



## CIGRE Opening Panel

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# Integrating Large Shares of Fluctuating Power Sources into Power Electric Systems

## Role of Storage

Geza Joos, Professor  
McGill University, Canada



## Role of energy storage – outline of the presentation

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- Background and justification
- Storage functions and benefits – general considerations
- Storage technologies – overview and operating characteristics
- Storage technologies and applications – case studies – wind farms and substation upgrades
- Hydrogen as a future viable solution – general considerations
- Hydrogen as a storage solution – a case study for remote communities
- Hydro and wind power integration – general issues



## Background and justification

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- The new electricity generation context
  - Increasing the penetration of renewable energy resources, mainly wind and solar, as well as hydro power and biomass
- The issues
  - Managing the intermittency of wind and solar energy, so that these resources can be incorporated into to the base load generation
  - Managing large load fluctuations – supplying peak consumption
- The solution
  - Storing energy from renewable sources and from the grid in a form recoverable as electrical energy when required
- The constraints
  - Technologies – equipment availability and life cycle
  - Capital and operating costs (losses, maintenance and others)



## Benefits of storage

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- Accommodating intermittent generation - allows it to operate at peak power and efficiency by storing surpluses
- Ability to dispatch energy during times of peak demand – peak load management
- Ability to supply peak demand locally and reduce transmission line demand (avoid transmission line congestion)
- Ability to provide voltage support, voltage regulation (voltage sag compensation, flicker) and power factor correction
- Ability to provide other ancillary services – frequency regulation, black start, reactive power
- Possibility of islanded operation
- Ability to perform arbitrage on electricity prices – electricity markets



## Integrating storage – electric power system issues

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- Scale and scope of installations – distributed vs centralized
- Location and connection to the grid – transmission, distribution (line or end user), substation
- Ownership – utility or independent operator
- Allocation of benefits – customer and/or grid operator
- Grid code issues
  - Control on the grid performance
  - Control of the equipment by the grid operator
- Policy – financial incentives
- Cost recovery – time frame and multiple benefits
- Storage vs stand-by generation (electric energy production/storage)



## Managing storage – operation and performance

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- Energy storage system interfaces
  - Electrical to electrical – static (power electronic) converters - benefits
  - Other energy storage devices – static and/or rotating converters
- Performance expectations
  - Losses and energy recovery (efficiency of storage process)
  - Availability and reliability
  - Life expectation – batteries
- Control and communications
  - Grid operator control – centralized vs local control
- Control functions and impact on the grid
  - Power dispatch
  - Voltage regulation
  - Frequency regulation
  - Ancillary services in general



## Utility-scale energy storage – benefits quantification

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- Benefits to participants
  - Cost reduction – grid operator
  - Business opportunities – independent producers
  - Multiple value streams – benefit allocation issues
- Value streams for the grid operator
  - Improved asset utilization – improved load factors
  - Deferred or avoided substation upgrade
  - Energy cost savings – reduced peak generation or electricity purchases
  - Deferred transmission and generation capacity increases
  - Regulation control and other ancillary services provision
- General impact on the security of the electricity supply
  - Availability and contribution to the security of the supply



## Storage technologies – general considerations

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### ■ Electrical storage

- Electrolyte type batteries – Lead Acid, Lithium Ion, etc
- Flow batteries – Vanadium Redox, Zinc Bromide, etc
- Capacitors and supercapacitors

