<u>Paul's Picks for Future SuperGrid Projects</u>

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Shadow Mackenzie Valley Project

Scope: Revisit Schoenung-Hassenzahl-Grant 1997 "Electricity Pipe" EPRI Report in the context of the Mackenzie Valley gas pipeline project.

Objective: Model a large gas pipeline project from the perspective of technologies pertinent to the SuperGrid

Focus:
1. How much NG will be turned into electricity in the lower 48?
2. Economics of producing electricity at the well head and transporting in a dc superconducting "electricity pipe" cooled by LN2.
3. Design of a "pipe" that could convey NG, and eventually H2, either in liquid state or high pressure gas along with electricity, viz., a "SuperCable."
4. Survey "well head" locations in the Mackenzie delta as to suitability for the eventual construction of (underground) "hydricity-generating" nukes when NG is exhausted

Cryo Bipolars

Scope: Examine feasibility and design of silicon bipolar discretes (thyristors, GTOs, IGBTs, etc.) for high current operation at cryogenic temperatures (77 – 120 K).

Objective: Computer model for the design of bipolar FACTS devices operating at low temperature.

Focus: (see 12/03 proposal from Vic Temple)
1. Computer study of configuration and packaging issues for a 40 kVA, 8 kV switch to operate within this temperature range.
2. State and ability of present silicon foundry industry to supply requisite material platforms (e.g., doping, diameter, etc.).

Future Supply/Consumption Balance Between Electricity and Hydrogen

Scope: Perform several scenario-based studies assuming "SuperGrid boundary conditions," viz., carbon-less economy and deployment of non-ecoinvasive generation technologies (nuclear) (note these assumptions rule out any massive efforts at sequestration).

Objective: A report summarizing findings of the tasks outlined in the Scope.

Focus:

1. Re-visit premises of Grant July 2003 Nature article which assumed a complete transition of US surface transportation fleet from petroleum to hydrogen (how fast can this be done and at what cost?).
2. Examine how societal division of hydrogen and electricity use by the industry/commercial/residential sectors, apart from transportation, will evolve as the SG boundary conditions start to apply, recognizing traditional patterns of application.
    a. Chemical energy/power is generally used for elevated temperature space conditioning and industrial processing, also called "heating." Although electricity can be used for these purposes, historically it has proved in most instances to be too expensive an alternative.
    b. Electricity is perhaps the most fungible form of consumable energy ever devised. Most modern uses of energy require a transformation into electricity at end point. It is hard to imagine using hydrogen directly to perform Boolean algebra or run the kitchen microwave. It's not a question of hydrogen vs. electricity, but at what point in the entire energy infrastructure their interconversion should occur.
3. To what extent would a "plug-in" electric/hydrogen vehicle change the equation, especially if the "prime mover/storage unit" were to be tailored for specific living environments (more electricity, shorter range for suburban commuters; more hydrogen, longer range for country dwellers).

Underground Nuclear Power Plants

Scope: Economic and engineering feasibility study an underground HTGCR reactor/generation plant, 300 MWe, 100 MWt, essentially a fleshing out of Wes Myer's "Carlsbad Concept" including hydrogen, carried out in collaboration with INEEL and industry.

Objective: A report summarizing findings of the tasks outlined in the Scope.

Focus:

1. Construction and operation costs above and beyond a similar above-ground facility. Are such costs scalable both up and down in size?
2. Water requirements, both for cooling and as hydrogen feedstock.
3. Inclusion of reprocessing facility in place on on-site burial contained in the Carlsbad Concept.

Opportunities for Deployment of dc Superconducting Cables

Scope: Aggressively ("boots on the ground") search out applications for superconducting dc cables and interties to alleviate cross-RTO bottlenecks and exploit opportunities for merchant transmission. Carry out in collaboration with FERC, RTOs and utilities and appropriate programs within DOE OETD with objective of identifying and proposing a suitable demonstration project.

Objective: Recommendations for deployment of superconducting dc cables to the EPRI constituency and DOE

Focus:

1. Use National Transmission Grid Study as starting point to identify bottlenecks. Then explore in detail exactly which circuits are possible candidates in terms of load, constraint, length and nature of rights-of-way (ideally, 10-15 % constrained, 1000 MVA bidirectional, 20 miles or less, with access to ROW under current transmission line).
2. Shadow New York Empire Connection HVDC Cable Project as it proceeds toward approval and initial construction. Model design and cost of an equivalent "unidirectional" superconducting LVDC cable of similar capacity.
3. Evaluate several possible cable designs, including the following issues:
    a. Monopolar/Coaxial – addressing advantages/disadvantages of each, e.g.:
        i. Maintaining some fraction of power flow during maintenance and service
        ii. ROW required
        iii. Fault handling capability
    b. For given power capacity and known properties of insulating materials at high electric field and low temperature, prospective cost of superconductor wire, what would be the optimum division between voltage and current specification?
4. Issues relating to future adaptation to hydrogen transport/storage.

