

National Economy and Industrial Development: Green Energy Innovative Integration Technology in Grid

Prof Rajendra Kumar Pandey

The national economy and industrial development are linked with the energy sector such as coal, power, oil and gas. The availability of quality coal and oil are limited for industrial and other applications. The GHG emission is known and its adverse effects on the health and environment at large is also well studied and reported at various forums. The natural calamity is associated with environmental imbalances which may be observed now a days quiet often as cloud burst and ocean turbulence and earthquake. The production cost of industries is very closely governed by the power price as a key factor. The emergence of new technology of solar and wind power generation and evacuation at remote load centres has open the gateway for massive industrial low-cost production if appropriately made available in real time depending on the requirements of industries. This may require the integration of innovative technology solutions of Green Energy evacuation through the Green Corridor and providing open access to renewable energy in real time power market for ensuring the cheapest power in entire country. The observations regarding real time power flow by POSOCO/POWERGRID through the transmission network by integrating Green Energy in the Grid and ensuring its availability at remote end industrial houses/industries/commercial organizations has been very promising and commercially viable. The only challenge as on date has been the massive Green Energy integration and its evacuation at remote end load specially under intermittency. It's noticed on various occasions that during intermittency the power injection pattern is modified which may affect the Grid operations hence a very detailed system planning has to be done with energy storage options in the transmission and distribution network utilising the benefits of large, pumped storage and battery storage depending upon the respective zone. The Green Energy Corridor with special feature of advance control to regulate the power flow at the desired location is the need of hours. The utilities associated with power generation and transmission & distribution now have to work in unison in order to have a quality power supply at the cheapest price for industrial houses and commercial organization as well. This concept paper outlines not only the challenges of Green Energy integration such as Solar, Wind and Bio Energy but also the new emerging Hydrogen Energy production and storage for industrial applications and fuel cell driven vehicles to provide the Green Transportation starting from the two-wheeler to four-wheeler and heavy load vehicle such as Truck and buses as well. The goods train and passenger trains may be also driven by hydrogen and fuel cell providing the entire green hydrogen massive usage in transportation sector thus minimising the stress on the existing lines feeding the electrified Train corridor. This concept will provide the stability to Grid and least excursion to existing assets of transmission and distribution networks.

Overview on the Energy Scenario:

Coal accounts for 37% of the global power supply. Particularly in Asia, it remains a preferred fuel of choice due to its abundance and well-developed thermal-related infrastructure as compared to the developing renewable energy infrastructure. Rapidly declining cost of renewable energy, emphasis on lower carbon footprint and rapidly increasing electricity demand, puts cleaner electricity at the centre of strategies for many developing economies including India for economic development. Sailing on the Government of India's ambitious nation-wide renewable energy capacity target of 175 GW by March 2022, which was recently updated to 450 GW by 2030 renewable penetration will reach significant levels in the overall Indian power mix. The variability of renewable energy presents a notable challenge to grid stability and reliability.

India's ability to manage grid in such scenarios is still untested and the necessary resources like flexible generation capacity, energy storage, demand management etc. seem inadequate. As per a recent report by POSOCO in May 20201, India's conventional generation capacity has limited flexibility with the report suggesting that only 36 units out of the 438 (~8%) thermal units analysed have achieved a minimum generation of 50% or lower, with only one unit (in Gujarat)

operated at generation level of 40% or lower. Thus, unless adequate aforesaid RE integration resources are developed & implemented, RE curtailment is inevitable with increased RE penetration. As per recent estimate, based on above mentioned planned RE capacity target and CEA estimated India's future demand projections, RE curtailment can increase to 10-15% by FY 2022 and >40% by FY 2030. RE curtailment is already a significant issue in many states in India including some of the ones highlighted above. Multi-pronged strategy is needed to address the above RE integration (or RE curtailment) issue and ensure that country's power supply-demand balance is maintained along the most optimal path. Some of the key steps for the same could be: (1) Acknowledging the urgent need for flexibility, (2) Supply and grid flexibility assessment, (3) Enabling market reforms