### ■ Magnetic storage

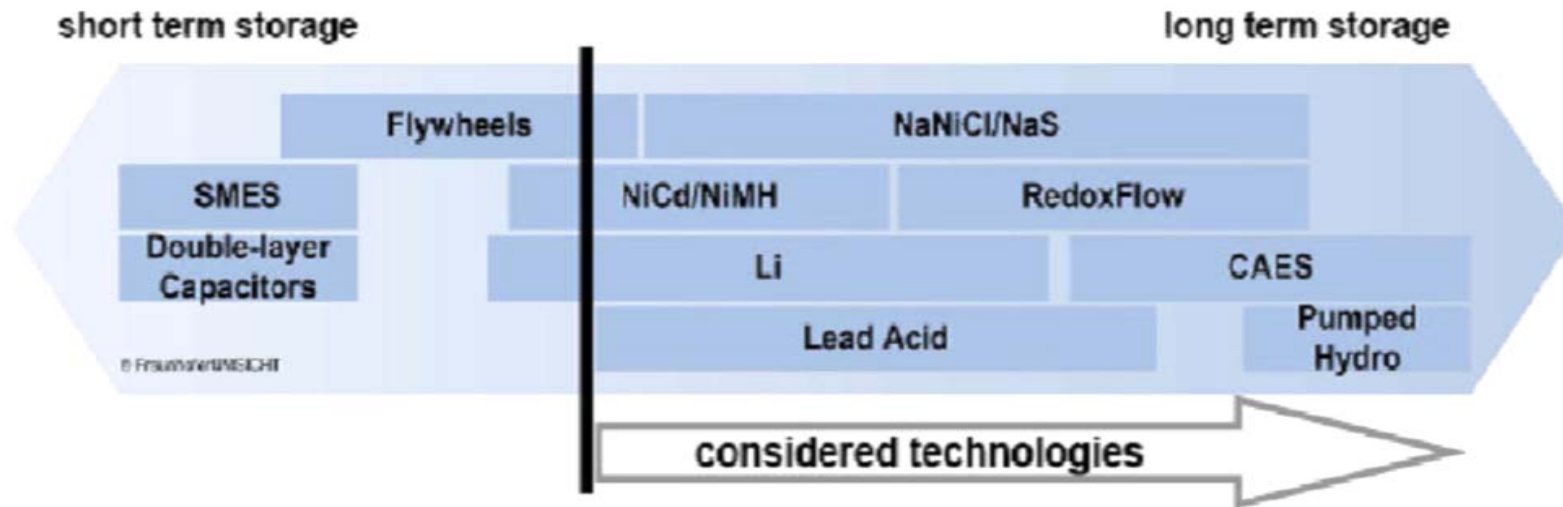
- Superconducting magnetic energy storage (SMES)

### ■ Mechanical storage

- Flywheels
- Compressed air
- Pumped hydro storage



## Storage technologies – operating time frames



### Worldwide survey on storage technologies:

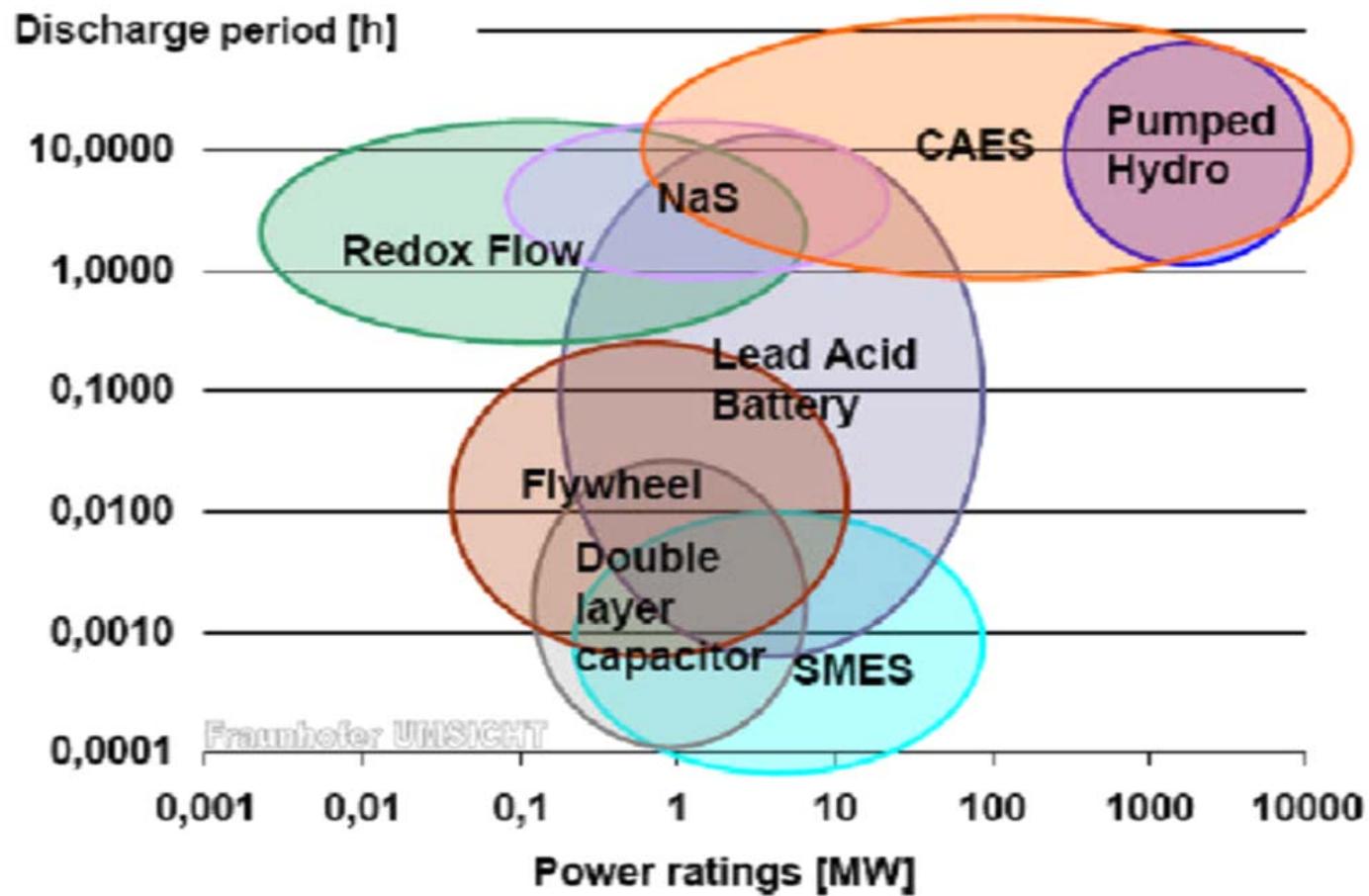
- only long term storage
- technical (and economical) data available
- capacity > 100 kW<sub>el</sub>

