

Challenges in Cyber-Controlled Smart Grid

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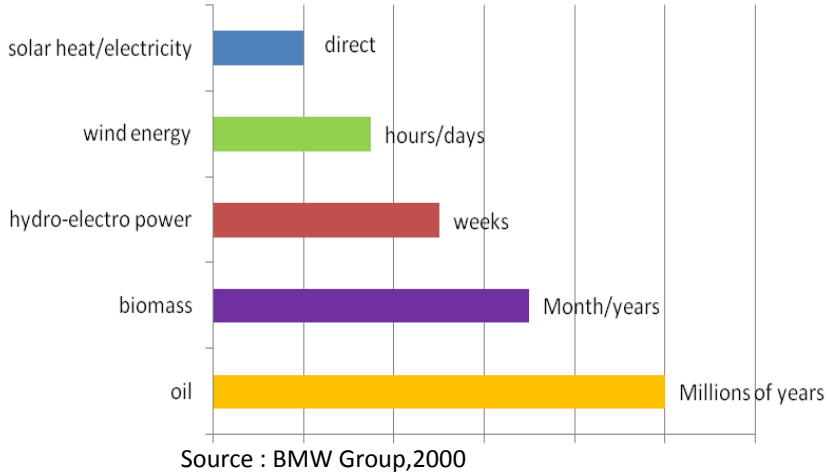
Overview

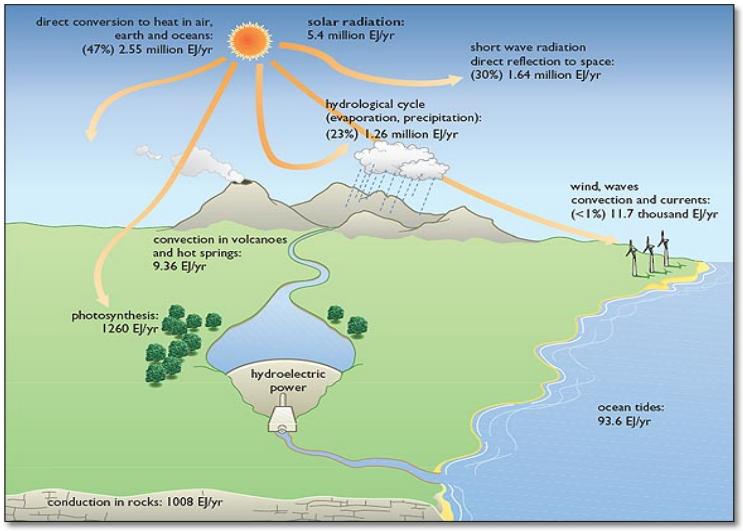
- Energy technologies have a central role in social and economic developments at all scales.
- Energy is closely linked to environmental pollution, degradation to economic development, and quality of living.
- We are dependent on nonrenewable fossil fuels that have been and will continue to be major cause of pollution and climatic change.
- Petroleum supplies are dwindling.
- Finding sustainable alternatives is an urgent concern.
- *GOALS:*
  - To develop technology for integration, control of renewable energy sources, control of energy consumption and load management.
  - To empower energy user for a sustainable living and to develop Distributed Generation system where energy user is also an energy producer.

Sustainable Energy Technology

Primary Energy: All we use comes from the sun. 7000 times current global energy use.



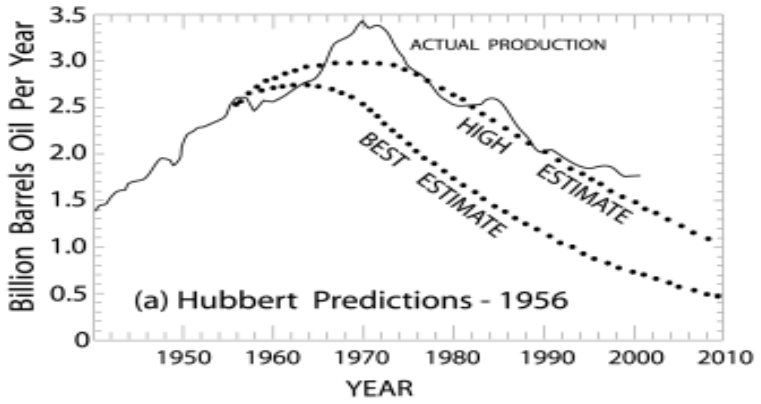
Source : BMW Group,2000



Key to Sustainability:

Utilize primary energy resource at the same rate at which it is naturally replenished on earth and without externalities.

