Grid Tutorial 101

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We Will Look At

1. The Central Station Power System
2. Frequency & Voltage Management
3. Distributed Generation
4. Distributed Generation Connection
5. Introduction to Micro-Grids

Background

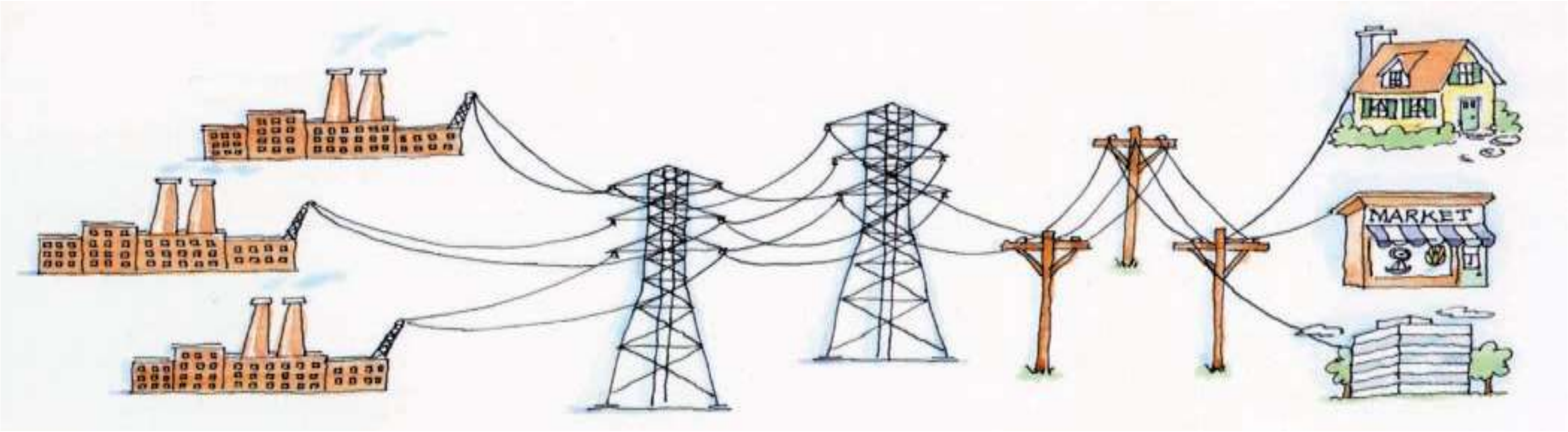
- 1990-2000: National Grid, UK
- Power System Planning, Generator Connections, Power Quality
- Unbundling & Privatization

- 2001-: ANF Energy Solutions Inc.
- Hydro Controls (to 2008)
- Distributed Generation Grid Connections (from 2006)

2014-: Innovative Hydro Controls Inc.

- DG Controls (Biogas, Hydro)
- Electrical Cabinets

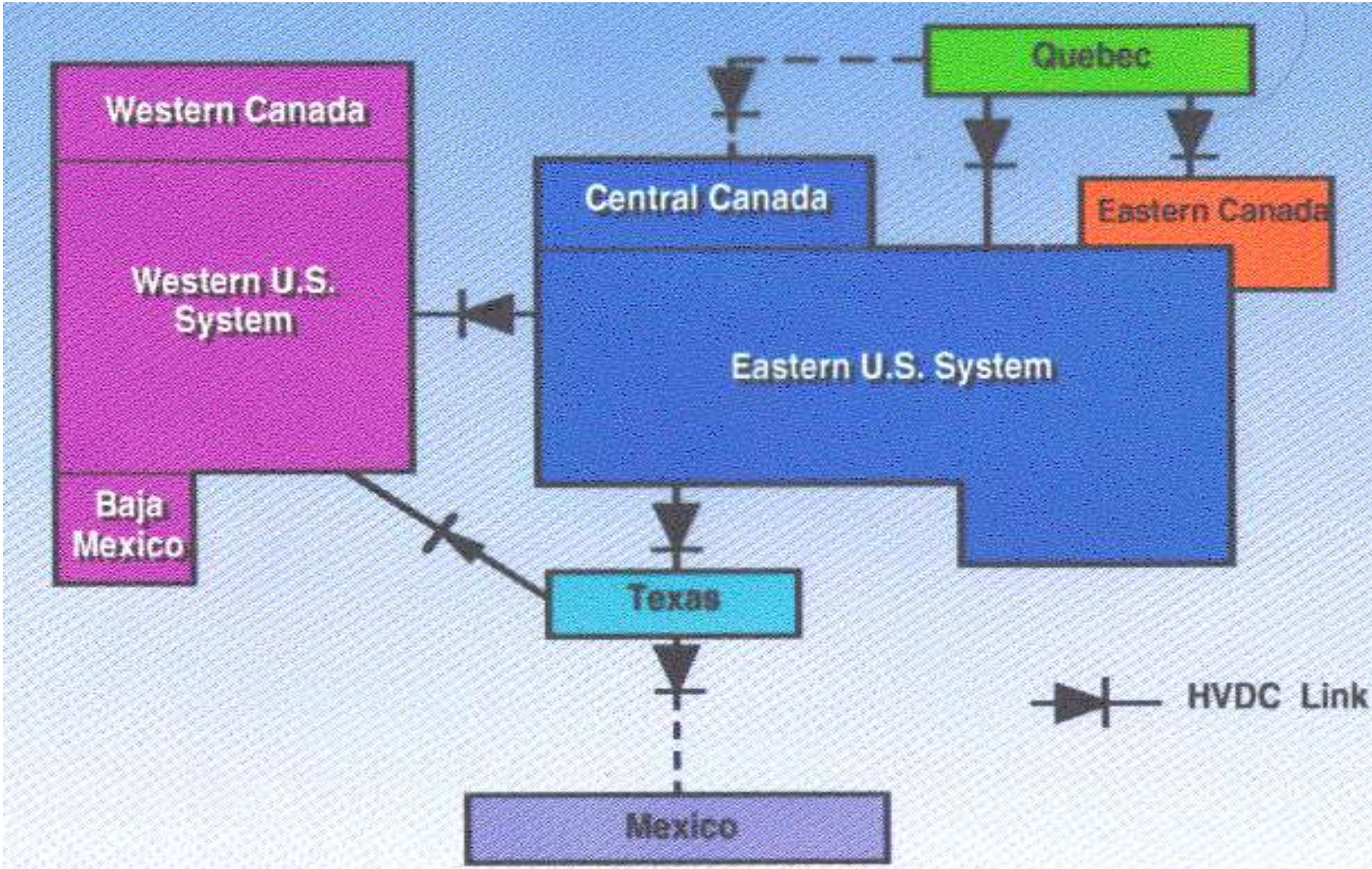
The Central Station Power System



- Historically very successful
- Applied worldwide under different political regimes
- Enormous intellectual investment – highly optimized
- Is currently being challenged

Central Station System Challenges

- Rising costs and debt
- Aging infrastructure
- Unbundling / competition (e.g. Ontario Hydro)
- Fuel availability/self-sufficiency (Peak Oil)
- Environmental / Pollution (Coal)
- New Distributed Generation technologies
    - High efficiency of local CHP
    - Renewables
- New electricity storage technologies