Hence, the ability of the Indian thermal power plants to achieve lower levels of technical minimums and to quickly ramp-up and ramp-down, i.e., operate flexibly vis-à-vis baseload operations gains unprecedented importance as a norm rather than an exception. Hitherto, flexible generation has not been a significant priority in India under grid conditions characterized by generation deficits and outages. One of the key reasons contributing to the lack of preparedness for flexible operations in India is the absence of sound regulatory framework and compensatory mechanisms for incentivizing required changes to the plant equipment, procedures and practices. It may be noted that the generation flexing is the only option as on date for accommodating the Renewable Energy and providing green energy to industrial houses but with upcoming evolving technology such as flexing transmission and distribution capacity with the deployment of Flexible AC Transmission System Controllers at appropriate location may drastically change the entire energy scenario. The Renewable Energy rich states may be connected with High capacity HVDC and HVAC lines with FACTS controllers which will facilitate the power flow from any location to other required location depending on the loading pattern of respective areas. The ATC of lines may be changed with FACTS controller to accommodate the RE power over and above the classical power from thermal power plants. One of the concepts for providing the cheapest power may be based on the methodology adopted such as:

1. The onset of the Renewable Energy power injection is tracked in real time along with the loading requirement of the transmission line at given point of time. The Thermal power available may be assessed in real time from various thermal power plants and in place of ramping down to the tune of RE penetration the power from thermal power plants is rerouted through the transmission corridor by FACTS controllers to the storage locations/industrial houses/farmers load and thus ramping down is avoided. This may benefit the thermal power plants management in terms of revenue and also cheapest power thus may be given to other loads of industrial importance/commercial organisations providing the product/services during that period at lower rates thus improving the economy of the country and this ensures sustainable development.
2. Solar power integration is expected to continue in the next few years, as governments push for renewable energy production to fight climate change. Further, solar power has the potential to be the most cost-effective renewable energy generation technology. Hence, the shortcomings of solar energy must be overcome with new and efficient technologies like energy storage systems (batteries) and mini/micro grids. Developed countries are now looking at energy storage systems to tackle solar integration problems. The use of energy storage systems for solar power is expected to grow in the coming decades due to its potential to stabilize the grid assets and reduce the dependence on thermal power plant back-ups. Instead of feeding the power generation directly into the grid, solar power can be fed into the battery, which, in turn, will supply power to the grid. This will enable the solar power plant to continue supply even when there is no active generation at night.
3. The utilities having pumped storage/energy storage may be planned at appropriate locations and the cheapest power may be stored for Grid balancing during intermittency. Also, with upcoming Electric Vehicles penetration in Grid, the cheapest power may be given to the respective states during the period in which RE energy predominant through open access. This may boost the Battery Swapping industries and also the cheapest power for charging the battery of Electric vehicles. Thus, it will not only allow more investment in the energy sector but also automobile sector and

distributed energy management as well.

Renewable Energy as Green Energy: Innovative Integration Technologies

The solar and wind energy have been found to manage the power demand in hybrid mode very effectively with intelligent control through Renewable Energy Management Centre. The Energy storage, specially pumped hydro storage and large NaS battery storage upcoming may play very important role for energy security once intermittency is observed by bridging the gap of power demand through intelligent power control. However, such technology requires a hierarchical control layer which can balance the power demand either under changing load scenario or intermittency very precisely thus ensuring quality power to the load.

With the increasing demand for electricity as the world shifts away from fossil fuels, cleaner sources of energy like solar and wind are becoming more and more common. However, as more solar power is introduced into national Grid, operators are dealing with a new problem that can be visualized as the "duck curve". In a world heavily reliant on electricity, utility companies have found better at using data to anticipate demand and trying to operate as efficiently as possible. Usually, power companies supply the least amount of power overnight while most consumers are sleeping, ramping up during the morning as people wake up and businesses get going. Then, at sunset, energy demand peaks. Utility companies use models to predict demand and operate as efficiently as possible by supplying more power during times of higher demand. But the introduction of solar power has brought about problems in these demand curve models. Since solar power relies on the Sun, peak solar production occurs around midday, when electricity demand is often on the lower end. As a result, energy production is higher than it needs to be, and net demand-total demand minus wind and solar production-falls. Then, when evening approaches, net demand increases, while solar power generation falls. This discrepancy results in a net demand curve that takes the shape of a duck, and the duck curve gets more pronounced each year, as more solar capacity is added and net demand dips lower and lower at midday. The drop in net demand at midday basically creates problems.

