Functional requirements for Blackstart & Power system Restoration from Wind Power Plants

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Blackstart & Islanding capabilities of Offshore Wind Power Plants
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Blackout Impact

Blackout is *HILP* event

<table>
<thead>
<tr>
<th>Year</th>
<th>Location (Region)</th>
<th>Impact</th>
<th>People-affected (million), or Length (billion customer-hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>Brazil (S)</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>India (N)</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>US+Canada (NE)</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>EU</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>India (N,E,NE)</td>
<td>670 (largest in history)</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Philippines</td>
<td>6.3 (longest)</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Australia (S)</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>Venezuela</td>
<td>30, &gt;3.1</td>
<td></td>
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Motivation

Increased risk of wide-area blackouts [1,2]
- High volume integration of RES far from loads
- Increased trans-national power exchanges
- Power electronics converter (PEC) interface
- Stronger network linking

Operation closer to dynamic stability limit

Large OWPPs with modern WTs can address Blackstart requirements targeted conventionally to large thermal plants: ENTSO-E codes

Steady winds far-from-shore, thus lesser availability-uncertainty
- Fast, fully-controlled, high-power environment-friendly BS capability of VSC-HVDC OWPP
- Advanced V,f control functionalities from state-of-art PE interface of modern WTs

\[ P(\text{black-out} \mid \text{no-wind}) \rightarrow \text{LOW} \]

Grid forming WT,WPPs [3]

Reduce the overall impact of a blackout event
- Minimize or totally avoid use of backup diesel generator for auxiliary power, thus cost benefits
- No wait for completion of network reconstruction; controlled islanding to ensure continuity of power supply
- Allow DRU / LCC-with-smaller-filter, thus reduce costs, increase efficiency & reliability
Power System Restoration

**Preparation**
- To save generation & ensure no accidental energization of faulted devices during PSR plan.
- **Decision:** Assessment of post-blackout status of system.
- **Defense:** Plan suitable Sectionalizing Strategy.
- **Definition:** Plan suitable BSUs & Restoration path; Avoid re-blackout.

**System Energization**
- To energize auxiliaries of non-BSUs & restore bulk transmission network.
- **Blackstart:** pre-determined BSU(s) startup & operation, Non-BSU crank-up, Houseload.
- **V-propagation:** Zonal – Backbone (skeleton) energization, HV lines (Cap MVars)
- **Load recovery:** Priority & closest loads, Islanding.

**Load Restoration**
- To minimize un-served load, while satisfying system’s operational constraints.
- **Block Loading:** Max. size to avoid UF, & UV in weak grids.
- **Meshing:** Enhance resilience.
- **Synchronization:** Re-connect islands when stable.

**Critical for PSR**
- Stable & Robust Load Recovery

**Stabilize V, f**

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BS Service Provider

Tasks

- Start-up independent of external supplies.
- Energize transmission/distribution network.
- Provide block loading of demand, in a stable power island.
- Crank-up other non-BS PGMs. ← Optional

Assets

Present

Future
BS Service Provider

- Tasks
- Assets
  - Self-starter eg. Diesel, BESS.
  - Cranking path (optional)
  - Main PGM(s)
- Present
- Future
BS Service Provider

- **Tasks**
- **Assets**

**Present** – *large thermal plants cranked up by*
- Pump-storage Hydro
- Gas-fired
- **HVDC** eg. DK-NO, IR-GB. \(\leftarrow\) *Top-bottom PSR*
- **Nuclear** – *security*
- Diesel, for OWPPs \(\leftrightarrow\) *BS by of OWPP*

**Future** – *alternate sources required \(\rightarrow\) resilience*
- *Changing* generation profile.
- RES \(\uparrow\) \(\rightarrow\) SG running hours \(\downarrow\)
- Large WPPs *can support* PSR [4,5], if not BS.
- ESS can mitigate *intermittency* issues for PSR.
Comparison

System Energization
- **Blackstart**: Self-start, Fuel supply, Restoration time.
- **V-propagation**: Var-requirement, V-management.
- **Load recovery**: V, f-management

Load Restoration
- **Block Loading**: P-requirement.
- **Islanding & TTH**
- **Synchronization**

Technical Requirements for Blackstart Service

Technical Capabilities of Wind Turbines

[Diagram showing BSU, Tx/Dx Network, Block Load]

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Codes vs. Wind

- Diesel gen.
- Gas-fired plants.
- Pumped-storage hydro.
- Stored E (BESS).

