9th Asia-Pacific Conference on Wind Engineering
Auckland, New Zealand
3-7 December 2017

Wind Energy Research and Development: Way forward in India 60GW by 2022

Dr.S.Gomathinayagam

A freelance Technical Adviser (Wind & Solar Energy, Structures & Foundations)
Former Director General, National Institute of Wind Energy, Chennai, India

Email: gomsluft@gmail.com

Abstract

To date, India is having 32GW installed capacity of Wind Energy from over 20 OEMs (Original Equipment Manufacturers) with as many as 50 plus models of wind turbines of varying nameplate capacities. In installed capacity of Wind Turbine generators India ranks fourth in the world. While design and intellectual property rights of various turbines and their components lies with the western European/American countries the manufacturing of every model marketed in India is mandated as per the international standards (IEC) for the accredited certified designs ensuring quality and reliability. Need based adoption of designs for the field wind and other grid/regulatory conditions form primary R&D carried out in closed doors within the company for reasons of commercial competition. Indian Wind Atlas preparation with R&D collaboration, micro siting of wind turbines using several wind modelling software, wake studies behind wind turbines, grid interfacing issues relevant to Indian grid, power quality issues, structural health/condition monitoring of blades, towers, and foundations, accurate forecasting and scheduling of wind energy mix in the utility grid, advanced power electronic conversion for variable speed operation of rotors in turbulent winds and measurement and data analytical techniques for power curve measurements and operational fatigue load measurements are some of the active research areas. Being global players exploiting the Indian market with moderate winds (6-7m/s annual average in most places except for few measured offshore sites with 8.65m/s annual average, the consortium based research happens in Europe with CoE (cost of energy) reduction as the primary goal. The paper intends to cover an overview of R&D in India and the required India specific R&D needs to be initiated involving repowering, hybridisation with solar, big data analytics, and the current trend of Internet of Things in effective utilisation of wind power with smart grid technologies, wind power for electric mobility in India, with strong Academic and industrial collaborations in the future.

Introduction

Energy is critical to the economic growth and social development of any country. Indigenous energy resources need to be developed to the optimum level to minimize dependence on imported fuels, subject to resolving economic, environmental and social constraints. This led to a boost in research and development as well as investment in renewable energy industry in search of ways to meet energy demand and to reduce dependency on fossil fuels with ambitious but achievable target of (100GW Solar + 60 GW Wind + 15GW other RE) 175GW by 2022. Wind and solar energy are becoming popular owing to abundance, availability and ease of harnessing for electrical power generation. India has been one of the dynamic market for wind energy development, having fourth largest installed base in the world, having a total installed capacity of over 32 GW of grid connected wind power plants(Table.1) The industry even though had its own ups and downs owing to policy changes and regulatory issues, the industry is largely driven by manufacturers of wind energy equipment in India, with international quality for long term reliability and sustainability.

The research and developmental activities in India has been having a different focus than that of Europe or other western developed countries. Mostly it has been conducted in closed doors of private companies or the corresponding OEMs (original equipment manufacturers) for obvious reasons of commercial competitiveness. In Europe, a consortium based approach towards the goal of achieving cost of energy (CoE) reduction with wind as a renewable resource has been beneficially practiced. Continuous innovations and technological break throughs have made the energy costs (onshore and offshore wind) falling down over the past decades year on year. On the contrary, in India research is happening towards indigenisation in manufacturing components, and the associated production processes and best practices using Indian technical skills to achieve international (IEC) quality standards. The other area of research in wind energy has been using technology to provide investors bankable wind potential, wind integration and interfacing with utility grids and real time wind power forecasting and so on. In spite of Government of India's special financial allocations for research, the proposals from the wind sector have been minimum and not backed adequately from Industry. Fig.1 indicates the % of research grants in various renewable energy technologies. It's not the lack of financial or technical support, it has been the reduced interest of the industry to generate viable research proposals relevant to India. The paper reviews the current research trends in the world as well as in India, and discusses research institutions and on going research along with action plans for the future.