Solar energy production wanes as the sun sets, just as demand for energy typically peaks. Utility companies are having to ramp up production to compensate for this gap, often overstressing a grid that is not yet set up for these peaks. Traditional sources of energy like nuclear and coal are only economic when they are running all the time. If you have to turn them off at mid-day because the power is supplied by solar, they become economically unfeasible. Due to overproduction, solar power is already being wasted in some places where the technology is widely used, like California. The problem is most intense during summer or spring when part of the solar panels has to be turned off to avoid overloading or even damaging the power grid.

Flattening the Duck

With more countries starting to rely on solar power, there are many potential solutions for the duck curve being explored (and implemented):

Energy Storage: Overproduction of solar power during the day can be utilized by improving batteries and grid storage capacity.

Powering Alternatives: Extra solar power can go towards powering energy generation at night, such as pumping water for hydroelectricity or overheating a material to dissipate energy later.

Other Clean Sources: Unlike solar energy, sources like nuclear, hydroelectric, and geothermal can operate continuously and fill in the demand gap.

While grid managers study how to serve the new supply and demand, the duck curve is one of the greatest challenges

facing renewable energy.

Use of Mini Grids

Mini grids are essentially smaller power generating and consumption units connected to each other without being connected to the main electric grid. The structure of a mini grid improves the stability of the main grid as it reduces grid load. This structure isolates the mini grid from any instability in the main grid. Mini grids offer enormous potential to the developing countries to improve electrification and simultaneously increase grid stability. The use of mini grids in consumption-heavy regions with large solar power plants will reduce the heavy demand from the plants and the supply fluctuations from the off-grid solar power plant, thereby keeping the grid stable.

How Does this Affect Renewable Energy Procurement?

The last decade of growth in investments and integration in renewable energy was mainly driven by the various incentives that the governments worldwide provided for renewable energy production. One major part of renewable energy procurements from corporates comes in the form of self-generating power plants. These power plants are connected to the main grid to sell the excess power to the grid and to get feed-in tariffs (FiTs). Owing to the problems of solar power integration and the increase in electricity prices driven by the solar incentives, many countries have reduced their FiT incentives, with the net result of disincentivizing solar projects. With the reduced FiTs, the return on investment (ROI) of a solar plant increase with an increase in the levelized cost of energy (LCOE) of the plant. Hence, corporations with significant solar power assets should consider investing in battery systems to keep their LCOE lower despite the lower FiTs. Installing battery systems will reduce the LCOE of the solar power plant as they increase the output and the efficiency of the solar power plant. A solar power generation system with an energy storage system can power the facility even at night and essentially can act as a mini grid and decrease supply fluctuations.

Hydrogen Energy BHU Pilot Project Overview:

Hydrogen, the world's most abundant and lightest element, has a wide range of applications in industries such as Steel, Fertilizer, Refinery, Petrochemicals, Automobile etc. It is also one of the richest and efficient sources of energy. Hydrogen demand has been increasing in India and is expected to reach 11.7 million Tonne by 2030 from present 6.4 Million Tonne. Hydrogen, based on how it is produced, can be divided into 'grey' (produced from fossil fuels), 'blue' (produced from fossil fuels with carbon capture and storage) or 'green' (produced by using renewable energy to power electrolysis that splits water molecules into their constituent elements: hydrogen and oxygen). Traditional means of producing hydrogen generate large volumes of CO₂. With world's focus on decarbonization, green hydrogen (which is more environmentally sustainable) is receiving unprecedented interest and investments. The advances in electrolysis technology and the falling cost of renewable energy are enabling the mass production of green hydrogen and driving the cost of production down. These developments have changed the dynamics of hydrogen in India and have created a significant opportunity for our country to boost economic growth, achieve energy security, and move away from fossil fuels, creating an environmentally cleaner and sustainable future of the country. It is expected that demand for green hydrogen could reach 1.25 million tonnes by 2030.