approx 500 projects  
taken into account

Sources: Internal Study / EPRI Handbook, USA 2003 / DTI Review, UK, 2004 / Gonzalez, Ireland, 2004



# Storage technologies – energy and power ratings



Source: Fraunhofer UMSIGHT



## Storage installations – wind farms – case studies

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- Benefits in large intermittent power generation systems
  - Smoothing wind farm power production
  - Providing firm power capacity
  - Meeting forecasted power production
  - Ability to meet peak demand
  - Provision for frequency regulation and spinning reserve
- Japan – Rokkasho – 51 MW wind farm – 2008
  - NaS batteries – 34 MW (65 % peak wind farm production), 245 MWH
  - Purpose: capacity firming
- Japan – Tomamae Wind Villa wind farm – 30 MW – 2005
  - VRB battery – 4 MW (15 %), 6 MWH
  - Purpose: wind power smoothing



## Storage installations – substations - case studies

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- Benefits in load fluctuations/variations
  - Daily peak load shaving and peak load management
  - Ancillary services – frequency regulation – voltage support/regulation
  - Substation and transmission upgrade deferral
- USA – AEP- Substation upgrade (W. Virginia) – 2006
  - NaS, 1 MW, 7.2 MWh
  - Availability (experienced): 93 % (overall), 100 % (peak periods)
  - Efficiency: 80 % (90 % considering reduced transmission losses)
- USA – AEP – plans
  - Plans – NaS, 6 MW, 43 MWh – 2008
  - Near term – NaS, 25 MW by 2010
- USA – AES substation – Lithium Ion battery
  - 2 MW, portable



## Storage installations – other case studies

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- USA – Long Island Bus Station - battery
  - NaS battery, 1 MW, 7.2 MWh (NGK)
  - Purposes: peak shaving, load shifting
- USA – Beacon Power – flywheel
  - 20 MW, 15 min, 5 MWh
  - Purpose: frequency regulation ancillary service, regulation market
  - Expected life cycle: 20 years, 24/7 operation
- USA – Delaware County Energy Storage Project – fuel cell
  - 5 kW Plug Power Fuel Cell
  - 11 kW, 20 kWh Gaia Power Tower
  - Purposes: load management, peak shaving (commercial)
- Other technologies: supercaps, ZnBr, Lead Acid, SMES, CAES



