Research and Innovation in Greening Electricity Generation, Transmission and Distribution

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Global oil prices rose from $50 a barrel in early 2007 to $100 a barrel on January 2, 2008. Subsequently, the price of oil peaked in July 2008 at $147.27 per barrel before a deep plunge to close to $40 by the end of the year. Since then the price of oil has stabilized at $100 per barrel level barring the drop to $80.00 seen in the second half of 2014.[1] While the plunge of 2008 has several political, financial, and technical aspects to it, the stability from 2009 to mid-2014 had been achieved on the back of US shale gas technology offsetting Middle-East woes. Technology investments continue to be critical to meet the energy demand from emerging markets in an environmentally friendly manner.

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Specific to the electricity segment, the next decade will see the world adding 225 Gigawatt (GW) on an average every year with half of it coming from China and India. This is based on China adding about 70 GW every year and India adding 20 GW every year. China and India will continue to add significant coal-based power generation while expanding nuclear power and exploring renewable sources of power. Due to policy issues in India over the previous few years, addition to the grid has dropped to less than 10GW from about 18GW. This drop in grid addition has been offset by the addition of distributed or consumer-based power, mostly in the form of diesel gensets. The grid collapse of July 2012 in North, Eastern, and North- Eastern regions serves as a wake-up call to relook at the electricity supply-demand-transmission scenario in India. Close to 50 GW of electricity was impacted, with over 600 million people affected. The report of the enquiry committee identifies a few areas related to the grid for improvement, including better outage management, mandatory generator response based on frequency variation, availability of real-time data and intelligence at the load dispatch centers, reactive power compensation, regulations to limit overdrawal / underdrawl, fail-safe relays, and wide-area monitoring systems.

While we get better at grid management, we need have a better understanding of the true demand for power in India. Current estimates of power shortage are un-

[1] *Late 2014 has seen a fall in global oil prices again, emphasizing the volatility of oil prices, even though long-term trends indicate high oil prices.*

derstated to be at 10-15%. These estimates are based on a 'fix the famine mindset' rather than position for the growth aspirations of a young nation. Even taking half the world average per-capita consumption as a benchmark, India has a 100% growth requirement for electricity in order to create jobs, alleviate poverty, and meet the basic needs of the population.

FOCUS AREAS FOR CLEAN ENERGY FOR INDIA

In order to study the global trends in energy research, we conducted an automated collation and ranking of author keywords in 2006-07, and then updated the work for results from 2011-13. The study included more than 160 journal titles. An interesting outcome is the emergence of carbon dioxide as the most used key word in 2011-13 (up from 11th position in 2006-07), emphasizing the importance of clean energy. Electricity generation typically contributes to 40% of total carbon dioxide produced from the combustion of fossil fuels. Overall, the focus on clean technology is high with hydrogen, wind, and biomass all featuring in in the top 10 list. Solar cells at position 17 in 20011-13 still moved up from the 47th position in 2006-07. This study gives a heat map of ongoing research including the technology trends.

Utilizing the trends discussed in previous paragraphs as a starting point and rationalizing the focus based on the energy ecosystem in India, the following are recommendations for research areas in electricity generation:

• *Hydrogen is an energy carrier rather than a fuel.* This is because hydrogen is not available in significant quantities on earth. Hydrogen is produced from water, as an example, by using available energy sources such as wind or solar to split hydrogen and oxygen. Hydrogen can also be reformed from natural gas and other fossil fuels. The amount of energy that can be obtained from hydrogen cannot be more than what was used to produce it in the first place – hence it is an energy carrier. The major areas of research in hydrogen hence are the economical production and efficient storage of hydrogen (hydrogen has very low energy density). The centralized production of hydrogen similar to the production of electricity can be achieved by various primary energy sources.

At this point of time, however, it is not easy to make a case for hydrogen either from a cost perspective or from an environment perspective for hydrogen fuel or hydrogen based fuel cells in India. For costs to be competitive without subsidies it will take at least a decade after the introduction of fuel cells at scale in the industry (most likely in automotive and telecom tower applications).