OBJECTIVE:

The objective of the Pilot project is to synergize the engineering/R&D strengths of BHU, BHEL, & BARC and jointly work towards mitigation of the challenges being faced in the adoption of hydrogen economy in India. The project involves demonstration and study of:

- Production of green hydrogen [66 kg/day; 500kW Alkaline electrolyzer]
- Hydrogen refilling station [H₂ compressor, High & Medium pressure storage, Dispenser]

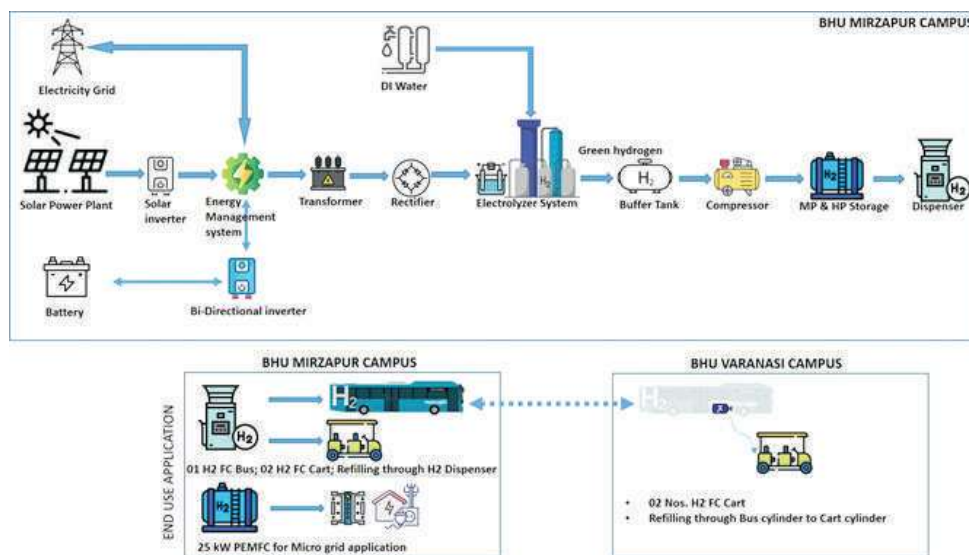
- Mobility application [9m FC Bus(01 No. 100 kW PEMFC) and Cart(04 Nos., 5kW PEMFC each)]
- Micro grid application for distributed power [25kW PEMFC] The overall pilot project layout is shown in Fig. 1.

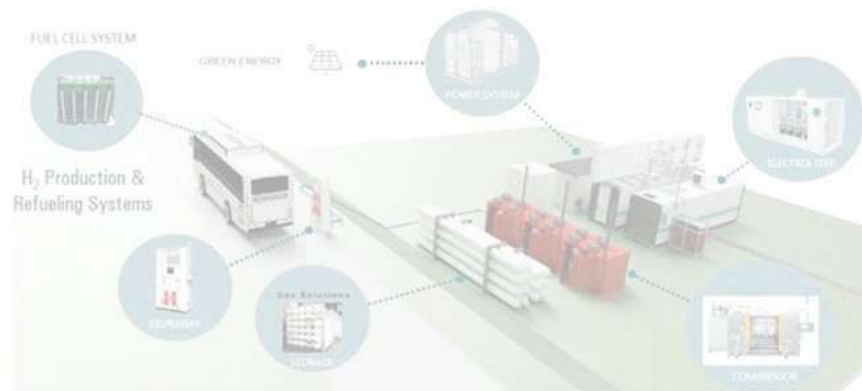
INTRODUCTION

The above-mentioned end-use application would require approximately 66 kg H₂/day. To cater this demand of green H₂, BHEL proposes to set up a 500kW Electrolyzer system for on-site hydrogen production at South Campus, Mirzapur. The electrolyzer system will be powered by 1MW existing Solar power plant (SPV) during the day, producing Green hydrogen. The green hydrogen produced will be stored and supplied for end use applications such as H₂ bus, Power backup and H₂ cart using BHEL in-house developed Fuel Cell (FC). The excess hydrogen (if any) can be used by BHU in its research laboratories.

DESCRIPTION

The alkaline electrolyzer system (500kW) will be powered primarily by solar power plant (1MW). However, as solar power is variable in nature, battery (300 kWh) has been considered in the system for adequate functioning of the electrolyzer. When the SPV output is more than the demand of electrolyzer, the battery will get charged and when the SPV output is less, the battery will provide balance power. In case of non-availability of electrolyzer system, the SPV output will be fed to grid. Further, in case SPV is not operational, the provision has been made where in the electrolyzer can be powered by grid electricity, in which case the H₂ produced will not be called green. The aforementioned management of electrical energy from the sources- SPV, Battery, Grid- will be achieved by Energy Management System (EMS), aptly designed for the desired purpose. The hydrogen produced will be compressed and stored in High pressure [250 bar(g)] and medium pressure [150 bar(g)] storage for cascade filling. The hydrogen will be dispensed through the dispenser. This whole infrastructure will be located at Mirzapur campus. For end use, the 9M hydrogen fuel cell bus (100kW FC) will ply between BHU Mirzapur and Varanasi campus. 02 FC carts will ply within Mirzapur campus. Further, 25 kW PEM FC based microgrid has also been envisaged to power a building in Mirzapur campus for 18 hrs. At Varanasi campus, 02 FC carts will be run for intra campus commute. These H₂ cylinders of FC carts at Varanasi campus will be refilled through special provision from Bus cylinders. The H₂ storage capacity on bus has accordingly been considered.