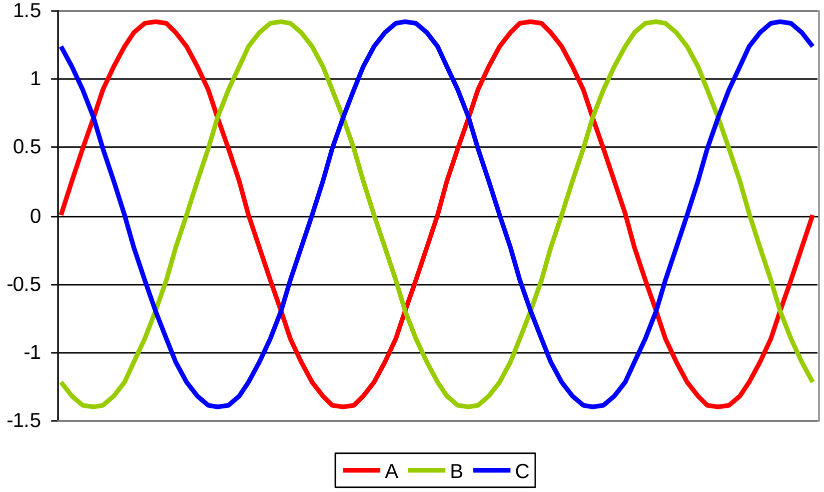
North America AC Power Systems and HVDC Interconnections

Source: HINGORANI

The AC Power System “Machine”

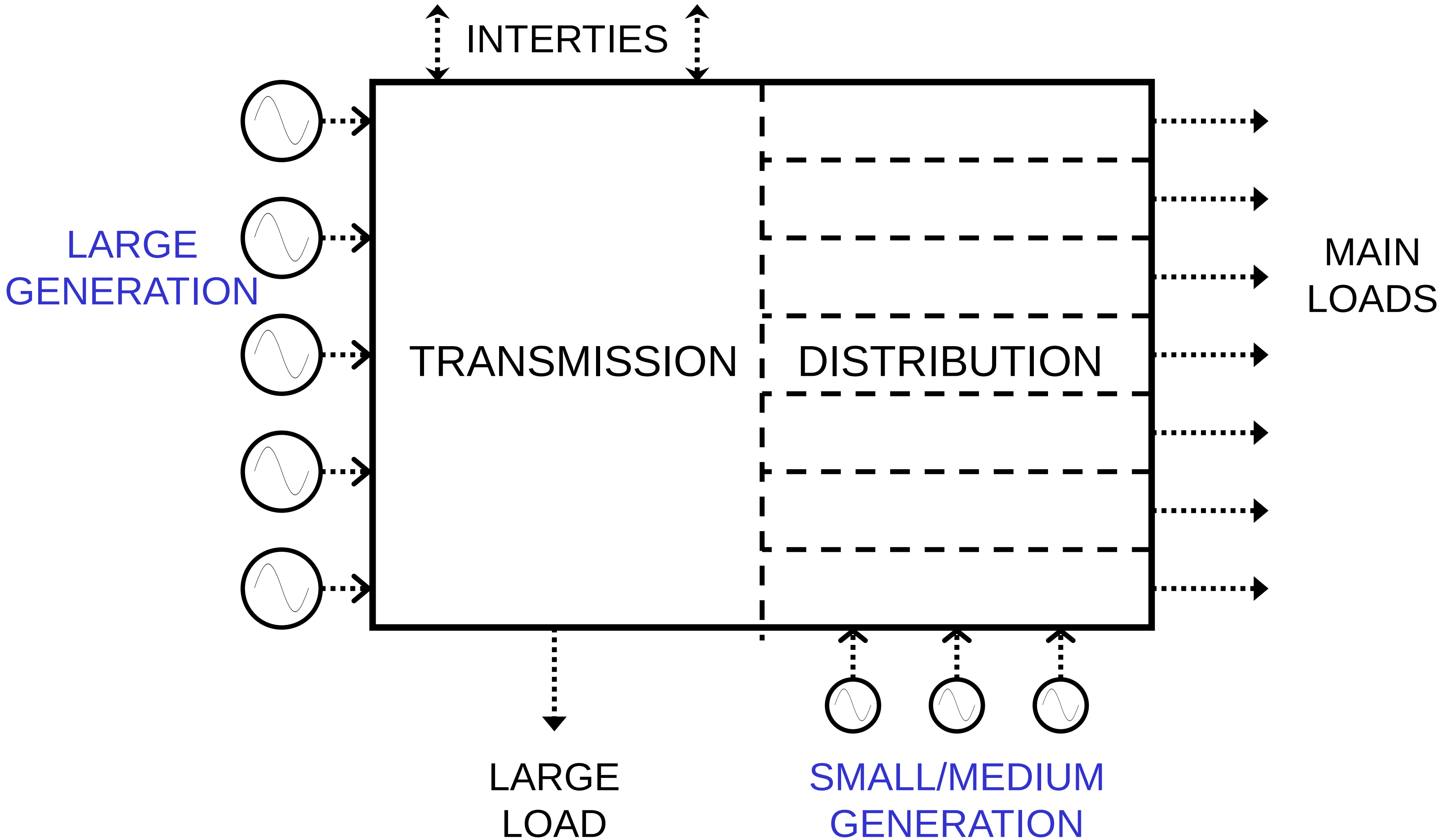
- Electricity produced on demand
- Acts as a single ‘just-in-time’ machine
- DC-links between the five AC components
- Motors and alternators rotating in synchronism within each AC component (e.g. from Ottawa to Florida)

Power System Characteristics



- AC – War of the Currents (1880's) – Edison v Westinghouse
    - Transformer & Alternator wins for AC
- 50/60 Hz – flicker & power transfer
- 3-phase (Tesla) – less wire & losses; uniform machine torque

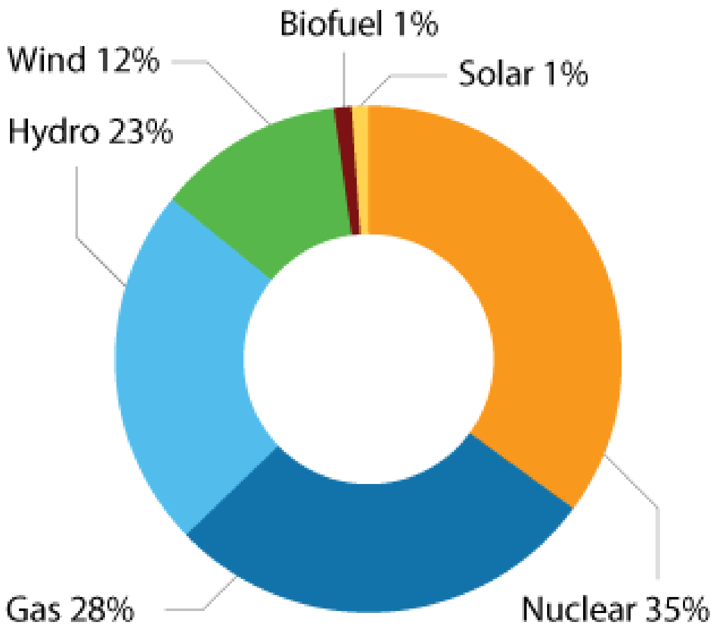
Power System Components



The Power System Backbone

- Large generation and transmission form the backbone of the central station power system:
  - Bulk generation & power transfer
  - Regulates system frequency and network voltage
  - Maintains grid synchronism
  - Centrally controlled
  - Contains redundancy (generation & transmission)