Survey Current and Future Tunnel Technologies

Scope: Prepare report surveying present advanced tunnel projects underway worldwide as well as those possible in the near future.

Objective: A technology roadmap for tunnel development to accommodate the SuperGrid.

Focus:

1. Technology employed on present and forthcoming large tunnel projects, to include:
    a. Boston's Big Dig
    b. NYC Water Tunnel #3
    c. Large Hadron Collider, CERN
    d. Maglev project in Japan
    e. Next Linear Collider (project approved, site yet to be choosen)
    f. Very Large Hadron Collider, Fermilab

    g. Subway construction projects underway or planned worldwide
2. An historical perspective of tunnels as a long term public investment covering:
    a. Expected lifetime (could be many centuries in seismically stable geological formations, e.g., tunnels under the Alps and throughout Italy; could be shorter for conveyance of fluids such as water).
    b. Future conversion to multiple use, e.g., highways to maglevs, "Fedex" of goods via pneumatic tubes, etc.

Bi-Directional Control of Power Flow on a Point-to-Point Superconducting LVDC Cable Inter-Tie

Scope: Study control problems unique to two-way power flow on high-current capacity point-to-point dc superconducting cables.

Objective: Design criteria for end point inverter/converter station to address the following issues:

Focus:
1. Given known and predicted ac loss parameters of high temperature superconducting wire, what is the level of ac ripple that can be tolerated (this is a multivariate problem involving comparative losses in ac cables, operating temperature, magnetic fields, and wire geometry)?
2. Control of power flow via voltage management rather than current (a major shift from the system control paradigm for HVDC), and the effect this will have on the circuit architecture built using presently available silicon bipolar discretes.
3. Control of energizing and (intentional) de-energizing line.
4. Control of faults, including:
    a. Damping L di/dt voltage spikes
    b. Where to dump large amounts of energy stored in magnetic field under normal operation.

Long-Distance, High Power Capacity, Superconducting LVDC Distribution Bus (The Original SuperGrid Concept)

Scope: Model a superconducting dc bus, either linear or ring in topology (not a grid), with tap-offs for local conversion and distribution on an ac system.

Objective: Practicality Assessment of Concept

Focus:
1. Review the design of the ABB "dc Lite" approach and determine its commercial success, if any.

2. Re-visit the 1993 EPRI report (Lasseter, Alvarado, et al.) on superconducting dc microgrids, especially their conclusions with regard to bus geometries vis-à-vis grid topology.
3. Investigate the suitability of a superconducting bus system for power distribution within the US Navy's "all-electric ship" concept, delivering power from a central nuclear plant with local end-use conditioning for weapons ("kinetic energy" and "passive offense") and electronics.
4. Application to power distribution and condition for large-scale manufacturing plants and buildings.

The Need for Nuclear Power

Scope: To demonstrate the overwhelming advantage nuclear power has to satisfy the "boundary conditions" imposed by the SuperGrid vision. However, whenever all the merits of nuclear power are discussed in the media or on public forums, it invariably contains the phrase, "…but it has perception problems."

Objective: Production of written and visual material designed to enlighten the general public and policymakers (the prototypical "Rotary Club" speech) to the advantages of nuclear power.

Focus:

1. Accidents: The worst possible nuclear power plant accident has likely already happened…Chornobyl (Ukrainian spelling), and is unlikely to happen again. Chornobyl should be put in perspective to the social cost of other industrial processes and accidents, e.g., those that occur ever year throughout the world mining coal for the production of electricity. An excellent starting point is the joint study on the after-effects carried out several years ago by a joint committee of the American and Ukrainian Physical Societies and presented at the 2001 General Meeting of the American Physical Society.
2. Safety: The new HTGCR designs cannot melt down. Probably no other industrial process is as safe as nuclear power. Underground placement would provide protection from intrusion under all circumstances aside from all-out war.
3. Waste: The nuclear fuel cycle as used worldwide today is poorly exploited, especially in the US. An estimate should be made of the radioactive waste left after passing fuel through all possible phases of reprocessing and breeding. Oddly enough, I can't find this exercise anywhere. The reply from the experts, EPRI and otherwise, is "Oh yes, something like that has been done," but can't tell me where to look.
4. Proliferation: Re-visit the IMRSS concept proposed by Chauncey Starr and others to separate on an international scale the refinement of actinide materials used for electric power production from weapons development.