In the long run, an economy that utilizes petroleum as a primary energy source is not sustainable, because the amount of oil in the Earth's crust is finite.



What If…..cover earth with solar cells

Solar energy potentials assuming that 10% of unused land area can be covered by solar cells

Region	A (Gha)	min R (W/m2)	max R (W/m2)	min f	max f	min P (TWh/y)	max P (TWh/y)	min P (EJ/y)	max P (EJ/y)
North America	0.5941	220	450	0.44	0.88	503778	2060909	1814	7419
Latin America and Caribbean	0.2567	290	460	0.48	0.91	313018	941302	1127	3389
Sub-Saharan Africa	0.6925	310	480	0.55	0.91	1034304	2649760	3723	9539
Middle East and North Africa	0.8209	290	470	0.55	0.91	1146978	3075627	4129	11072
Western Europe	0.0864	210	420	0.44	0.81	69934	257485	252	927
Cantral and Eastern Europe	0.0142	230	430	0.44	0.81	12588	43326	45	156
Former Soviet Union	0.7987	180	430	0.44	0.81	554132	2436920	1995	8773
Pacific OECD	0.1716	280	460	0.48	0.91	202032	629246	727	2265
Other Pacific Asia	0.0739	320	480	0.55	0.89	113936	276554	410	996
Centrally planned Asia and China	0.3206	260	450	0.44	0.91	321287	1150063	1157	4140
South Asia	0.1038	270	450	0.44	0.91	108023	372353	389	1340
World	**3.9334**	**260**	**453**	**0.48**	**0.88**	**4275749**	**13699140**	**15393**	**49317**

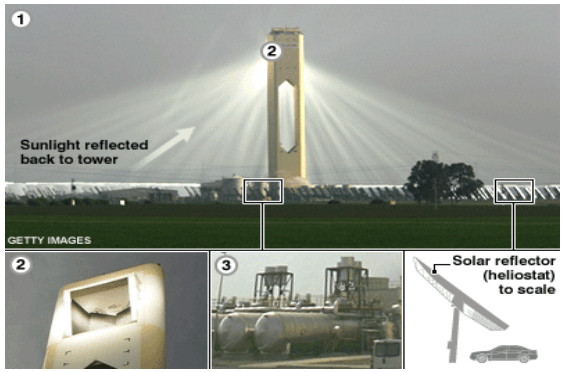
Nielsen, R. 2005, 'How Much Solar Energy Can We Harvest?', http://home.iprimus.com.au/nielsens/.

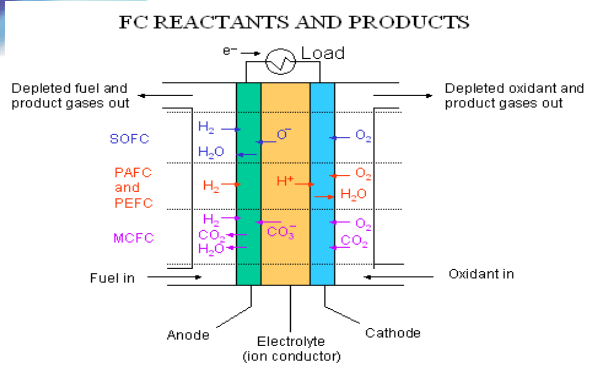
A — Total surface area of the currently unused land in billion hectares (Gha).
R — Annual clear sky solar irradiance (the intensity of solar radiation in watts per square metre (W/m2)).
f — Annual fraction of time when the sky is clear.
P — Solar energy potential (the energy delivered by the Sun to the 10% of the currently unused land) expressed either in in trillion watt-hours per year (TWh/y) or in exajoules per year (EJ/y).

-- 1% of earth unused surface is sufficient for 4 times the required global energy.