The environmental argument can be made on basis SOx and NOx reductions. CO2 reduction is tied to higher efficiencies of fuel cells (can be twice that of internal combustion engines) and the implementation of acceptable sequestration techniques. Application of fuel cells can be classified broadly based on steady or dynamic demand and on the output being KW range or MW range. The Proton Exchange Membrane (PEM) Fuel Cell is a leading candidate for dynamic demand kilowatt range applications (automotive and telecom), while the Solid Oxide Fuel Cell (SOFC) is gaining momentum for the steady demand megawatt range application (stationary power generation).

The Ministry of New and Renewable Energy (MNRE) has programs in the development of fuel cells right from materials research to development of infrastructure to support application of fuel cells. These programs funded at the universities and CSIR labs would be well served by having industry partnerships and taking a stock of roadmap to commercial feasibility. MNRE and the Ministry of Power (MoP) should focus efforts on the fuel side of fuel cells to determine availability and price of natural gas to make fuel cells viable. Accelerated commercialization of PEM Fuel Cells for telecom towers and SOFCs for distributed power generation should be specific application focus in partnership with the industry.

• *Wind research should be focused on optimization of wind farms and wind power forecasting.* In farm optimization, data analytics can play a big role. Each wind turbine

in addition to being an electromechanical system is also an instrumented computing node. Several wind turbines of the wind farm interconnect to form a local area network. Several wind and other power generating units interconnect to form a wide area network. With appropriate optimization for better yield and stability at a grid level rather than only at a turbine level better utilization of wind capacity can be envisaged.
However, in India there is limited availability of historic data at the required heights. Hence, while encouraging wind forecasting, Indian regulators need to have a technology panel review the feasibility of norms before implementing them. There should be a soft implementation of the future predictions to benchmark the best in class before penalizing producers on prediction and performance standards which are not implementable.

India is a low wind regime country with average wind speeds of 6-8 m/s at altitudes of about 80 m. Continued research is needed to ensure that the cost of energy at the lower wind speeds makes it a viable option in the long run. Optimized rotor dimensions and hub heights are already on the roadmaps of commercial entities. MNRE funded research on materials and new mechanical designs for improved transportability on Indian road and improved capture of wind is recommended. However, it is ill advised to go after wind regimes with average wind speeds of 3 m/sec or lower from a cost or environment benefit analysis.

Another critical area to investigate is storage techniques to counter wind power's intermittency and its availability during off-peak hours. The induction generation used in wind turbines requires reactive power to be supplied from the grid. For stable, grid friendly operations extensive forward and inverse models need to be developed especially in India where grid predictability is an issue.

• *Biomass research directions should be focused around production of syngas containing hydrogen through the gasification of biomass, and production of bio-oils through the pyrolysis of biomass.* Some reports state that there is sufficient biomass from agricultural waste in India to produce 80 GW of power. MNRE should sponsor an independent assessment of practical power generation possibility from agricultural/forest waste. There is limited justification for growing biomass for power generation as solar cells are far more efficient in producing power from the sun compared to photosynthesis. MNRE funded research is also needed to develop effective techniques to collect and distribute biomass either as itself or converting it to biogas and bio-oils before distribution. Industry partnerships in producing pure hydrogen from biomass for use with fuel cells should be another area of focus.

• *Solar research is focused on cost and efficiency and has seen significant advances in the past few years.* Some recent advances have been accomplished in layered solar cells with each layer optimized for absorbing a different part of the solar spectrum reporting cell level efficiencies of close to 45%. Conventional thin film technology using CdTe and CIGS has reached module efficiency of 17% with the potential of much lower costs than crystalline silicon PV. N-Type mono solar technology offers higher efficiencies than poly crystalline PV and lower degradation over time. For all of these, R&D efforts in India, plus commercialization efforts, must be stepped up.