EXPECTED BENEFITS

1. The installed green hydrogen generation system would help to understand the Techno- Economical aspects of Green Hydrogen Generation, compression, storage, dispensation,
2. Experience of system engineering, integration, project execution including production, compression, storage, and dispensing of green H₂ project with end usage.
3. Experience of safety aspects and Handling of hydrogen gas.
4. Further research on cost reduction and IPR
5. The success of this project will build confidence and lead as an example of Industry and academia collaborative effort. Such collaborations are much needed in the country to address the challenges of niche and emerging technologies.
6. Project will provide a platform for training and research on green hydrogen technologies to the academia and industry.
7. The pilot project will include indigenously developed systems (>80%) and will provide big boost to 'Atma nirbhar Bharat' vision of our honourable PM.

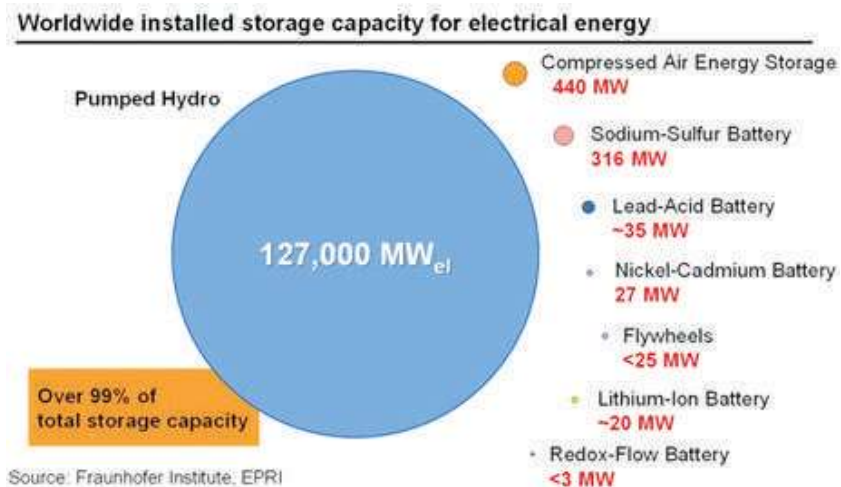
Storage Technology:

There are different options for the storage of electricity to make it available when needed in the context of the renewable (wind/solar) integration. The main technologies available or under development are: Large size batteries, Fly wheels, Pumped Hydro Plants, Compressed air, Hydrogen storage, Superconducting magnetic energy, Thermal storage

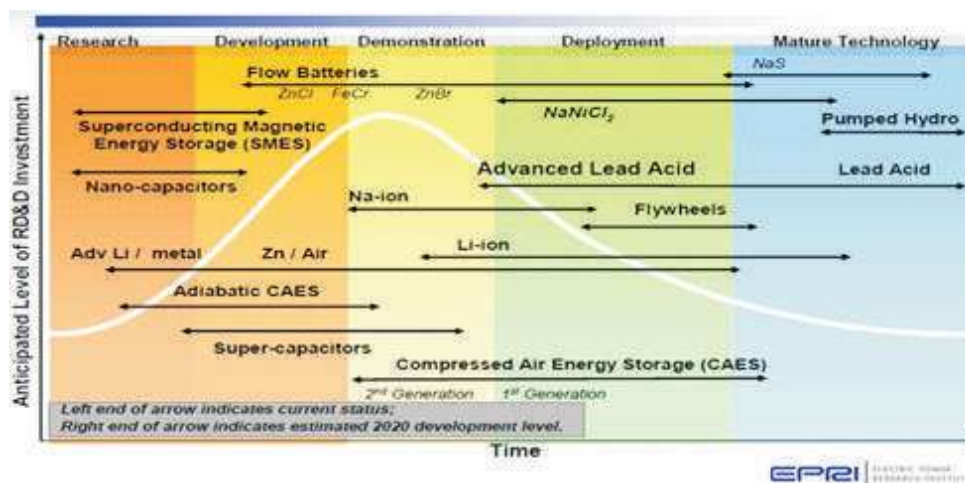
More than 99% of global grid scale storage is done today by pump hydro method. This method stores energy in the form