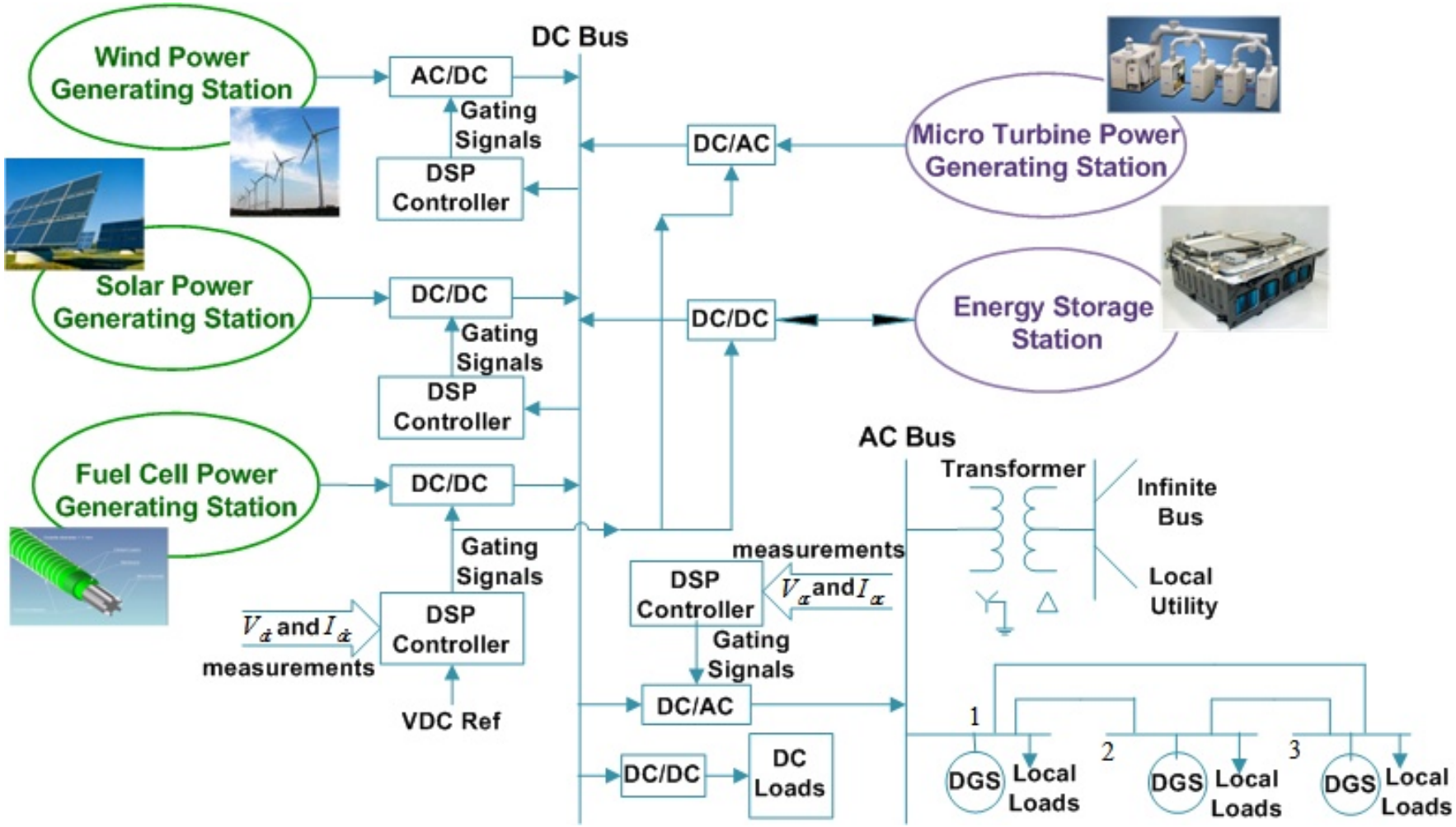
Dyson Sphere!!! 1959 Journal of Science

Sustainable Energy Technology





Smart Grid Distributed Generation System (DGS)

