) - ToU Charging
Way Forward

- **Diversified and Prioritized** resource locations for VRE
- Establishing *wind and solar forecasting systems* to the national dispatch center.
- Providing Variable Renewable Energy (VRE) *curtailment rights* to system operator
- Base load power plants with **increased flexibility.**
- Utilizing *Demand side management and response* to provide flexibility
- **Continuous upgrades to RE integration studies**
- Proper and **timely implementation** of VRE and other major power plants
Thank You