## Storage deployment – limitations and opportunities

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- Deployment limitations – batteries and other technologies
  - Need to reduce costs - expensive
  - Life cycle and asset management
  - Life cycle for severe environments – to be determined
- Building a business case
  - Storing vs direct use of electric energy
  - Losses – complete cycle from storage to retrieval
  - Amortizing capital and operating costs – capitalizing losses
  - Current electricity costs – competing with low production costs in large scale generating plants
- Possible business opportunities
  - Remote location and new developments (no electrical infrastructure)
  - New installations requiring high power quality and reliability



## Hydrogen economy – general considerations

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- Main applications – energy supply for
  - Motive power – transportation (cars, buses, trucks, boats, planes)
  - Off-grid electrical power generation
  - Distributed generation – embedded and strategic applications
- Elements of the hydrogen infrastructure
  - Production – electrolysis of water, fossil fuel (natural gas), other
  - Storage – pressurized or liquefied, in a compound, solid storage
  - Transportation and delivery – hydrogen pipeline and filling stations
  - Utilisation – fuel cells (35-45 % efficient), internal combustion engine (20-30 %)
- Competition
  - Direct use of electricity produced by renewable energy sources
  - Direct use of fossil fuels (with the associated GHG production)



## Hydrogen technology – advantages and limitations

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- Advantages of hydrogen as a fuel
  - Clean fuel – limited GHG
  - Hydrogen as an energy storage medium
  - Considered renewable energy if produced from renewable energy source (wind) – building a sustainable energy supply
  - Large existing production for industrial uses – known technology
- Limitations to the deployment of the hydrogen technology
  - Constructing the infrastructure (compare with water, oil and electricity)
  - Transportation over long distances – pipeline requirements
  - Efficiency as a fuel – complete energy cycle from production to use
- Options – bypassing technical limitations
  - Infrastructure needs – distributed, rather than centralized, production
  - Increasing overall system efficiency – combined heat and power



## Hydrogen storage – applications to remote locations

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- Hydrogen production from wind energy
  - More than 50% of the wind energy in a given configuration may be wasted (dumped) as it can not be absorbed into the isolated diesel grid
  - Excess energy can be used for hydrogen production
  - Hydrogen fuel contributes to the firm power available to the community
- Hydrogen as an energy source – advantages
  - Emission free combustion in internal combustion engine (and fuel cells)
  - Transportable renewable energy source
- Hydrogen as an energy source – issues
  - Overall process (generation-storage-consumption) efficiency
  - Effective integration of multiple energy sources
  - Availability of the technology and commercialization issues