of water pumped to an elevation when the demand for electricity is low and utilized to generate power to meet the demand when required. But sites available for such pumped hydro systems are scarce in the Indian context. Batteries are portable, can be customized and are easier to install; thus, making them increasingly attractive for grid level storage. However, they still have high capital costs. With continued innovation and bigger production scales, large-scale battery storage should get more economic.

The picture below gives a relative ranking of some of the storage options--



Given below is an overall picture of storage technologies at various stages of maturity--



It's clear that NaS and Li-ion battery systems are amongst the front runners in the electrochemical storage sector, Sodium sulphur battery:

National status: No manufacturer and installation in India as of now.

International status: Sodium sulphur battery technology has been demonstrated at over 190 sites in Japan totalling more than 270 MW with stored energy suitable for 6 hours daily peak shaving. The largest sodium sulphur installation is a 34 MW, 245 MWh pack for wind stabilization in Northern Japan. Several projects are under development in Europe, as well as in Japan and the US. As of 2010, NaS batteries have been used by utilities worldwide in 221 projects with a total capacity of 316 MW. EPRI estimates that with current efforts the installed capacity of NaS batteries will increase to 606 MW. Currently, the only NaS battery manufacturer for utility scale grid applications is Japan based NGK Insulators Ltd. in collaboration with the Tokyo Electric Power Co. (TEPCo). A lower temperature version of the NaS battery is also being developed in Utah by Ceramtec. In March 2011, Sumitomo Electric Industries and Kyoto University announced that they had developed a low temperature molten sodium ion battery that can output power at temperatures under 100°C. This needs further validation. Recently, Posco, South Korea has also claimed the development of NaS battery, having more than 3 times higher density than existing batteries and a lifespan of more than 15 years. The largest system currently under construction is 34 MW/238 MWh NaS storage for the Rokkasho wind farm in northern Japan. On the R&D side, the electrolytes play a fundamental role in terms of current density, electrochemical stability and the safety of batteries and hence their continuous improvement and innovation are critical to the overall battery performance.

Li-ion battery:

Despite being one of the best battery systems in terms of energy density, the prohibitive cost has limited the large-scale deployment of LIB. A recent report from consulting firm McKinsey & Company predicts that the cost of lithium-ion batteries could drop to about \$200 by 2022. South America has more than 60% of global Li reserve and hence the Li based batteries would cost lesser in future when more manufacturing plants come up there. Many research groups around the world are working on high-capacity silicon-based anodes and manganese oxide-based cathodes for lithium-ion batteries, but so far these are not stable enough for grid applications.

Basic research needs to be carried out for developing the methodology for designing high power lithium-ion batteries for Indian requirements. This will require both mathematical modelling as well as experimental work. Mathematical modelling expertise, at different length scales (multi-scale), needs to be developed. The models, however, have to be translated to computationally fast models, so that optimization of design parameters (material, geometry and electronic circuit) can be done. Experimental validation would involve actual fabrication of the battery and evaluation of the performance.

National status: There is currently no manufacturing of lithium-ion battery taking place in India. Right now, all the lithium-ion batteries for various applications are imported, thus increasing the cost of the equipment/product enormously. India is putting significant efforts in the alternative energy sources - solar, wind etc. This sector will benefit significantly by the indigenous development of lithium-ion battery. The state of art batteries is mostly based on graphite anode and LiCoO₂ cathode/related systems. Use of LiCoO₂ makes the batteries toxic and there exists a problem of disposing them. Also, LiCoO₂ makes the batteries costly for Indian market. For Indian conditions much cheaper and environmentally friendly batteries are needed. Also, safer technology is a key issue in the Indian scenario because the safety awareness is not up to the mark. Alternate technological routes which produce safer batteries via safer procedures are mandatory. Thus research and development activities focused at designing lithium ion batteries, which are well-suited for Indian conditions, is indispensable.