Researchers are also working with various aspects of nanotechnology, to produce hydrogen through photo-catalysis, and use nanostructured semiconductor based solar cells. An emerging area is hybrid (nanotechnology and plastics electronics) solar cells with various thin film oxides. At the end of the day, various technologies have to compete based on cost of electricity. For India, the right mix of solar between crystalline silicon, thin films, and concentrated solar thermal will be determined by availability of land, roof-tops, and appropriate tariff structure.

Indian industry should focus on leap-frogging solar cell technology and continue to optimize the balance of systems

MNRE should study long term solar costs when modules from China are no longer available at current prices. MNRE is working on a roof top solar policy which would help promote increased penetration of solar. Net Metering is a critical aspect of implementing the rooftop solar policy and should be studied in detail under MNRE funding. Indian industry should focus on leap-frogging solar cell technology to differentiate from Chinese cells and continue to optimize the balance of system.

• *Conventional research areas such as heat transfer* and combustion continue to draw heavy research with hot spots such as heat transfer enhancement using aqueous suspension of multi-walled nanotubes (or in general heat transfer in nanofluids) and swirl combustion systems. Also, use of catalysts and adsorption for reducing emissions is a key area of research. In these areas India would be best served at this point by being early adaptors. India should take lead in developing technology for improved use of coal (from environment and cost standpoints), and high-ash coal in particular. Coal beneficiation, coal liquefaction, and coal transportation should be major focus areas for the Ministry of Power for policy and PPP implementation.

SMART GRIDS

To understand the research directions in transmission and distribution, it is important to understand the 'Smart Grid.' (See chapter 9 for more on Smart Grids and clean energy). Smart Grid is grid modernization. The EPRI definition of Smart Grid states: A Smart Grid is one that incorporates information and communications technology into every aspect of electricity generation, delivery (transmission & distribution) and consumption in order to minimize environmental impact, improve reliability, service, efficiency, and reduce costs. To the EPRI definition, one could also add asset modernization as an important element of Smart Grid.

The following are some of the research activities in smart grid for electricity generation, transmission, distribution, and consumption and potential application for India:

• ***Generation:*** The ability to use renewable energy is limited by the fact that renewable energy sources are intermittent. Intermittency brings the quality and reliability of power under question if more than 20% of generation is dependent on renewable sources. Smart Grid have effective power-factor control and intelligent resource deployment making renewable energy more grid-ready.

• ***Transmission:*** Transmission occurs at high-voltages (and lower currents) so as to minimize the I2R losses. In addition to the I2R losses, reactive losses in transmission can be significant. Another issue is that of grid congestion with increased generation capacity and demand but with a grid that is behind times. Smart Grid encompasses existing technologies to mitigate losses such as intelligent deployment of capacitor banks to offset reactive losses and new opportunities through the visualization and prediction of grid state to handle grid congestion issues.

• ***Distribution:*** In a round table on Smart Grid organized by the Digital Energy Solutions Consortium, representatives from the Indian Ministry of Power highlighted detection of theft as a chief area of focus in addition to technical losses. Smart Grid for distribution requires asset (meters, transformers, switches, and breakers) modernization and will provide tools for optimal asset deployment. In addition effective visualization can identify and isolate theft locations.

• ***Consumption:*** Smart Grid enables distributed power generation where consumers are able to feed back into the grid via smart meters. Also, the consumers can deploy their appliances during off-peak tariff hours using smart meters with integrated appliance programming and control. Additionally, as plug-in hybrid usage increases, the grid needs to turn smart and deliver power to the vehicle while optimizing availability and other demands. Smart metering and Smart appliances will bring the smart grid to the consumer.

The Smart Grid has benefits at multiple levels. The nation moves towards energy independence through increased renewable use. The people benefit from new

This work was conducted by the Whitney Knowledge Centre at the GE John F. Welch Technology Center utilizing Scopus database.

jobs created and a control over their electricity bills. The industrial growth is spurred through a reliable grid. The utilities continue to be profitable despite rising fuel costs. And most importantly lower emissions through better usage of the electricity generated and better control of how it is generated.