- Onshore – NO.
- Offshore – can BS & self-sustain aux.; NOT ready to re-energize cables.

Innovative solutions → bright future: High $P$-density ESS at WTDC link & High $E$-density ESS at PoC.

Grid-following WTs connecting in initial stages of PSR → re-blackout.

System Energization

- Blackstart: Self-start

BSU

Tx/Dx

Network

Block

Load

Grid-forming
Codes vs. Wind

- 90% availability.
- Min. E (stored) for 3 sequential blackouts.
- Backup fuel supplies for 3-7 days.

- Aux. & Backup Diesel gen, on offshore platform.
- Large MW-scale OWPPs, further away from shore → steadier wind conditions → lower availability uncertainty.
- 10-20 BS-able WTs → reliability + cost benefits.

System Energization

- Blackstart: Fuel supply

BSU

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Grid-forming
Codes vs. Wind

• **Blackstart:** Restoration time

- Startup time – 20 min for thermal units, 5 min for hydraulic.
- BSU must operate for at least 24 hrs; *not applicable to* pump-storage hydro.

- Startup time – 40 sec.
- Similar *relaxation* can help develop BS-service technology in WPPs.
BSU must absorb MVars generated by connection of overhead lines, low-loaded cables.

V-instability due to insufficient Var reserve → major blackouts.

FRT mode in WTGs – support V-recovery at PoC.

VRT, RCI in grid codes (DE, DK, IR, ES, UK).

Diversity Energization

- V-propagation: Var-requirement
Codes vs. Wind

- Soft (LV) energization
  - Cable MVar
  - Trafo Inrush
  - PSR time
- Long HV lines with unloaded trafo at remote end → energization is critical as possible resonance → high OV.
- Feeder restoration such as to limit increment of MVars generated.

- PEC interface → advanced V-control & V-support functionalities like fast Var response.
- Local V-control requirement expected in future grid codes, esp. DE & ES.

Grid-forming

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Codes vs. Wind

- LFSM-O/U operation & $f$-control during OF/UF.
- Initial load restoration – small steps; nearest loads first.
- Before load pickup, $f$ min. 50 Hz (preferably higher).
- 1 isochronous control gen & others in droop set-point control.
- Upward reserve for $f$-instabilities, eg. 70% (Elia), 50% (EirGrid).

PEC interface → fast (down-regulating) P-control → spinning reserve margin.

FFR by using KE – reduces initial RoCoF, but doesn’t support overall PSR.

$J$- emulation & POD expected in future grid codes, esp. ES & DE.

System Energization

- Load recovery: $f$-management

Grid-forming & Power-Delta Control

• Load recovery: $f$-management

Tx/Dx Network BlockLoad

System Energization

BSU

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Codes vs. Wind

- **Block Loading:** P-requirement

  - 10 MW (Elia), 35-50 MW (UK).
  - $f$-range: 49-52 Hz (Elia), 47.5-52 Hz (UK).
  - V-range (Elia) \[6\]:

40 MW block load is only 10% of nominal power for a 400 MW WPP. Intermittency Risk.

**Goal:** high priority loads, non-BSU aux. with available margin for fluctuations.

**Curtailment,** **Power-Delta control**
Codes vs. Wind

- Islands connected (synchronization) when stable.
- Parallel operation of BSU with other PGMs, in an island.
- PGM with TTH → speed up PSR as no restart needed.
- Tennet Grid Codes for Islanding & Houseload operation.
- Houseload operation NOT used in PSR, except FR.