Ontario's Backbone - Generation

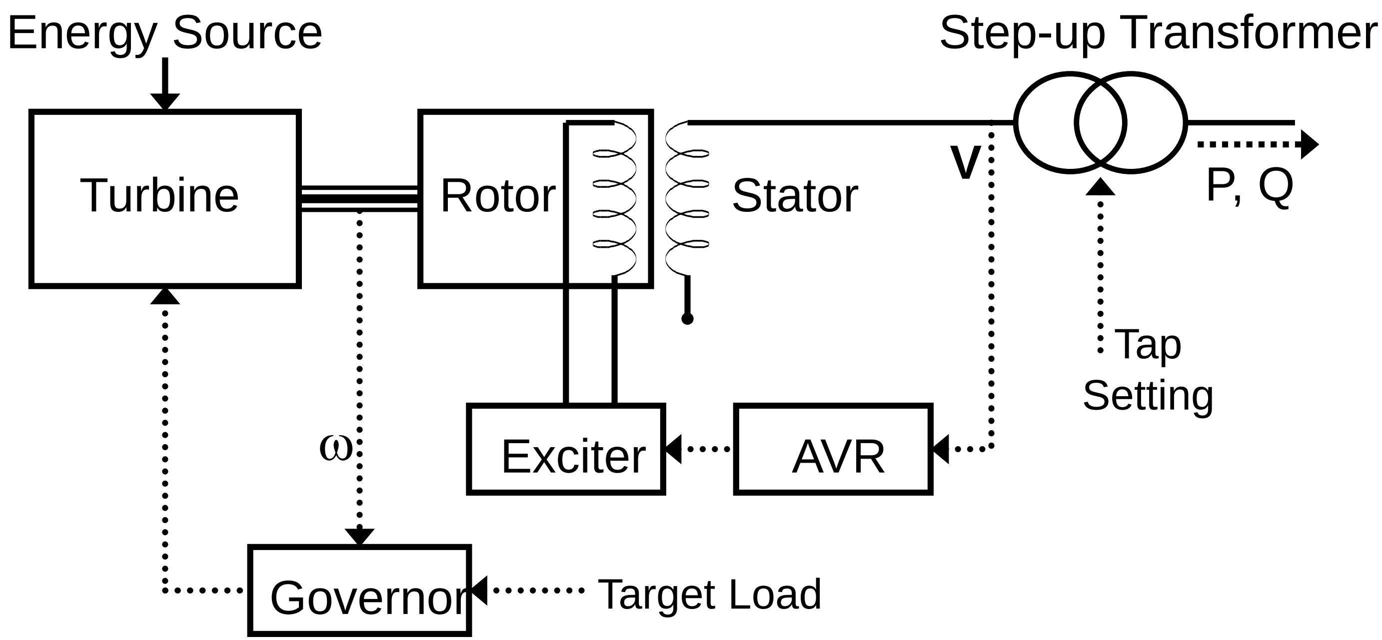


Nuclear	13,009 MW or 35%
Gas/Oil	10,277 MW or 28%
Hydro	8,472 MW or 23%
Wind	4,412 MW or 12%
Biofuel	495 MW or 1%
Solar	380 MW or 1%

Source: IESO 2018

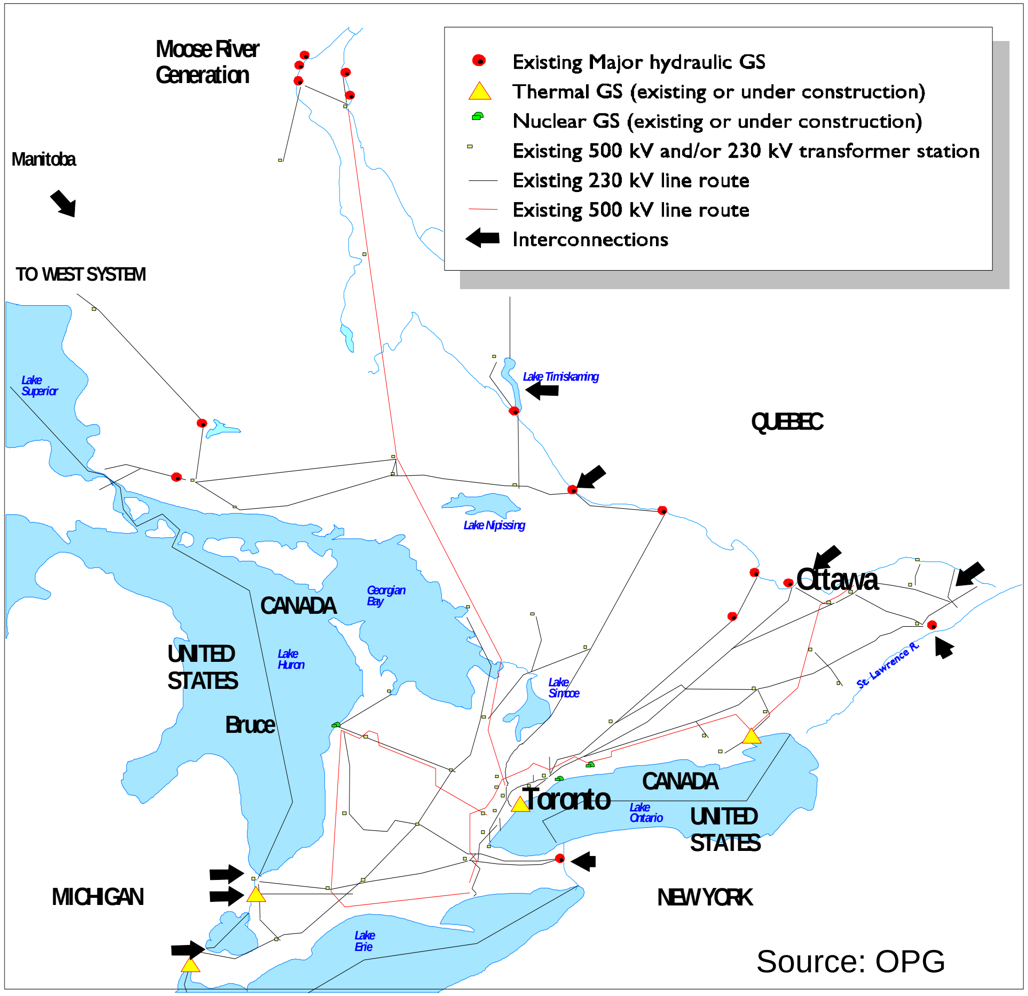
- Traditionally by large synchronous machines
- Wind penetration limits in several countries

Central Station Generator



- Energy source turns a rotor shaft – rotor is electro-magnet
- Spinning electro-magnet induces AC electricity in stator
- Governor controls energy source (e.g. fuel valve) – speed is locked
- AVR/exciter controls rotor magnetism and hence voltage

