Icelandic Transmission System

Load peak: **2400 MW**

Total Energy: **17.7 GWh/year**

100% Renewable energy:
- 70% Hydro
- 30% Geothermal

Power intensive users ~80% of total load

The grid includes more than 3,000km of transmission lines and about 76 substations

East-Iceland
Centre of inertia
Hydro: 846 MW
Geo: 150 MW

West-Iceland
Centre of inertia
Hydro: 996 MW
Geo: 595 MW

132 kV Ring connection

220 kV
Icelandic Transmission System

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- **Hydro: 846 MW**
- **Geo: 150 MW**
- 220 kV
Extensive WAMS monitoring & records (~80 PMUs)
Good quality communications network
Landsnet & grid-stakeholders willing to trial innovation
New control is measurable on small system
Why WAMS?

Q: Why do operators need WAMS, isn’t it too much information?
A: I prefer to drive my car in the dark with the headlights turned on

Ragnar Stefánsson—Operator at Landsnet
Landsnet’s Control Room – without headlights
Landsnet’s Control Room – with headlights
WAMS
Real-time Monitoring
WAMS
Real-time Monitoring
Post-fault Analysis
WAMS: Real-time Monitoring, Post-fault Analysis, Oscillation detection

- 1.2Hz Mode
  - Before PSS tuning
  - After PSS tuning

- 0.8Hz Mode
  - Improved Performance

Bustie opened
PSS off in KRA
PSS on in KRA

Mode Amplitude (MW) vs. Mode Decay Time Constant (sec)
WAMS

Real-time Monitoring

Post-fault Analysis

Oscillation detection

Commissioning & Testing

Frequency

Voltage

Generation

Commissioning & Testing
WAMS

- Real-time Monitoring
- Post-fault Analysis
- Oscillation detection
- Commissioning & Testing
- Model validation
Effect of Sparse Centres of Inertia

- Iceland shows frequency & angle divergence between centres of inertia

### Diagram Details

**A**
- \( T=0s \)
- Industrial load #1 reduction (first stage)

**B**
- \( T=0.2s \)
- Industrial load #1 reduction (second stage)

**C**
- \( T=0.36s \)
- Industrial load #1 trip

**D**
- \( T=1.1s \)
- Area angles separated by 60°, result in high E-W power. One route opens by special protection

**E**
- \( T=1.2s \)
- Areas accelerate away from each other; synchronism is lost and system islands

### Frequency and Angle Differences

- **Frequency Differences**
  - West Frequency
  - East Frequency

- **Angle Differences**
  - West Angle
  - East Angle

- **Time**
  - 1.2s to Islanding
  - 4s to Frequency Peak

### Notes
- \( \Delta f=0.25\text{Hz} \)
- \( \Delta t=0.3\text{s} \)
- \( \Delta \delta=60^\circ \)
General Method for Locational Fast Response

Area 1 (4 x pmu)
- $V_{angle1}$
- $f_1 \rightarrow \frac{df_1}{dt}$

Area 2 (3 x pmu)
- $V_{angle2}$
- $f_2 \rightarrow \frac{df_2}{dt}$

System Average Angle.

System $f$
- $f_{sys} = \text{Agg}(A_1, \ldots, A_n) \rightarrow \frac{df_{sys}}{dt}$

Fast initial response, self-correcting

Initial event leads to steep RoCoF

Step responses slow RoCoF in < 1s

Ramping response stabilises frequency

\[ \Delta P = H \cdot \text{SystemROCOF} \]
General Method for Locational Fast Response

- Fast
- Locational
- Proportional to disturbance

- Response Driven
- Event Driven
Smart-Grid Projects

- Smelter Load Control
  - 2015

- Reykjanes Microgrid Load control and Geoth. control
  - 2018-2021

- Hydro Fast Ramp
  - 2017-2018

- Thr Microgrid / Geoth. control
  - 2018-2021*

- Thufaða Microgrid / Geoth. control
  - 2018-2021

- Vestfirðir Microgrid
  - 2015

- Smelter Load Control & Microgrid
  - 2016

- Fish factories Load Control
  - 2014, 2017-2018

- RioTinto
  - 2017-2018

- Migrate
  - 2017-2018

- Atnorth
  - 2018-2021
Implementation
Smartgrid Project in Reykjanes – Load Shed Control and Generator Governor Mode by using GOOSE [IEC 61850]

FIT

ADC - RTAC
ADC Selective Trip
Unit 1
Unit 2
Unit 3

REY – HS Orka
Switch to freq-mode
Governor
REY Gen1

Protection. Equipment for SP1, SP2, SP4, SP5,

Smartgrid Controller
LN - RTAC
LN - PhC

SEL Switch – Software Defined

ADC

REY – HS Orka
Switch to freq-mode
Governor
REY Gen1

ADC

ADC Selective Trip
Unit 1
Unit 2
Unit 3

Landsnet
REAL SYSTEM RESPONSES

LOAD LOSS EVENT BEFORE WACS IMPLEMENTATION

- Frequency
- Generation
- Load

Trip of 180MW

No Islanding occurred
REAL SYSTEM RESPONSES

LOAD LOSS EVENT AFTER WACS IMPLEMENTATION

1. Load response in <0.5s, reduces frequency peak.
2. Hydro fast ramp start at 3.5s, replaces fast temporary load response. Rate & volume greater than primary control.
Latest Development in Wide Area Control
for locational frequency response and regional re-balancing

Goal: Quickly find the imbalance of load and generation for a region in the presence of dynamic power swings, so that we can re-balance the area.

\[ P_n = P_{Imbal} - H_n \cdot ROCOF_n \]

Instantaneous Boundary Power
Region n Power Imbalance not directly measurable
Effective Area Inertia
Region n Ctr of Inertia
ROCOF

REF: C2-142 2020
CIGRE e-Session 2020
Example of Region 3 load loss and oscillations

Power and Frequency

- $P_{imb_{al\_R3}}$ step 42 → 79 MW
- $P_{imb_{al\_R4}}$ no change (54MW), no oscillation
- $\Delta P_{imb_{al\_R3}}$ +37 MW
- $P_{inst\_R4}$ oscillates
- Islanding triggered by SPS after unstable oscillation

**Region 3**

- G
- THR
- KRA
- G
- 2x30 MW
- G
- Total 27 MW

**Region 4**

- LAX
- RAN
- KR1
- KR2
- RA1
- G
- TR2/KS1
- TR1
- G
- 45 MW
- 56 MW
- 45 MW

**Power and Frequency**

- $P_{imb_{al\_R3}}$
- $P_{imb_{al\_R4}}$
- $P_{imb_{al\_R3}}$
- $\Delta P_{imb_{al\_R3}}$
- Freq$_{R4}$
Conclusion

• WACS have improved the system performance during disturbances:
  • The system operators experience less severe disturbances, improving system security
  • The generator operator experiences fewer plant trips and large frequency excursions which extends the lifetime of the machines
  • The load customers in the region experience fewer and shorter interruptions and better power quality

• There are still many promising WACS project proposals, more capacity of regulating units in south west, harnessing the fast response of geothermal units, regulating options with datacenters and wide-area-damping.

• Fast Frequency Response (FFR) ancillary service is in development.

• Digital Substation projects increase the demand of fast and reliable communication between substations. Which opens the option for routable GOOSE,SV [IEC TR 61850-90-5] for enhanced protection and control.
Thank you for your attention