- OWPPs TTH with islanding of offshore/ regional onshore zone → early stage PSR support & f-instability defence.
Bridging the Gap

- **Grid-forming (BS-able) WTs** [7]
  - Self-start
  - V, f-control
- **Cable Vars**
  - Array cables ✓
  - Onshore Export cable ✗
- **Trafo transients**
  - Inrush → V-dips
  - Overexcitation → transient busbar OV
  - Resonance with long HV lines → OV
- **CIO**

Initial Results [8]
Considerations

- **Grid codes:** DK, DE, ES, UK, IR
  - PQ-control, V-support, FRT, J-response, P-quality, Protection.
  - Exempt from PSR services.
  - Major driver for WT technology (eg. RCI, VRT; J & POD).
  - Ongoing dialogue between TSO & Wind Industry.

- **Case Study:** 2016 South Australian Blackout (AEMO) ← UCIO
  - Protection settings – redesign required, especially in areas with high wind penetration.
  - CIO – practical measures for stable islanding required.
  - Wind intermittency & excessive speeds NOT material contributor to blackout.
  - Further investigation: WPP reduction during faults, WT over-speed cut-outs.

- **WPP early in PSR:**
  - BSU impact limited only to first 4-6 hrs of PSR.
  - Option for DK, DE, ES ← more familiarity with high wind share.
Thank You

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Target State 1

- **Housekeeping** – internal UPS / BESS [9]
- **Grid forming** [7] GSC + RSC
- **Down-regulation:** Power-curtailment / Idling modes

• Grid-formers: Grid-followers

• STATCOM mode – VAR compensation [12]

• Intelligent control-mode switching [11]
Target State 3

- **Stiff, controlled Voltage source** – WPPs coordinated parallel operation
- **Controlled Islanded Operation**: stability & robustness
  - Offshore & DC grid faults
  - Harmonic instabilities [13]
  - HVDC link resonance issues [14]
  - Substantial network configuration changes [15] eg. load pickups, WT connections/disconnections
Grid forming WT [7]

- Controls $V_f$ at WTT
  - Inner loops - dq
    - $C_i$: limit current during transients/faults.
    - $C_v$: control WTT V
  - Outer loops – Droop=$VSM(v_{J,D})/PI/LL$
    - $C_q$: QLC
    - $C_p$: PLC
- Additions
  - Ext f-P droop ($\sim R$ in SG)
  - Ext Q-V droop ($\sim AVR$ in SG)
  - Virtual impedance (single/multiple $f_j$ to damp inrush/OC/harmonics.)
VSG [16]

- Q-V & P-f (~SM)
- QLC: Q-V droop
- PLC:
  - VSM (virtual J, D)
- Addition [17]:
  - Ext f-P droop
  - Virtual admittance
  - Active damping
PSC [18]

- Q-V & P-f (~SM)
- QLC: PI (optional)
- PLC: P
  - Ext f-P droop
- AVC: (~ SM exciter, but I & not P)
  - Req'd for weak grids/islands
- CLC:
  - Normal mode: ~active damping (HF:R)
  - Faults: OC limit & switch to PLL
- Proven response for weak grids.
DPC [19]

- Q-V & P-f (~SM)
- QLC: I
- PLC: PI
- Addition:
  - Ext V-Q droop
  - Ext f-P droop
- Faults: current limitation ~ PSC
Distributed PLL \([20]\)

- PLC: PI \((d\text{-axis})\)
- QLC: P \((q\text{-axis})\)
- Addition:
  - PLL based fLC:
    \[ V_{f_q} > 0 \Rightarrow f > f_0 \]
    Thus, \( V_{f_q}^* = k_f (f_{\text{ref}} - f) \)
Comparison

1. Distributed PLL
2. VSG
3. DPC
4. PSC
References


References