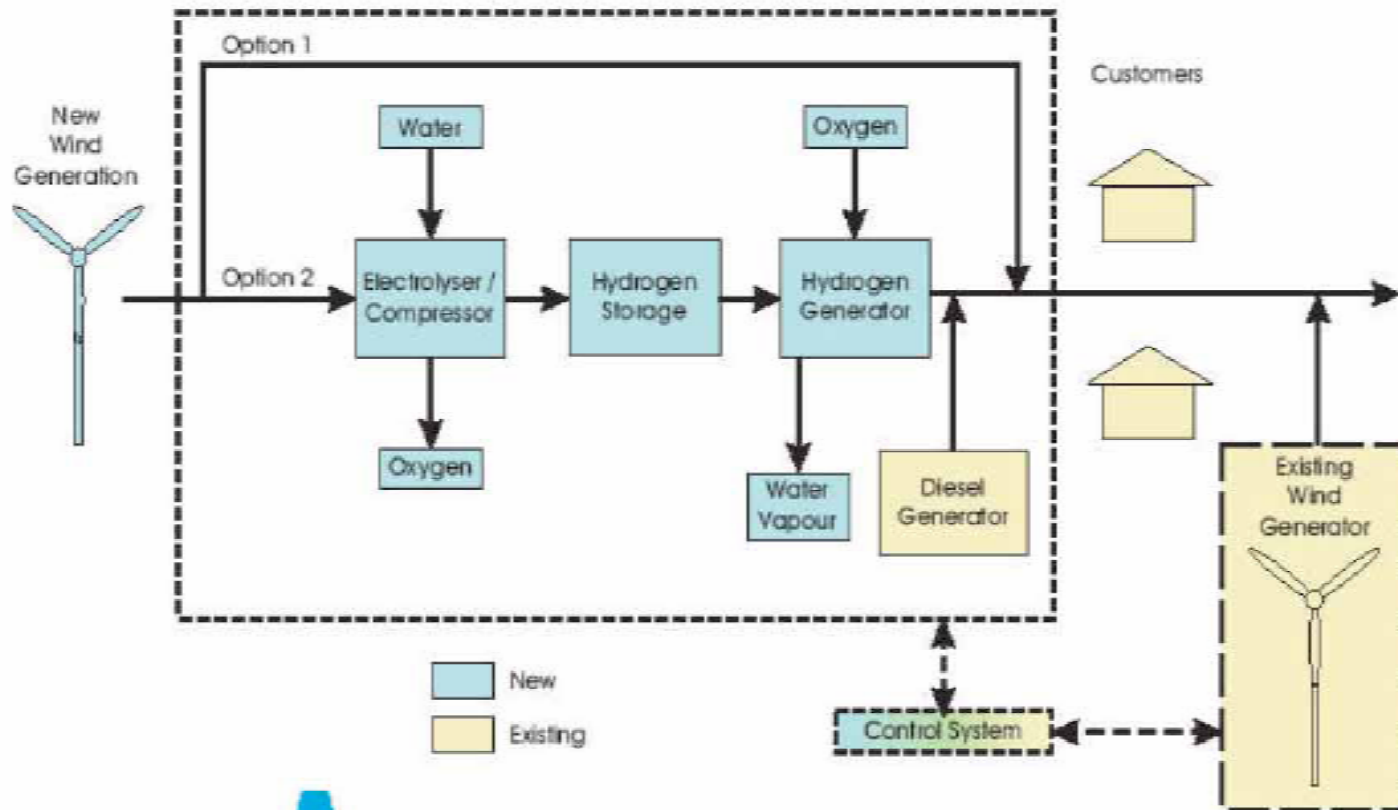
## Hydrogen storage – case study – Canada

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- Wind-Diesel System in Ramea, Newfoundland
  - Installed diesel capacity:  $3 \times 925 \text{ kW} = 2,775 \text{ kW}$
  - Often one only diesel generator running at 300 kW
  
- Installed wind capacity:  $6 \times 65 \text{ kW} = 390 \text{ kW}$ 
  - Real wind capacity:  $390 \text{ kW} \times 0.33 = 129 \text{ kW}$
  - Total energy produced = 4,201 MWh in 2005
  - Diesel / Wind (90% / 10%)
  - Excess wind energy is dumped, therefore, storage would increase wind penetration



# Case study – hydrogen storage – Canada



Natural Resources Canada  
Ressources naturelles Canada

Source: NRCan



## Technology options – hydrogen use – case study

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- Hydrogen storage
  - Leaves smaller environmental footprint than batteries – long-term storage applications a key to a hydrogen economy
  - Considered a complement to NRCan's existing R&D activities into advanced utility-sized batteries (e.g. VRB and NaS)
- Hydrogen generator – a viable option to fuel cells
  - Known, reliable internal combustion technology – previous operator experience
  - Lower cost than fuel cell
  - Current fuel cell technology not mature enough
- Overall (round trip) efficiency: approximately 25 % (expected)
- In service: end 2008



## Wind and hydro power – integration

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- Issues – power balancing
  - Wind penetration – limits (below 10 %, and above)
  - Nature of the hydro reservoirs – storage capability – yearly or multi-year reservoirs – pumped storage
- Wind power integration issues
  - Integration costs – transmission upgrade
  - Integration costs – power balancing
- Impact of wind integration
  - Impact on generation dispatch - mitigation by means of precise wind forecasting methods
  - Impact on real time and day ahead market operation
- Operational constraints
  - Impact on hydro plant efficiency and life



## Wind and hydro power – integration experiences

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### ■ Case studies – Canada

- Manitoba Hydro – 5,500 MW capacity (98 % hydro) – 100 MW wind
- Hydro-Quebec – 38,800 MW capacity (96 % hydro) – 4,000 MW wind (2015)

### ■ Other case studies

- Finland, Norway, Sweden, USA

### ■ Integration expectations/experience

- Integration issues – manageable
- Economic limitations – cost of hydro power vs wind power and export capabilities (interconnections)
- Environmental issues – building wind farms, a decision to integrate large amounts of renewable energy



## Acknowledgements

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