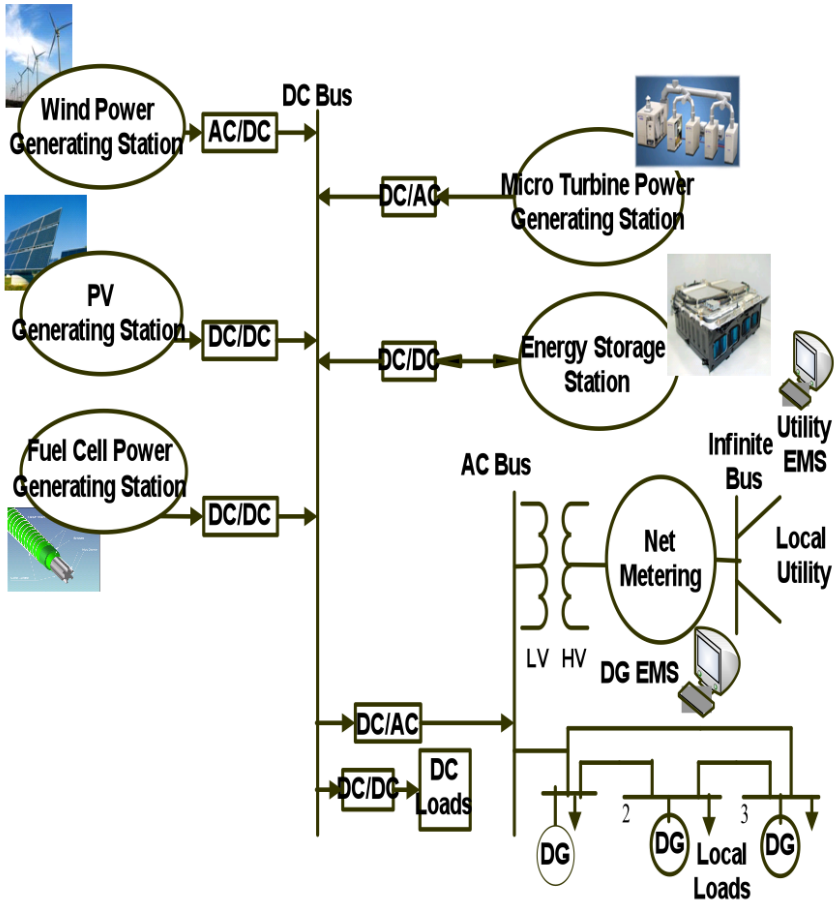


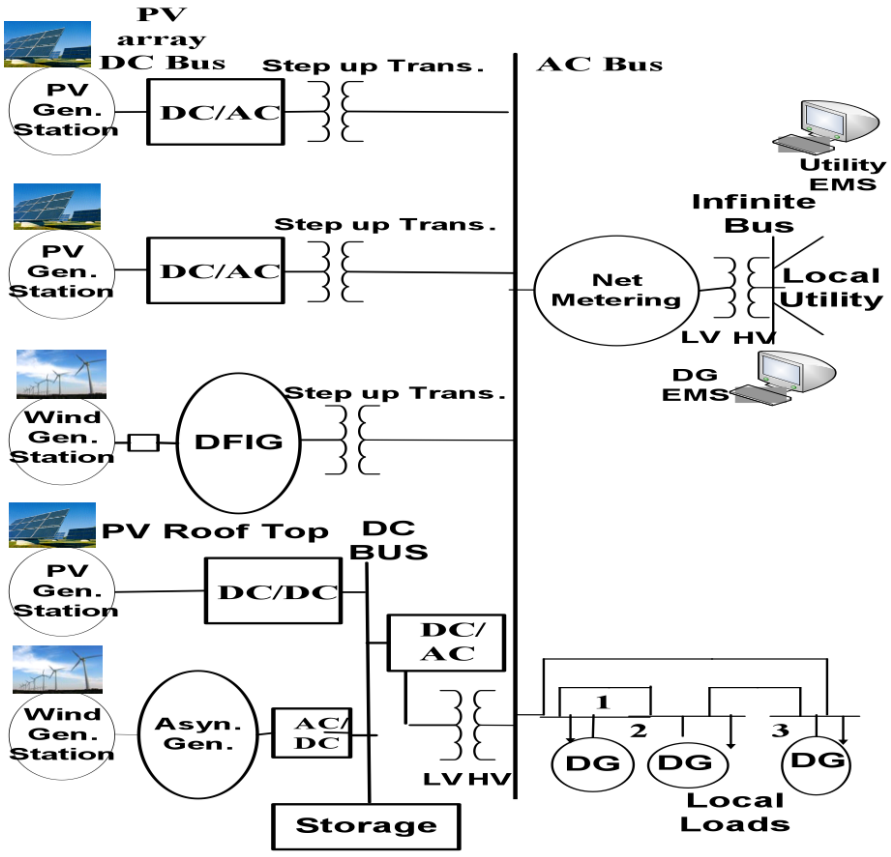
Smart Grid: Power Grid + Local Generation + Cyber (Internet) + Intelligent Fault-Tolerant Distributed Control + Real-Time Pricing

