Future Defence Plan Requirements with High Penetration of Renewable Generations

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Wind Power in EU

ANNUAL INSTALLED CAPACITY (MW) AND RENEWABLE SHARE (%) [EWEA - Wind in power, 2016]

CUMULATIVE WIND POWER INSTALLATIONS IN THE EU (GW) [EWEA - Wind in power, 2016]
Renewable Sources in India

Renewable Installed Capacity Target by 2022 [GW]

- Wind Power
- Solar Power
- Biomass
- Small Hydro

Wind Power in Denmark

- Capacity, onshore [MW]
- Capacity, offshore [MW]
- Wind power production as a percentage of demand

Henning Parbo, “Distributed Generation Trends and Regulation: The Danish Experience”, EPRG Workshop on Distributed Generation and Smart Connections
Power System States

- Normal
- Alert
- Emergency
- Defence Plan
- Blackout

System Restoration

- (n-0)-state, no loss of elements, no load mismatch etc.
- (n-1)-state, no violation of operational limits
- Violation of operational limits, interruption of supply/transits, Loss of stability
- System collapse Blackout
Definitions of Defence Plans – ENTSO-E

- Normal / Exceptional Type of Contingency
  - Normal State
  - Emergency State

Alert State: Activation by Event or System Response

Emergency State: Activation by System Response

Defence Plan

- Special Protection Scheme (SpPS)
  - SpPS 1
  - ...
  - SpPS N
  - Counteracts: Violation of operational limits (e.g. over-loadings, voltage excursions, instability phenomena...)

- System Protection Schemes (SyPS)
  - SyPS 1
  - SyPS 2
  - SyPS 3
  - SyPS 4
  - Counteracts: Oscillatory Instability, Transient Instability, Frequency Instability, Voltage Instability

Objective

- Maintain Alert State / Avoid transition to Emergency State
- Stabilize System, Avoid transition to Blackout State
System Integrated Protection Schemes (SIPS)

• Set of coordinated automatic measures intended to ensure that the overall power system is protected against major disturbances involving multiple contingency events, generally not caused by natural calamity.

• Defence plans are used to minimize and reduce the severity and consequence of low probability and unexpected events and to prevent system collapse.

• Examples: load shedding, generator rejection etc.
Definitions of Defence Plans - NERC

Special Protection System

• **automatic** protection system designed to **detect** abnormal or predetermined system conditions, and take **corrective** actions other than and/or in addition to the isolation of faulted components to maintain system reliability.

• **does not include** –
  • Underfrequency or undervoltage load shedding
  • Fault conditions that must be isolated
  • Out-of-step relaying (not designed as an integral part of a Special Protection System)

North American Electric Reliability Corporation (NERC)
System Protection Scheme

- A system protection scheme in addition to the normal protection system to take care of some special contingencies like tripping of important corridor/flow gates etc. to avoid the voltage collapse, cascade tripping, load generation mismatch and finally blackouts in the system.

- Generally event based and can be divided to:
  - Tripping of critical line / corridor
  - Safe evacuation of Generation
  - Overloading of Transformers

- Defence actions:
  - Generation rejection
  - Load rejection
  - HVDC controls, etc.
Frequency Stability

**Causes**
- Inadequacies in regulation / control of power plants
- Poor coordination of control and protection equipment
- Protection trips leading to islands or high imbalance
- Out of step of plants
- Voltage instability
- Insufficient generation reserve

**Consequences**
- Sustained frequency swings leading to tripping of generators and/or loads
- An aperiodic transient.
  - **System splitting into islands**

**Defence plans not sufficient**
- Italy at 2003,
- Southern Sweden and Eastern Denmark at 2003
- 2012 Indian Blackout

**Blackouts prevented**
- 1999 in South-West of France
- 4th November, 2006 at UCTE

**Defence Actions**

<table>
<thead>
<tr>
<th></th>
<th>Overfrequency</th>
<th>Underfrequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator Rejection</td>
<td>Fast start-up</td>
<td></td>
</tr>
<tr>
<td>HVDC fast power change</td>
<td>Underfrequency load shedding</td>
<td></td>
</tr>
<tr>
<td>Tripping of hydro units / pump storage</td>
<td>Controlled opening of interconnection</td>
<td>HVDC fast power change</td>
</tr>
</tbody>
</table>
Indian Blackout - World’s largest blackout on 30th and the 31st July, 2012

Disturbance occurred in the Northern Region leading to a blackout affecting almost the entire Northern region covering 8 States.
- Frequency before the incident was 49.68 Hz.

Disturbance occurred in the Northern Region affecting the Northern, Eastern and North-Eastern grids.
- Frequency before the incident was 49.84 Hz.