Ontario's Backbone - Transmission



- 115kV 10,109 km
- 230kV 13,650 km
- 500kV 3,762 km

Transmission & Distribution

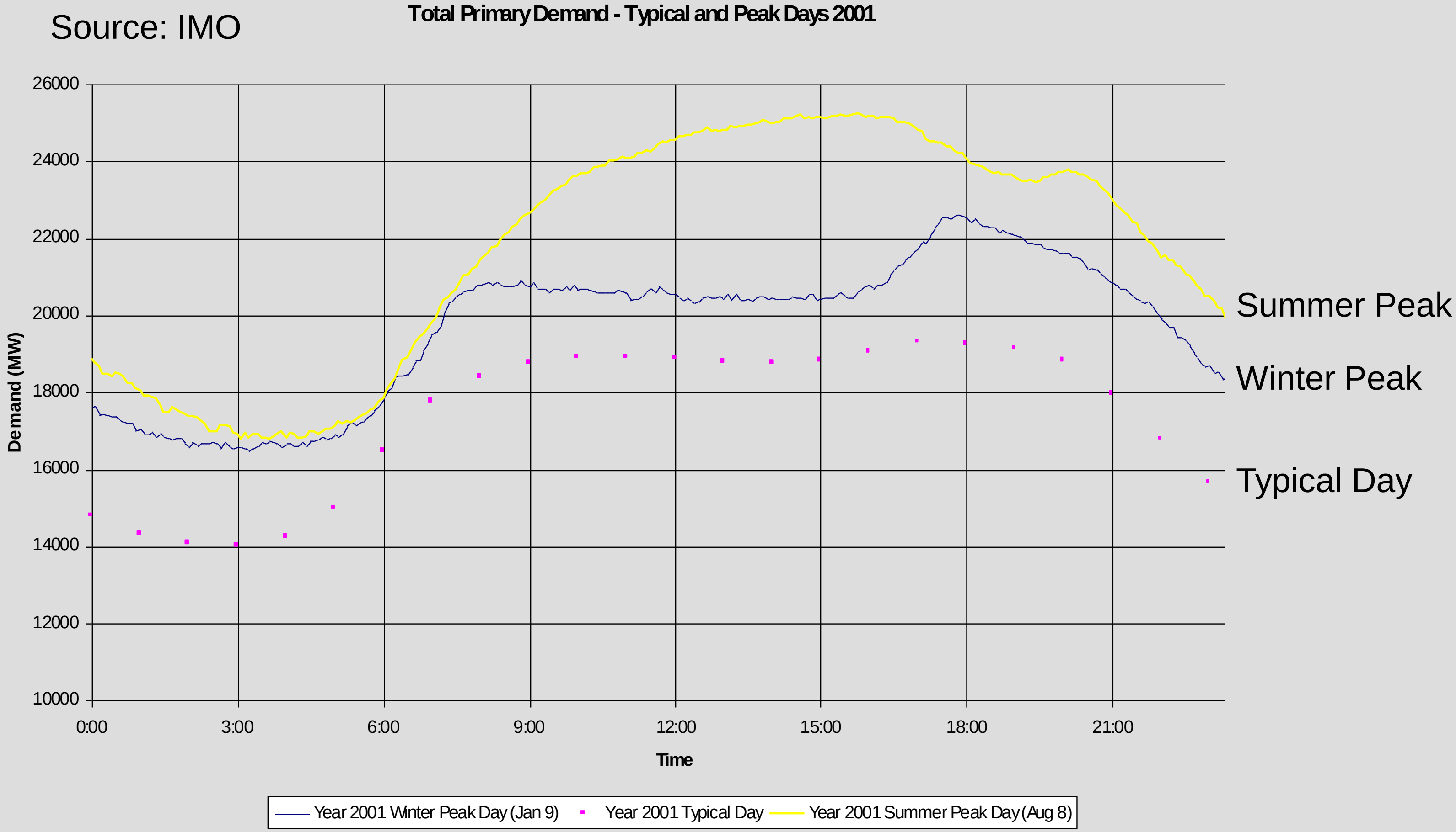
Transmission	Distribution
>100kV, 3-wire	44kV, 3-wire <30kV, 2-wire & 4-wire
Bulk long-distance transfer of power	Local transport of power
High voltage to reduce losses	Reducing voltage as load approached
Connects large generators and consumers	Provides point of connection for most consumers
Requirement for redundancy	Some redundancy, but at greater cost

Loads (Consumers)

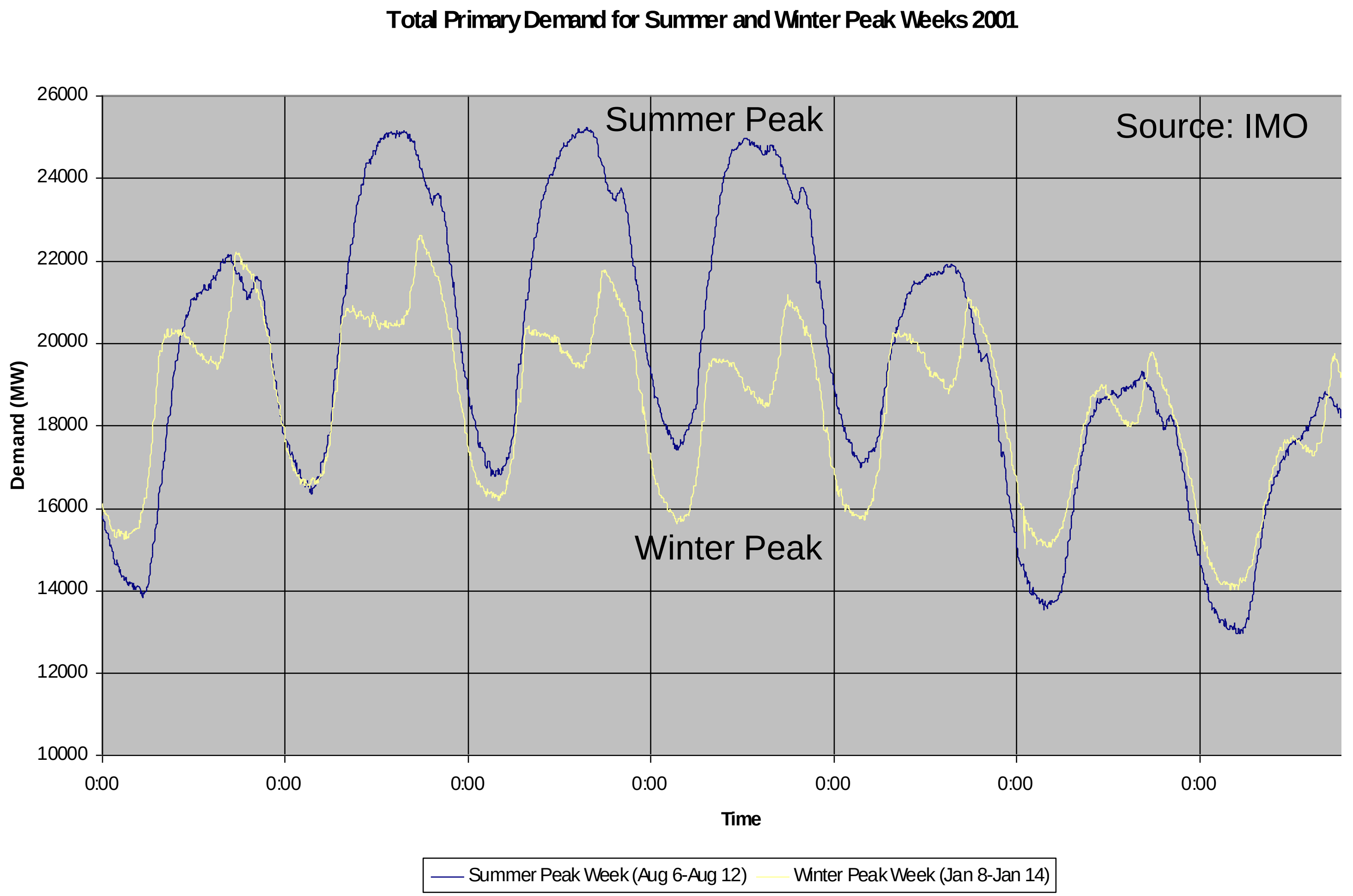
- The reason for the power system
- Vary from fraction of a Watt to Megawatts
- Three-phase or single-phase
- Can distort and reduce voltage
- Vary by time of day, time of week, time of year

