Challenges in integrating renewable energy into electricity industries

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Energy service delivery in the stationary energy sector (a complex technological system)

Primary energy forms e.g: coal, gas, nuclear, renewable

The electricity supply industry
- generation
- transmission
- distribution

The natural gas supply industry
- treatment
- transmission
- distribution

Equipment providers

End-use equipment delivering energy services e.g: light, heat, motive power

Energy losses & external impacts

Continuous energy flow

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Features of wind & solar energy fluxes

- Non-storable, stochastic primary energy fluxes:
  - Not available when wind or insolation low
- Generation type & size:
  - Wind & solar thermal electric: large & free-standing
  - Solar PV: small, building-integrated, electronic interface
- Can possibly contribute to:
  - Local voltage & waveform control
  - System security management
  - Subject to rating, fault ride-through capability & coordination between multiple generating units

UK wind capacity factor as function of:
1. Season & time of day (right)
2. Load level (below)
(National Grid, Winter Outlook 2008/9)
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The Art of Knowing and Doing
The study of technology concerns what things are made and how things are made. Technology, from the Greek science of (practical) arts, has both a material and an immaterial aspect.

Technology = Hardware + Software + "Orgware"

Hardware: Manufactured objects (artifacts)
Software: Knowledge required to design, manufacture, and use technology hardware
"Orgware": Institutional settings and rules for the generation of technological knowledge and for the use of technologies

Technology's most important characteristic: Continuous change >>

Scope of the National Electricity Market

Market regions:
• Queensland
• New South Wales & ACT
• Victoria
• South Australia
• Tasmania

NEM regions are on state borders, generation/load zones are joined by national transmission flow paths (NTFPs)
### Decision-making framework for a restructured electricity industry (EI)

| Governance regime | ▪ Formal institutions, legislation & policies  
|                   | ▪ *Informal social context including politics*  |
| Security regime   | ▪ Responsible for core integrity on local or industry-wide basis, with power to override  |
| Technical regime  | ▪ Engineering design to allow industry components to function as single, industry-wide machine when connected together  |
| Commercial regime | ▪ Decentralised decision-making according to commercial criteria within a market context  
|                   | ▪ Includes formally designed markets  
|                   | ▪ *Needs adequate competitive pressures*  |

### Technical regime

- **Objective:** “plug & play” capability for the millions generation, network & end-use “components” of an electricity industry “machine”:
  - Implemented through design rules & operating guidelines
- **Connection requirements:**
  - Technical performance standards
- **Operation requirements:**
  - Fault-ride through, centralised control if/when required
Commercial regime

- **Objective:** *economic operation of existing resources & investment in new resources:*
  - Requires effective coordination of decentralised decisions
- **Operation of existing resources (commitment & dispatch):**
  - Requires effective & efficient spot & ancillary service markets
- **Investment in new resources (resource adequacy):**
  - Requires efficient & effective derivative markets

Security regime

- **Objective:** *Continuity of end-use energy service delivery subject to willingness to pay:*
  - Requires an ability to maintain electrical energy flow
- **Short-term security:**
  - Power system operator interventions to maintain power system within secure operating envelope
  - Requires capability & protocols
- **Long-term security (resource adequacy):**
  - Investment in appropriate generation, network & demand-side resources, considering primary resource availability & direct & indirect costs
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Security & commercial regimes (global & local)

- Unreachable or unacceptable futures
- Present state
- Secure operating limits (probabilistic)
- Renewable energy increases future uncertainty but forecasts can help
- Emergency control
- Time
- Growing uncertainty

Commercial regime: Possible futures managed by decentralised decisions

Security regime: Possible futures managed by centralised decisions

The Australian National Electricity Market (NEM)

- Generation Sector: Large generators
  - Gen 1
  - Gen 2
  - Gen 3
  - Gen X
- Multi-region National Electricity (spot) Market (NEM)
- Financial instrument & REC (emission) trading
- Intentions offers & payments
- Tx network pricing
- Transmission Sector
- NSW, Victoria, South Aust., Queensland, & Tasmania
- Distribution Sector
- Retail Markets
- Embedded generators
- Contestable end-users
- Franchise End-users
- End-use sector
- End-use Equipment & Distributed resources
- Retail sector: Retailer 1, Retailer 2, Retailer 3, Retailer Y
- Retailer 1: Distributor 1, Distributor 2, Distributor Y
- Distributor 1: Network access

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**NEM commercial & security processes**

*Australian Wind Energy Forecasting System (AWEFS) now integrated into these processes*

- **Medium Term (MT) PASA**
- **Short Term (ST) PASA**
- **Now**
- **5 min dispatch & pricing (4 sec AGC, online security processes)**
- **5 min predisp.**
- **Upto 40 hr ahead, 30 min res. 30 min update**
- **1 wk ahead, 30 min res., 2 hr update**
- **Upto 2 yr ahead, 1 day (MD) res., 1 wk update**
- **10 yr ahead, 1 yr update**

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**Capability & protocols for wind energy & security management in the NEM**

- **Australian Wind Energy Forecasting System:**
  - Procured & operated by NEMMCO
  - Produces forecasts from 5 minutes to 2 years & beyond
  - Has potential to forecast solar energy as well as wind

- **Technical requirements for NEM wind farms:**
  - Fault ride through, voltage & waveform management
  - Semi-dispatch capability for control by NEMMCO
  - Verified simulation models

- **Security management protocols:**
  - Rules under which NEMMCO & NSP’s can intervene

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Source: NEMMCO; S Thorncraft
Issues for high levels of penetration

- High penetration at the local distribution level:
  - Low diversity between converted renewable energy fluxes
  - Management issues (+/-): voltage fluctuations, flow constraints, harmonics, islanding

- High penetration at the regional transmission level:
  - Medium diversity between converted RE fluxes
  - Management issues (+/-): voltage fluctuations, flow constraints, resource mix, system security

- High penetration at the system-wide level:
  - High diversity between converted RE fluxes
  - Management issues (+/-): resource mix, system security

Wind penetration (%energy) globally & for South Australia

(Wiser & Bolinger, 2008)

Expected renewable energy penetration in South Australia

(ESIPC-SA APR, 2008)
Wind farms in South Australia (ESIPC APR, 2008)

Wind generation in South Australia, Aug 08
### NEM income for SA wind & other generators

**(ESIPC-SA APR 2008)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume Weighted Price for Wind Generators</th>
<th>Volume Weighted Price for Other SA Generators</th>
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<tbody>
<tr>
<td></td>
<td>Full Year ($/MWh)</td>
<td>Summer ($/MWh)</td>
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<tr>
<td>2004–05</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>2005-06</td>
<td>32.57</td>
<td>39.59</td>
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<tr>
<td>2006-07</td>
<td>49.69</td>
<td>51.55</td>
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<tr>
<td>YTD 2007-08</td>
<td>66.99</td>
<td>63.94</td>
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</table>

### NEM wind penetration by state

**(NEMMCO, 2008)**

<table>
<thead>
<tr>
<th>Region</th>
<th>Existing</th>
<th>Committed</th>
<th>Proposed</th>
<th>Total</th>
<th>Summer(07/08)</th>
<th>Winter (07)</th>
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<td>SA</td>
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Low-pressure cell over southern Australia
(BoM, 2006)

Visualising possible power output of 3 wind farms (Cutler, 2008)
Conclusions

- PV penetration still small at regional & system levels
- However, capabilities & protocols & simulation models required if penetration rises
- The PV industry should be preparing for this now & commence discussions with network service providers & power system operators
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Managing electricity industries with high levels of PV penetration

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