Underfrequency Load Shedding (UFLS) in Northern Region:
- Planned load shedding capability: 10 GW
- Frequency based: 4 GW
- RoCoF based: 6 GW

The rapid frequency decline illustrated that actual UFLS was not realised as per the planning.
UCTE Disturbance at 4th November, 2006

- **Western Area**
  - UK-France HVDC (RTE-NG)
  - G = 182,700
  - (REE-MOROCCO)
  - G = 490
  - (Terna-HTSO)
  - G = 310
  - G = 170

- **North-Eastern Area**
  - Kontek, Baltic cable, SwePol, DK DC Cable
  - G = 62,300

- **South-Eastern Area**
  - G = 29,100

**European grid splitting**

- Grid switching date: 22:10:31

**Graph**

- Zone WEST
- Zone South East
- Zone North East

**Map**

- Total load shed: ~17,000 MW
- Total tripped generation in Western area: ~10,900 MW (6%)
- High frequency - High flows
- Risks of further outages

- Frequency: 49 Hz
- Frequency: 49.7 Hz
- Frequency: 50.60 Hz
Challenges for Future Defence Plans

• How to prevent emergencies with respect to frequency instability in future power systems with high penetration of renewables?
  • What volume of reserves are required?
  • Is volume of reserve a sufficient condition?

• If frequency emergency becomes inevitable, how to prevent blackout?
  • Overfrequency Emergency
    • How should renewables behave?
    • Should they start disconnecting?
    • Should they reduce their power output? At what rate?
  
  • Underfrequency Emergency
    • How to reduce consumptions?
    • If we disconnect feeders, how to minimize disconnection of distributed generations?
Adequacy of frequency Reserves

Anticipated installed onshore and offshore wind power capacity in GW of different ENTSO-E networks for 2020 and 2030

<table>
<thead>
<tr>
<th>Network</th>
<th>2020 Onshore</th>
<th>Offshore</th>
<th>2030 Onshore</th>
<th>Offshore</th>
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<tbody>
<tr>
<td>UK</td>
<td>12.5</td>
<td>9</td>
<td>19</td>
<td>32</td>
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<tr>
<td>CE</td>
<td>166</td>
<td>25</td>
<td>217</td>
<td>94</td>
</tr>
<tr>
<td>Baltic</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td>5</td>
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<tr>
<td>Nordic</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Ireland</td>
<td>2</td>
<td>2.5</td>
<td>1.5</td>
<td>3</td>
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<tr>
<td>Total</td>
<td>189</td>
<td>46</td>
<td>248</td>
<td>162</td>
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</table>
Adequacy of frequency Reserves

- Probabilistic risk of imbalances reduce exponentially with increase in volume of secondary reserve
- Probabilistic risk of imbalances does not depend on speed of secondary reserve activation

* Risk depends on the quality of wind power forecast. Results are conservative and if better forecast methods can be available in future, risk will reduce.

Overfrequency Defence Plans

16578 buses
3240 generators
14044 lines
9654 transformers
total load of 400 GW
Implemented in Eurostag software

Underfrequency Load Shedding Considering Distributed Generations

- Impacts of high penetration of distributed generation (DG) on Underfrequency Load Shedding (UFLS):
  - Unintentional disconnection of DG
  - Not disconnecting required amount of load
  - Poor frequency response

- Motivation for development of an advanced UFLS algorithm

"IEEE Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration" - tripping feeders that have active DG certainly diminishes the beneficial affect of load shedding, and can even have negative impact by eliminating sources of generation that supports system inertia.
Underfrequency Load Shedding Considering Distributed Generations

ENTSO-E Recommendation for UFLS
Underfrequency Load Shedding Considering Distributed Generations

Static load shedding scheme (LSA-Static) uses traditional flat frequency based relays.

LSA-Directional scheme has an additional directional element to prevent disconnection of a feeder with reverse power flow.

LSA-PF is an intelligent relay which uses the power flow measurements from all the available feeders:
- Identify the required amount of load to be disconnected based on real-time measurements.
- Tends to disconnect more DG, however ascertaining that the designed amount of load is disconnected.

LSA-DG uses available data about DG along with power flow measurements to estimate and optimize the required amount of load disconnection while disconnecting minimum amount of DG.

Underfrequency Load Shedding Considering Distributed Generations

<table>
<thead>
<tr>
<th>LSA</th>
<th>ConsReduction</th>
<th>GenReduction</th>
<th>FreqNadir</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Abs. [p.u.]</td>
<td>Improvement over LSA-Static [%]</td>
<td>Abs. [p.u.]</td>
</tr>
<tr>
<td>LSA-Static</td>
<td>1.4288</td>
<td>-</td>
<td>1.0802</td>
</tr>
<tr>
<td>LSA-Directional</td>
<td>0.862</td>
<td>38.67</td>
<td>0.5055</td>
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<tr>
<td>LSA-PF</td>
<td>0.9994</td>
<td>30.05</td>
<td>0.3975</td>
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<tr>
<td>LSA-DG</td>
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<td>46.35</td>
<td>0.1123</td>
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</table>

- LSA-DG scheme disconnects much less consumption and generation than other schemes
Conclusions

• Revision of traditional defence plans are essentially required when operating the system with high penetration of renewables.

• Additional reserves will be required to handle forecast errors of renewable generations in order to prevent frequency emergencies.

• Modern power electronics based renewable generations have fast control capabilities.

• Control and protection schemes should be developed for renewable generations for emergency operations.

• System protection schemes such as UFLS should be redesigned taking into considerations of high penetration of renewable generations.
Thank you for your attention.