Ontario Load Profile (2001)

Source: IMO



Ontario Load Profile (2001)



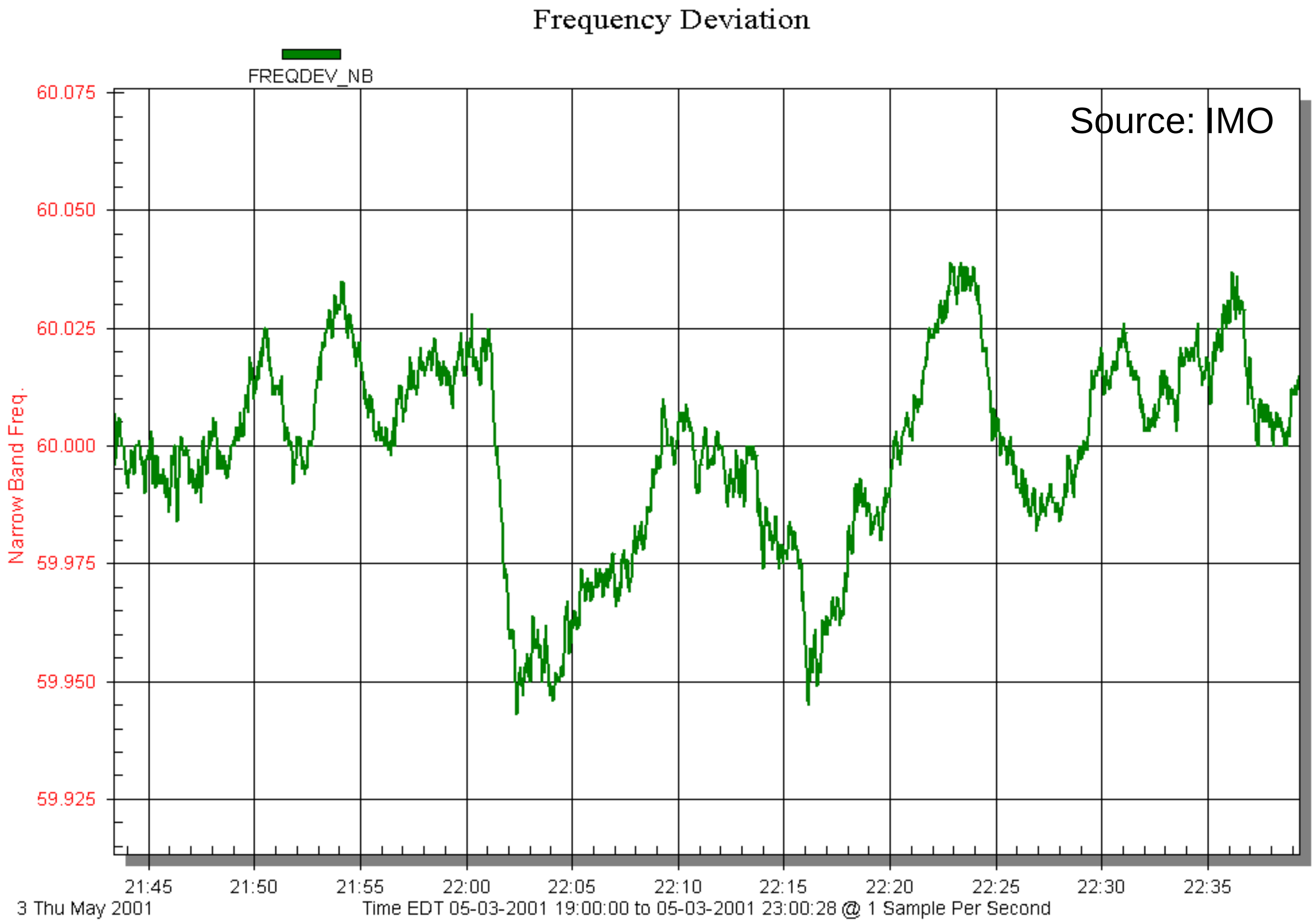
Revenue Meters

- Enabled electricity to be traded as a commodity instead of as a service (e.g. purchase kWh instead of say lighting)
- Allowed the AC "machine" to grow with multiple owners and operators

Many Other Power System Devices

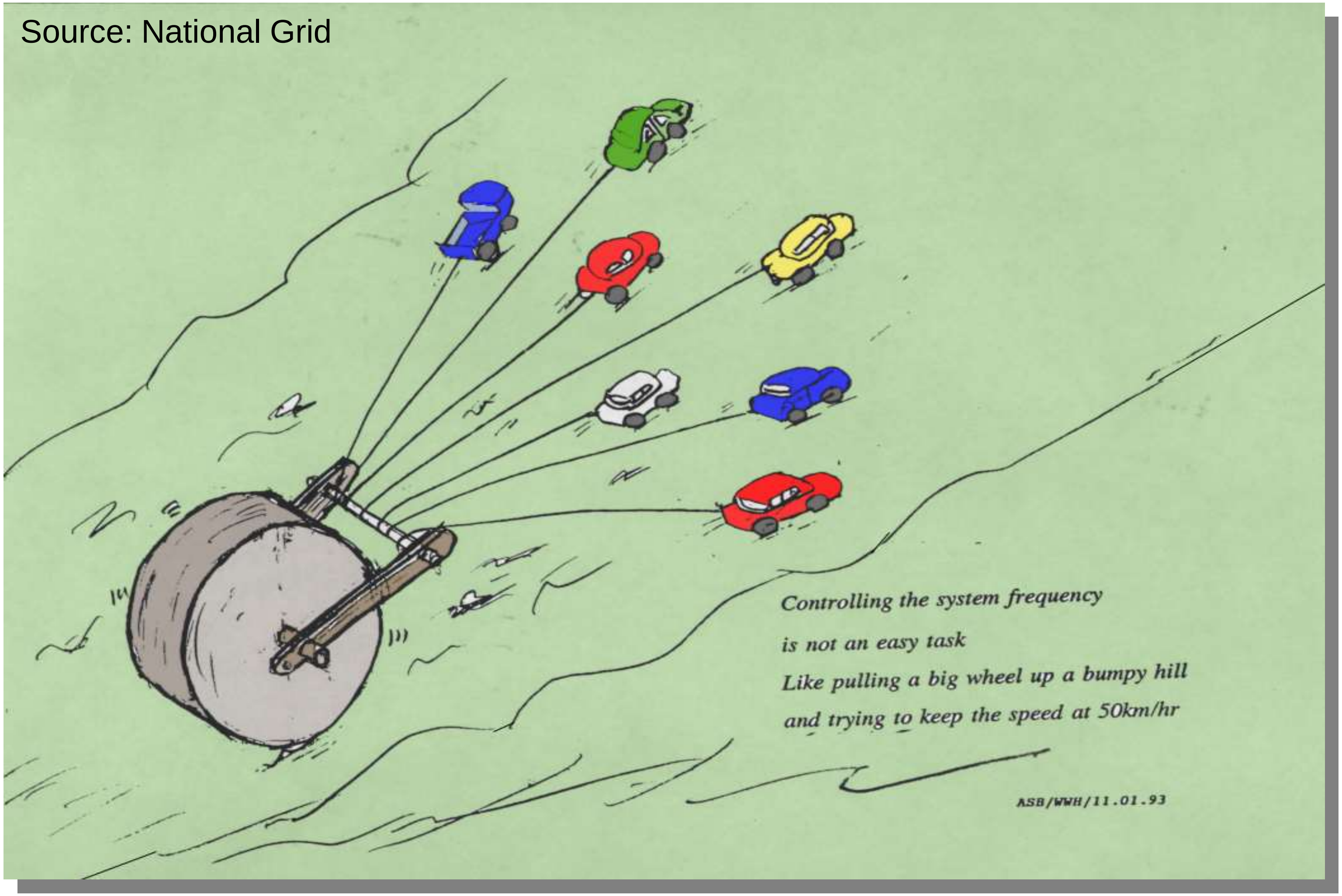
- Transformers: inter-bus & instrumentation
- Protection & circuit breakers: for short-circuit faults
- Disconnectors and isolators: non-fault operation
- Surge protectors: lightning protection
- Voltage control devices: e.g. capacitors, reactors
- Power flow control devices
- Power electronics (FACTS) & HVDC