Emerging Liquefied Natural Gas Distribution System Adapted to Liquid Hydrogen

Scope: North America is currently consuming its natural gas reserves faster than new ones are being discovered. On the other hand, plentiful proven gas reserves exist worldwide. FERC has predicted that the United States will rapidly become dependent on imports from abroad in the form of liquefied natural gas shipped aboard large specialized tankers already used to supply Europe and Japan, and has recommended the construction of 37 new ports (5 now exist) distributed along America's coastlines. Such ports will undoubtedly require LNG pipelines (NB…LNG has two meanings within the gas industry…"liquid natural gas" such as butane and propane which are found in small amounts in natural gas wells that become liquids under moderate pressure, and "liquefied natural gas" which is cryogenic methane stored at 112 K. Herein we will mean the latter.) between the ships and on-shore storage and gasification facilities. With appropriate attention to insulation properties, such "distribution pipelines" might also be designed to eventually transport liquid hydrogen.

Objective: A report detailing the number and average distance of LNG pipelines expected to serve new delivery port expansion, their design, cost, and adaptability for use in transporting liquid hydrogen.

Focus:

1. Range of quantity and rate of transport of LNG over a given distance between ship and storage/regasification facilities.
2. Maximum distance over which such transport will occur (in some circumstances, this could be as long as 20 – 30 km).
3. Design of the pipeline:
    a. Flexible or rigid?
    b. Diameter
    c. Cryogenic state maintenance throughout transport (i.e., how often is refrigeration required to keep the methane liquid, or can it be transported eventually as a cold gas?).
    d. Thermal insulation properties and suitability for use at 20 K.

Demographic Fluctuations and Impact on Future US and Global Energy Requirements and Implications for SuperGrid Deployment

Scope: Current wisdom holds that world population will reach or surpass 10 billion by 2050. However, current birth rates are on the decline in France, South Korea, Japan, Italy, and Russia and vigorous, almost draconian, efforts are underway to restrict population growth in China. Studies indicate this is also taking place in the United States when immigration, especially from Mexico, is factored out. If such trends are a harbinger of population expectations as global democracy and industrialization progresses, some predict a population implosion beginning around 2040 with a 25% decrease for each succeeding generation, perhaps leveling out at 2 – 3 billion about 2100.

On the other hand, it is likely, in the absence of an unexpected holocaust, all will subsist at an extremely high energy intensity, scaled from present American level. How will such a development impact the need for the SuperGrid concept?

Objective: A report addressing the above issues.

Focus:

1. Research current literature concerning the likelihood of a sharp reversal in current population trends
2. Extrapolate likely energy intensity requirements for a global "American standard of living" population.
3. What impact, if any, will this have on the "boundary conditions" underlying the SuperGrid vision?

High Pressure Electrolysis

Scope: Assess the potential and practicality of electrolyzing water under high pressure conditions.

Objective: Preparation of an RFP

Focus:

1. Explore thermodynamic advantage, if any, of a high pressure process compared to present high temperature and ambient techniques.
2. Possible symbiosis with subsequent liquifaction of hydrogen and oxygen gained by starting the "Carnot" cycle at high initial pressure.
3. Does high pressure offer any advantage to separation of deuterium via a electrolytic diffusion path? (NB…in a developed hydrogen economy that produces vast amounts of hydrogen via electrolysis, does the opportunity also exist to produce large amounts of heavy water…plutonium production?)
4. Include in this effort an assessment of "reversible fuel cell" concepts and their practicality.

Identify Ongoing DOE and NSF Programs That Support the Vision

Scope: What current and ongoing programs in DOE and NSF could be enhanced and aligned in support of the SuperGrid vision? What new programs could be started?

Objective: Proposal to state and federal governmental R&D agencies of a unifying "umbrella" program with the "exajoule" emphasis on a symbiosis of nuclear, hydrogen and superconductivity.

Focus:

1. Nuclear: Gen 4 reactors & AFCI Program

2. Hydrogen: Advanced Electrolysis and Fuel Cells
3. Superconductivity: SCLVDC Cables and Gen II Wire
4. Nat Lab Programs

Role of Low-Eco-Impact Renewable Energy Technologies

Scope: Examine the prospects for solar roof and urban/agricultural biomass waste generated power as adjuncts to baseline power supplied by nuclear.

Objective: A report addressing the above issues.

Focus:

1. Assess future trend of PV solar efficiencies and scale to typical useable urban roof areas to determine both peak and availability factors (may be in a DOE report).
2. Is there a role for passive solar heating?
3. Local storage of solar-generated hydrogen in building using "reversible" fuel cells.
4. Estimation of combustible urban/agricultural waste biomass available per capita
5. Siting of biomass generation plant near nuclear-hydrogen generation facility to take advantage of oxygen produced to enhance efficient combustion.
6. Examine concept of centralized location for nuclear-hydrogen, waste biomass combustion and sewage treatment (using oxygen resulting from hydrogen generation).