Smart Grid: Future Grid Integration Concept

National and international: Smart Grids are an evolving transformation of the power system that use information and communications technology (ICT) to enable greater reliability, robustness, consumer choice (including grid-tied renewables and storage) and flexibility. It impacts all aspects of the power sector, from generation to transmission to distribution; a likely major thrust will be in distribution, which includes consumption. Many components of smart grids are available today; the main challenges include improving the price-performance and the integration of the solutions

in a manner that is open, modular, standardized, and scalable. Pilot Project "Design and Development of a Smart Energy Grid Architecture with Energy Storage" has been executed at BESCOM by IIT (BHU), Varanasi under the leadership of Prof Rajendra Kumar Pandey. The screen shot is shown below Fig 1 and Fig 2:



Fig 1 Smart Meter Operation Control (SMOC) Room BESCOM

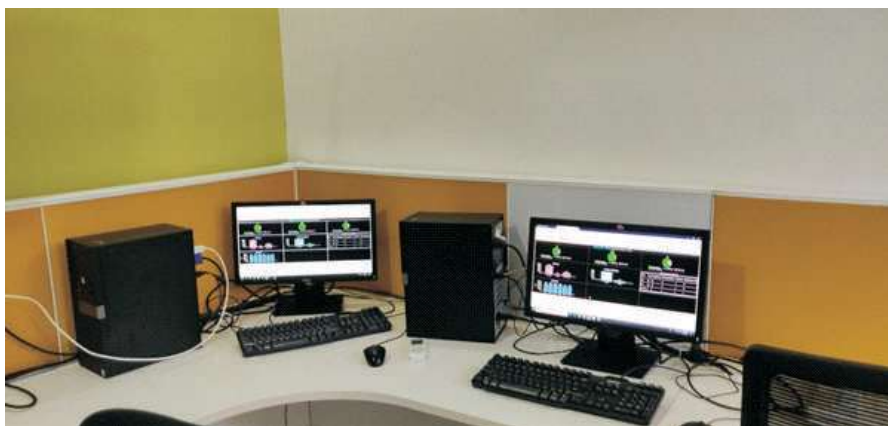


Fig 2 Server Communication in SMOC BESCOM

A Roof Top Solar Power Project with capacity of 6.025 MWp is executed at BHU having three different locations such as BHU main Campus, RGSC Campus Mirzapur and Kamachha Campus in main city of Varanasi utilising IoT and SCADA for real time monitoring and ensuring operation & control through data analytics. The screen shot of the Project is shown below Fig 3:

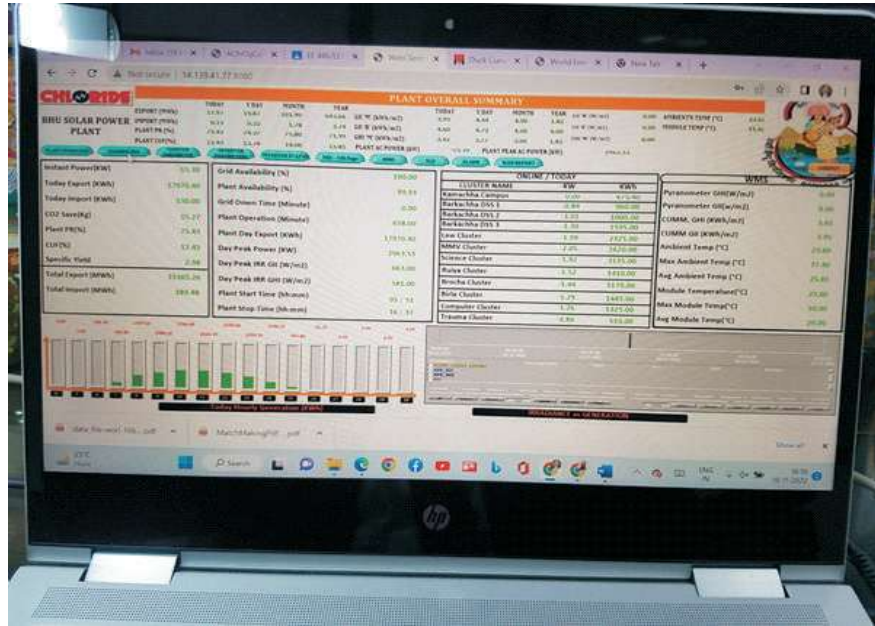


Fig 3 BHU Solar Power Project SCADA screen shot of Nov 10, 2022

Various utilities around the world have taken steps towards deploying a smart grid. A few nations also have regulations and legislation towards smart metering if not smart grids. Perhaps the largest deployment to date has been Enel, in Italy, where all 32+ million consumers have smart, bi-directionally communicating and controllable meters. However, with continuous improvements in technology, new deployments (e.g., Boulder, Colorado, or Southern California) are "smarter" in their capabilities. There are other projects ongoing around the world. As there is no "single" accepted level or standard for Smart Grids globally, the different utilities are in different states of implementation. Some utilities are at experimental level while a few are implementing smart grids commercially with main focus on smart metering. In developing countries like India, smart grids have not been the focus of the utilities given the other challenges they face, including supply shortfall, power theft, financial losses, etc. However, it is possible that they could leapfrog to smart grids, while at the same time using them as a means to improve their operating and financial sustainability.

The vision of this project proposal is to study the present grid conditions and future scenario with addition of renewable resources of different capacities. The analysis of the operational problems associated with substantial renewable resource penetration and examine the possible solutions like use of the Smart Grid Technology and storage options for smooth and safe operation of the network. It is also proposed to make an assessment of the requirement and economics of storage options to overcome the variability of the renewable sources of generation.

Critical to the planning and design of decarbonized grid architectures is a detailed understanding of the potential benefits, risks, costs, policy instruments, performance and reliability of the various technology options. An integrated assessment is required to avoid suboptimal solutions.

The scope of this project includes multidisciplinary fundamental and applied research, economic and policy analyses, development of framework for pilot projects and outreach. The activities are designed to gain the key fundamental understanding required for implementing smart grids with large-scale renewables penetration, and prepare a framework to test these ideas in the real world conditions.

Research Challenge

The present energy infrastructure is engineered for large-scale centralized conventional generation, transmission, and distribution. The present share of renewable sources such as solar and wind power is less than 12% in India. A future energy infrastructure capable of large-scale renewable integration presents the following challenges:

1. **Managing intermittency:** Solar and wind are inherently intermittent sources. Large variations cause serious operational difficulties, as experiences in several countries have shown. Earlier the variations in wind power generation in the state of Karnataka for four typical days have been observed. With an installed wind base of 2,000 MW, the generation fluctuates by almost 400 MW within 60 minute and 200 MW in a 15-minute duration. At present, the state is able to manage these fluctuations with the available hydro reserves. Large-scale wind and solar power, on the other hand, require quick ramp-up generators and storage devices to offset the variability in generation.
2. **Energy Storage.** At present, pumped hydro is the only cost-effective technology for grid level energy storage regarding the global scenario. Future capacity addition is, however, limited given the ecological concerns with building reservoirs for water storage and the strict geological/geographical requirements for pumped hydro. There is a critical need to develop other cost-effective energy storage options for both grid-connected and off-grid power systems.
3. **Demand response.** Renewable power generation does not coincide with the load curve. Therefore, there is a need for 'management' of the load curve, in particular shifting the peak load. This requires both, strategies for load management and control such as 'demand response' and innovative tariffs such as 'time-of-use' or 'real time pricing'.
4. **Micro-grids .** Decentralized power generation is an important option to pursue. In India, utility-scale generation would take several years to provide quality electricity to consumers, particularly in remote villages. The gradual decline in the price of solar PV makes it possible to envisage decentralized (especially rural) micro grids with energy storage in India.

Research Objective, Thrusts and Novelty: A Way Forward for New India in Energy Sector

Given the scale and interconnected challenges, it is necessary to examine in detail the following options:

- (1) Distributed and grid level energy storage options.
- (2) Smart Grid technology for Renewable Energy Integration and Open Access Market
- (3) Hydrogen Energy Production with Solar Power and Storage for Transportation/ Industrial usage

The research thrusts and objectives at present have several cross-cutting competencies, innovation aspects and themes including materials synthesis and processes for prototype battery fabrication; design and optimization of storage with renewables, modelling and simulation, techno-economic and policy assessment and most importantly, development of a framework for a few pilot projects to demonstrate integration of a renewable energy source with the grid using smart grid and storage options.