Frequency Management (Ontario)



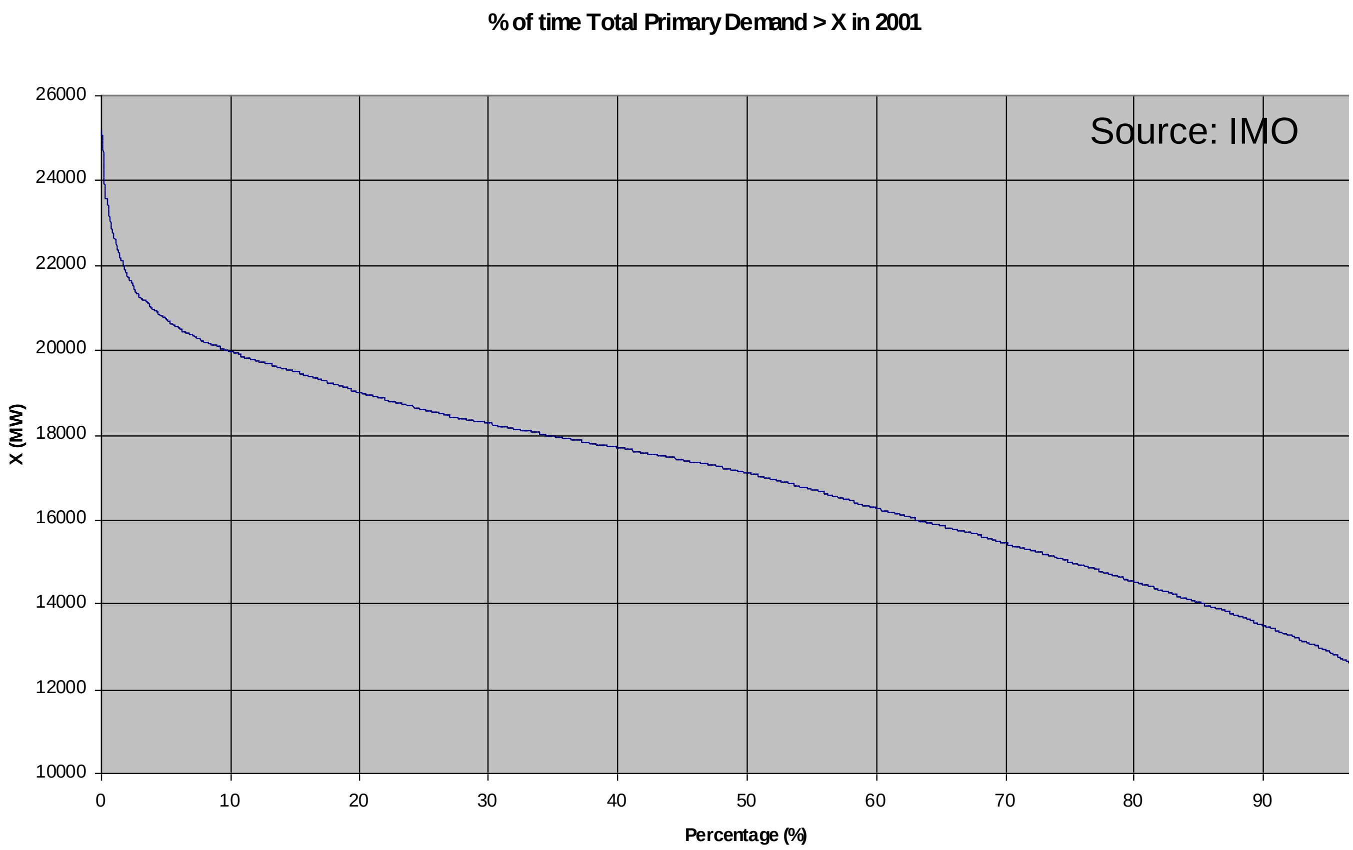
Frequency Management

- Frequency comes from the rotational speed of the rotors
- Electrical power mismatch
  - $\Rightarrow$ acceleration/deceleration of rotors
  - $\Rightarrow$ increasing/decreasing system frequency
- Frequency management $\Rightarrow$ Power matching
- Response to forecast load changes: Dispatch
- Response to generation loss: Contingency Reserve
- Automatic generator adjustment: Droop
- The larger the AC-grid $\Rightarrow$ More Inertia $\Rightarrow$More stable