Monitoring and Anomaly Detection

- Extensive sensor deployment (voltage, current, power, temperature, pressure, wind, etc.)
- Intelligent autonomous messaging between components to enable adaptive and efficient ahead-of-time response
- Detection of anomalies, stress/failure conditions, and intrusion attacks
- Real-time observer based on dynamic models of expected feasible behavior of the interconnected smart grid
- Detection of deviations from expected behavior

Distributed Generation System Architecture

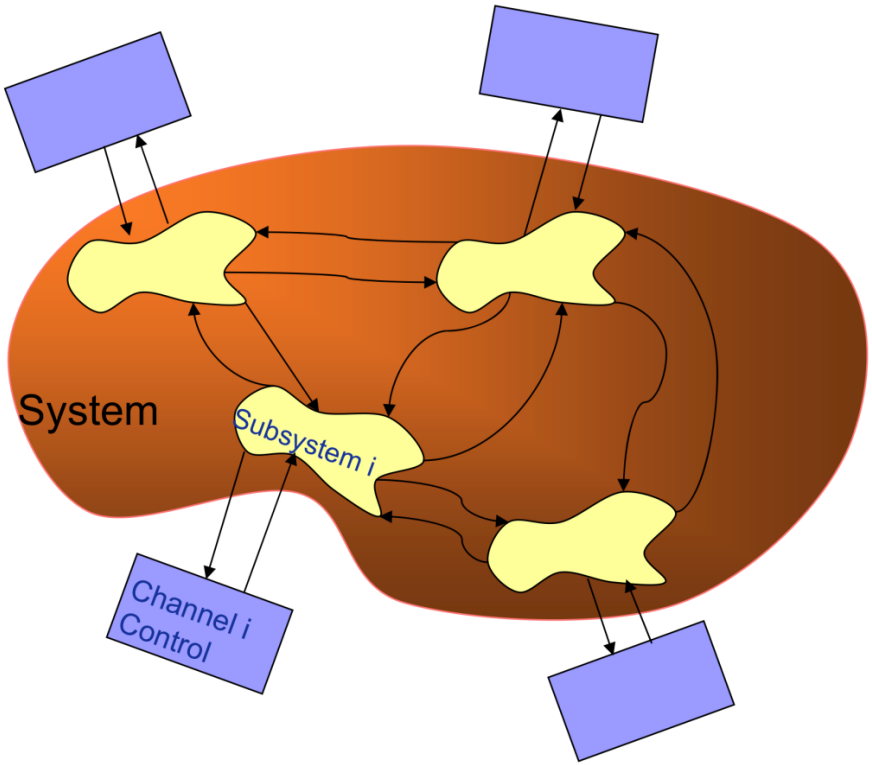




Control Design

- Power quality optimization … mix of multiple objectives
- Real-time decentralized and cooperative control schemes … synchronization over wide geographical areas through large number of geo-referenced phasor measurement units
- FACTS (Flexible AC Transmission System) devices for implementation of smart switching controllers
- Control loops at multiple levels
  - microgrid, local, regional, national
  - distributed generation units and PHEVs (Plug-in Hybrid Electric Vehicle)
  - complex multi-agent system
- Real-time metering for peak leveling … economics of real-time pricing closely linked to control and switching strategies

Large-Scale Systems and Distributed Control



- Grid integration, interaction, and scheduling
- Decentralized disturbance attenuation
- Reduction of total harmonic distortion
- Switching between island and connected modes
- Failure/anomaly detection and fail-safe algorithms
- Voltage-frequency control