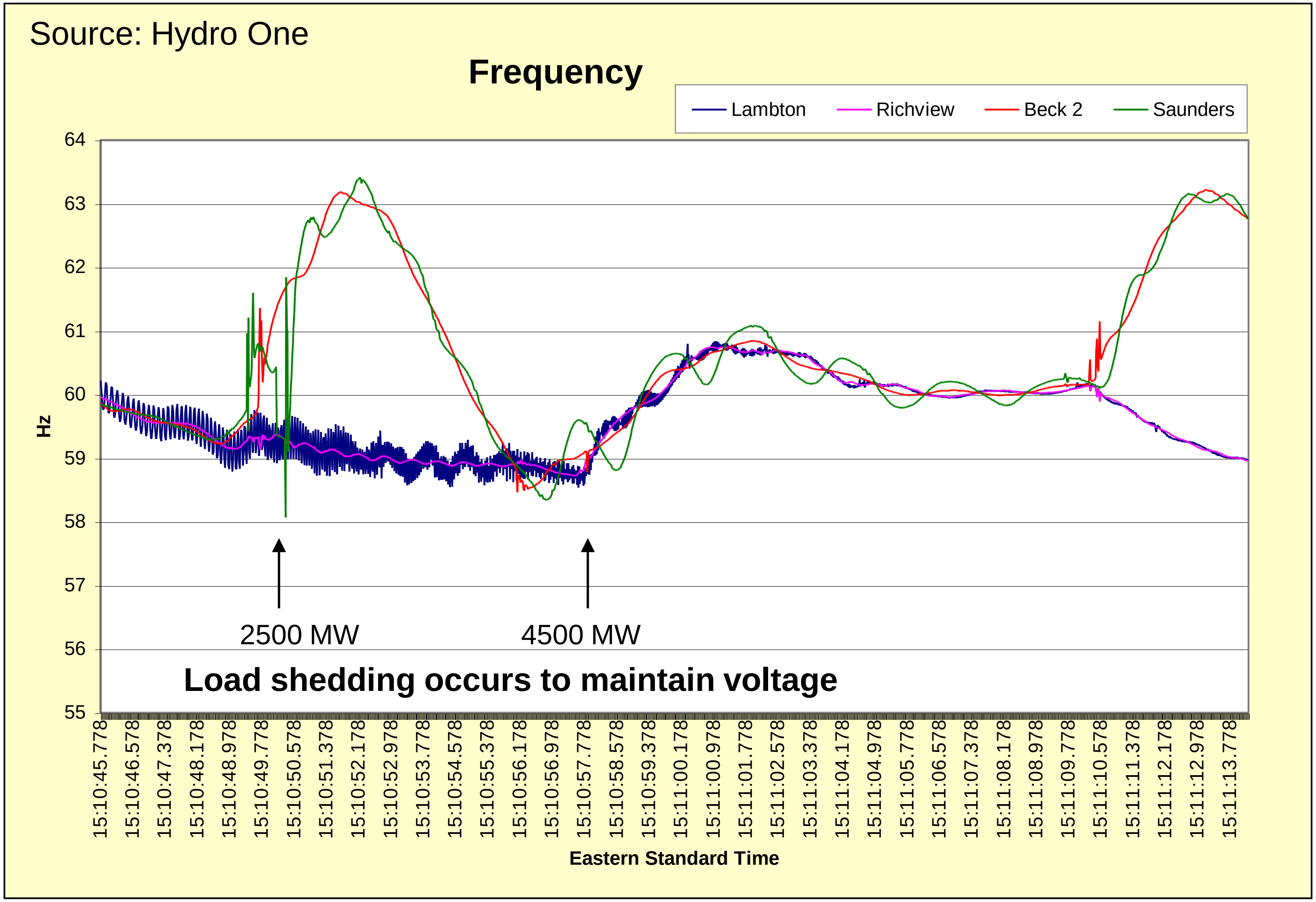
- Slope varies: load change
- Boulders in the path: TV pick-ups
- Vehicle may break down – others must have reserve, with more on standby
- Some only pull when sun shines or the wind blows

Load Duration Curve (Ontario 2001)

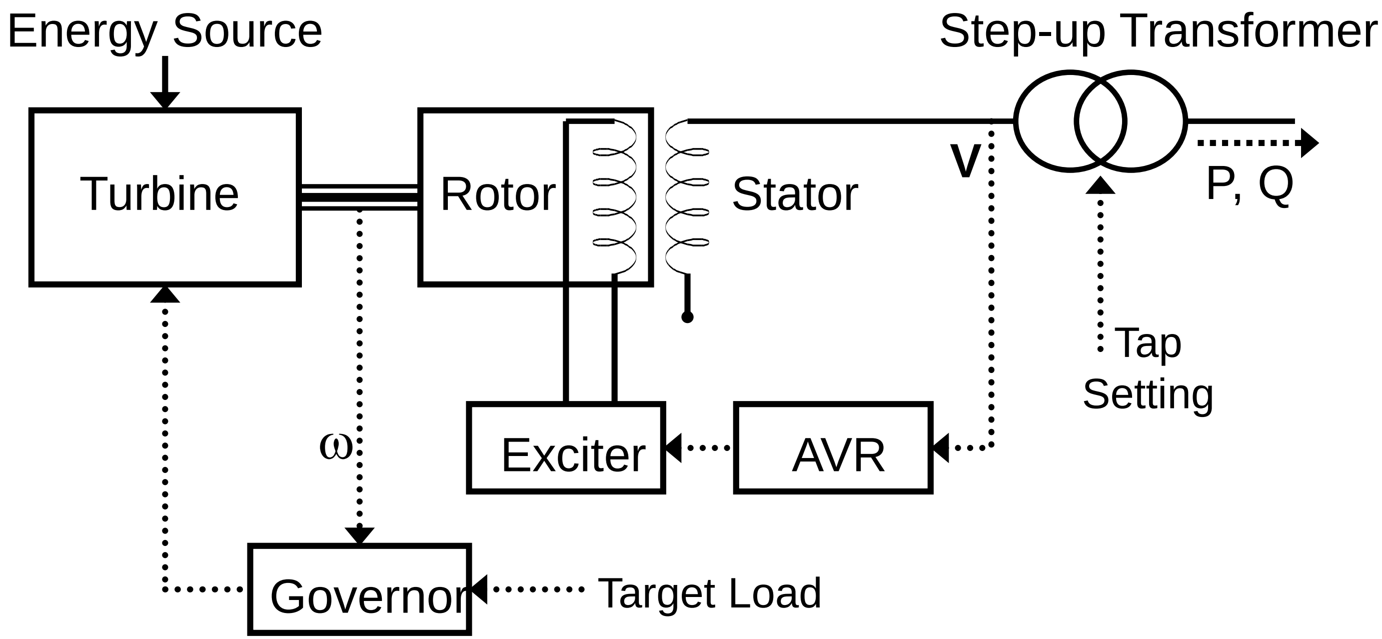


- Solar/wind do not provide firm capacity to meet peak

Generator Frequency :14 August 2003



Voltage Management



- Large generators are the main devices for controlling voltage
- Increasing generator rotor excitation (magnetism) increases voltage (locally)
- Excitation must respond fast to support voltage during a fault
- Machine inertia provides fault ride-through

Distributed Generators - Biogas

Distributed Generators - Hydro

Distributed Generators

Rotating	Electronic
Synchronous •Creates its own voltage •Off-grid or synchronize to grid	Inverter – Off-grid (Hybrid) •Creates its own voltage •Requires battery
Induction •Follows grid voltage •Can self-excite	Inverter – Grid-tied •Follows grid voltage
Have inertia	No inertia

Frequency Management Comparison

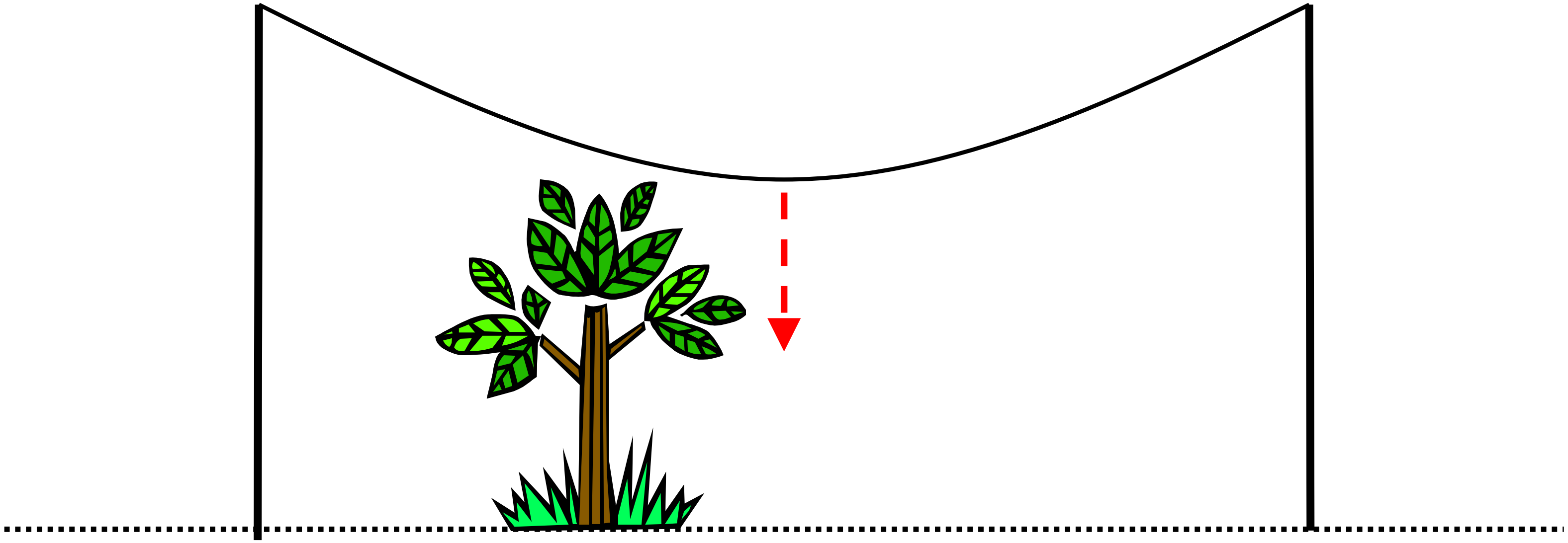
Central Station Generator	Distributed Generator
Source of electrical energy	Source of electrical energy
Firm capacity	May be Intermittent (wind, solar)
Store of kinetic energy & provides inertia (rotating)	May not store kinetic energy & not provide inertia (inverter)
Dispatched to match load	Self-dispatching
Frequency droop control	May not have droop
May be part loaded or on standby for reserve	May not hold reserve
Supports grid frequency	**Assumes grid frequency**

Voltage Management Comparison

Central Station Generator	Distributed Generator
AVR operates in Voltage Regulation mode	AVR operates in Power Factor Mode
Excitation responds fast to short-circuit faults	Excitation has limited response None from Induction Generators
Attenuates voltage drop during faults	Tripped off during faults (treated as negative load)
Visible to system operator	Invisible to system operator
Deterministic contingency analysis	Stochastic contingency analysis
Supports grid voltage	**Assumes grid voltage**

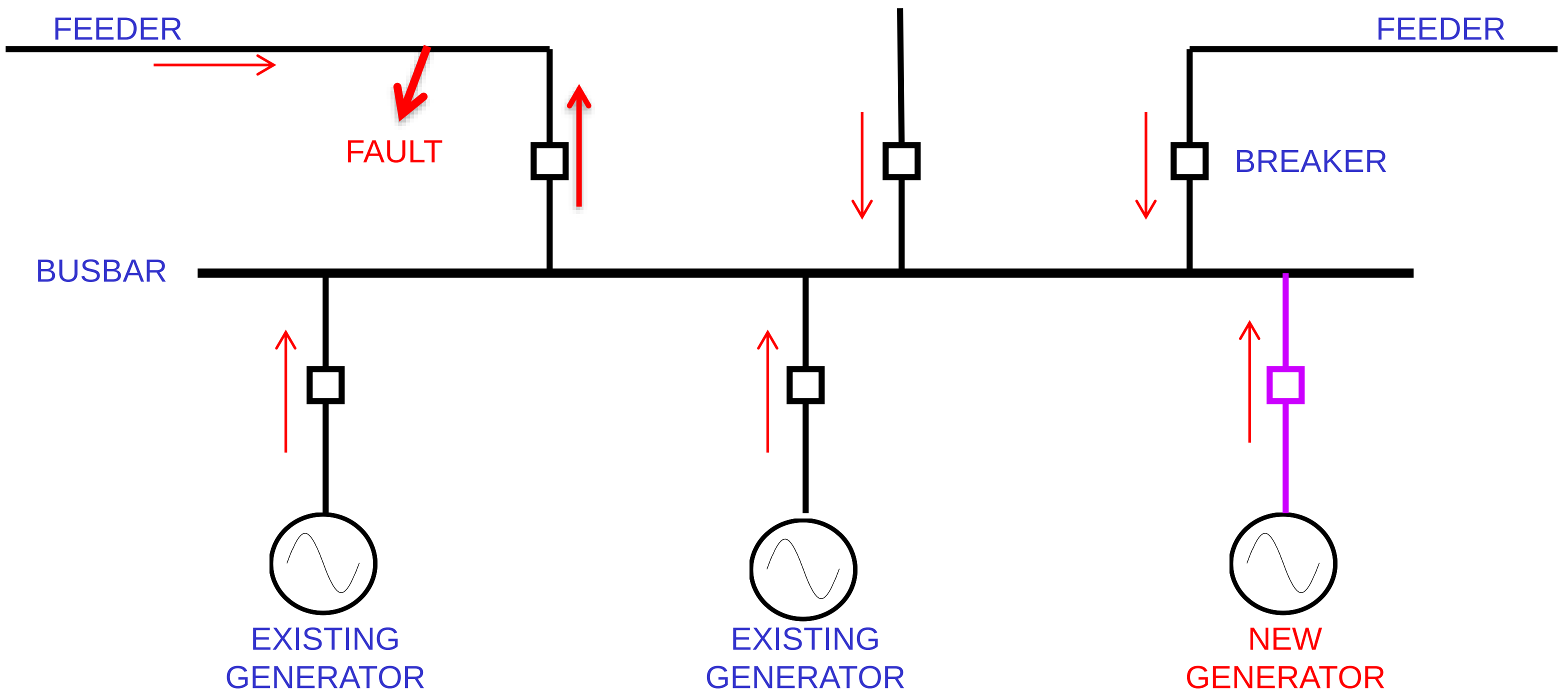
DG Connection - Thermal Constraints

- Overheating from excess current (e.g. transformers, cables)
- Applies to FIT, Net Metering and even load displacement
- Reduced clearances (sag) from thermal expansion



DG Connection – Short Circuit Constraint

- Circuit breakers can only interrupt so much current
- New generator adds fault current, especially rotating
- Applies to FIT, Net Metering & Load Displacement
- Additional constraint: Voltage-distance rule



Deep v Shallow Entry

- Deep Entry: Proponents pay for their connection and all reinforcements in the Distribution & Transmission Network
- Shallow Entry: Proponents pay for their local connection only. Reinforcements within the Distribution & Transmission Network are socialized across the customer base
- Deep Entry produces anomalies:
  - Can get cheap connection for large generator, and expensive connection for small generator on the same feeder
  - Lack of transparency as to which project (generation & distribution) is triggering the reinforcement
- Most Distributed Generation regimes adopt Shallow Entry

Shallow Entry – Ontario

- Fall 2006: OPA Launch of Renewable Energy Standard Offer Program (RESOP) with Deep Entry
- May 2008: OPA suspends RESOP
- May 2009: Passing of Green Energy Act
- September 2009: Launch of FIT & micro-FIT Programs
- October 2009: Distribution Code Amendment EB-2009-0077 – Shallow Entry replacing Deep Entry
- Includes transfer-trip and SCADA
- Utilities creative to avoid costs
  - Passive anti-islanding instead of transfer-trip
  - Categorizing costs as Transmission (transfer-trip and SCADA)

Introduction to MicroGrids

- Capable of operating not connected to the "Main Interconnected Power System"
- Come in a range of sizes
- Can be "isolated", "grid-connected" or connected to other MicroGrids
- Must be able to control their own frequency and voltage
- May need excess generation or load banks for power matching
- Requires at least one voltage source generator
- Not required to have redundancy (c.f. transmission)
- May require a Distribution License
- Can offer robustness by disconnecting during system disturbances