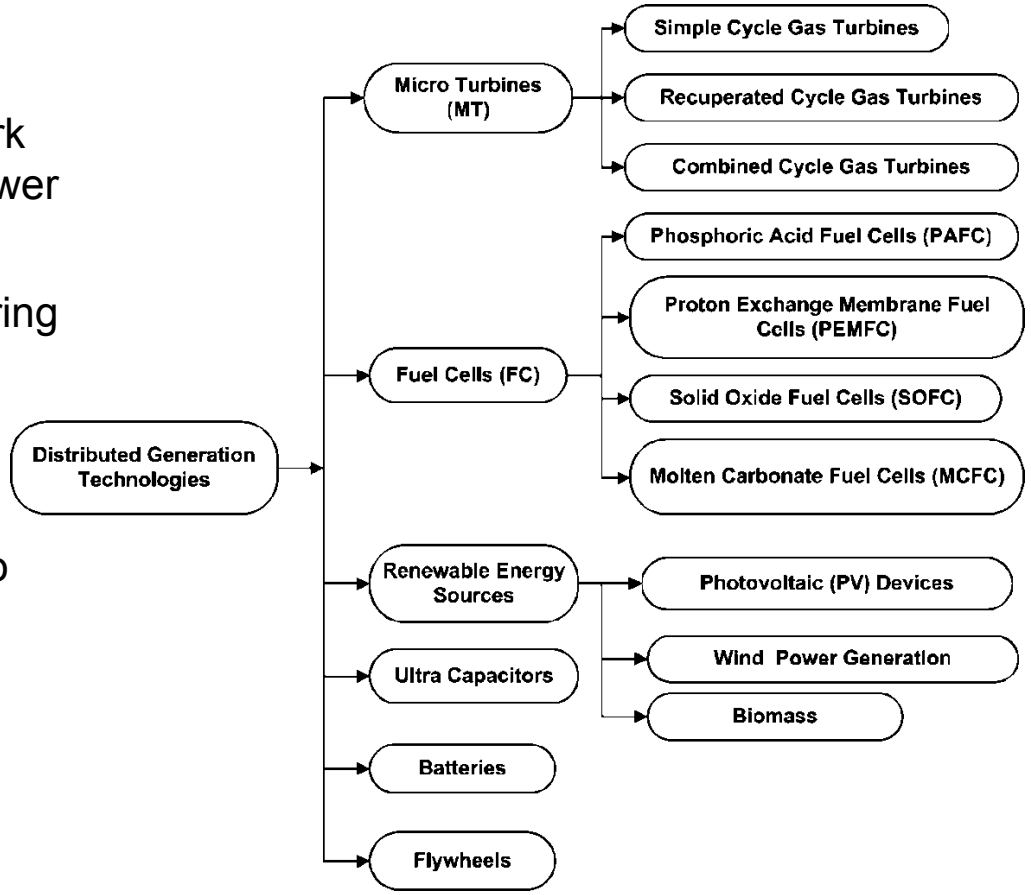
Intermittent Power Sources

- Various green energy sources such as solar and wind power are time-varying
  - Stochastic models for intermittent energy sources over different time scales
  - Adaptive forecasting of energy generation profiles extrapolated from time history of sensor data
  - Anticipatory smart switching control algorithms for efficient load matching

- Storage devices for asynchronous matching of the load dispatching with the power generation

Benefits of Distributed Generation Systems

- Installation near to the local loads.
- Power losses of distribution network can be reduced by reducing the power flow in the transmission lines.
- On-site standby power systems during grid outages
- Peak load shaving
- Modular structure makes system expansion easy, e.g., fuel cell-micro turbine or micro turbine-battery systems.
- Combined heat and power (CHP) applications.



Key Research Areas

- Smart Grid Architecture
- Cyber Security
- Modeling and Control
- Smart Metering and Pricing

Challenges

- Highly variable supply patterns … stochastic problem
- Efficient distributed algorithms required to process massive amounts of data for real-time control
- Adaptive and self-healing control algorithms required for attaining high efficiency, reliability, and security of the large-scale distributed system
- Secure protocols, firewall mechanisms, intrusion prevention