Contemporary Research Orientation in India

Scattered academic interest in wind energy research has been limited to the small wind systems financially facilitated through MNRE, Government of India [1] inviting request for proposals on specific thrust/identified areas.

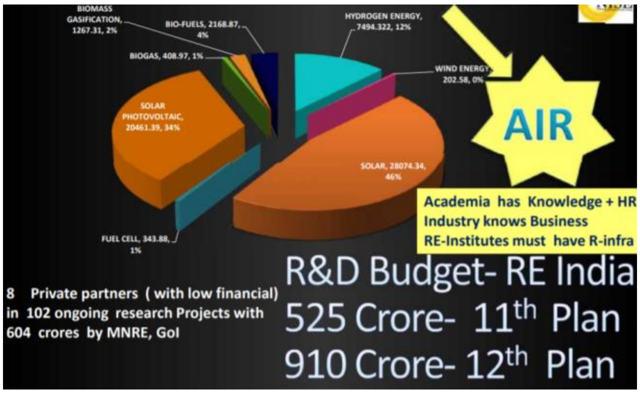

Fig.1. Relative fraction of research projects in Wind Energy

While several institutions in India has renewable energy research programmes, wind energy research is mostly in small wind, few developmental studies at National Institute of Wind Energy, NIWE,which includes wind resource characterisation, wind energy penetration in the Grid, wind power forecasting with scheduling and need based "closed door research" in industries.

Renewable Installed	Cumulative April 2017
Grid connected Wind Power	32287 MW
Solar Power	12505 MW
AeroGenerators,Small Wind	3.1 MW

Table 1. Installed capacity of wind power plants [1]

Institutional Research

Few years back, preparation of a country report was sponsored by APCTT [2] (Asia Pacific Centre for technology transfer –of UNESCAP Country report-India) towards compiling the list of various institutional research in renewables carried out in India. Very few original research projects have been undertaken by the Industry as well as Government of India. However several market research and policy research in renewables have been completed by special institutions and limited research has also been carried out by private educational institutions and universities. The autonomous National Institute of Wind Energy (formerly known as Centre for Wind energy Technology, C-WET, Chennai, India) has several ongoing inter-institutional collaborations Some of them are highlighted in the following:

Wind solar Hybrid systems

NIWE focuses on integrated hybrid renewable energy projects consisting of wind and solar energy. Ministry of New and Renewable Energy directed NATIONAL INSTITUTE OF WIND ENERGY, Chennai to prepare a report on hybrid wind and solar energy production analysis. NIWE, has chosen 24 wind potential sites based on met-masts installed in, Tamil Nadu (Akkanayakanpatti,Melamandai,Veralimalai,kondurpalem),Telangana (Kompalli, Sunkisala, Chadmal), Karnataka (Mustigeri, Taralkatti, Machenahalli, Haikal, Nirana), Gujarat (Suigam, Kuran, Pandhro, Moti Baru, Gaga), Madhya Pradesh (Ganesh Goshla, Jamgodrani Hills) and Rajasthan (Dag, Gara, Bassi)and their respective closest available Solar Radiation details to study the possibility of integrating Wind and Solar power generation projects. This feasibility study report hosted in NIWE's web site [1] gives the over all view of the wind and solar energy generation possible at the respective sites and would help the developer to understand the feasibility and focus, highlighting the potential advantages of the complementary nature of wind and solar in different seasons of the year to develop hybrid projects in the respective states.(Fig.2 &Fig.3)

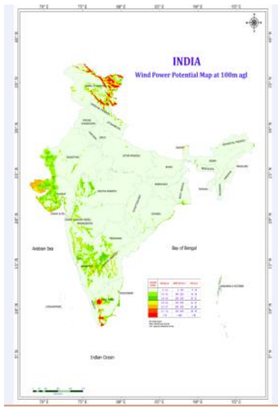

Fig.2 Web-GIS 100m Wind Atlas (niwe.res.in)

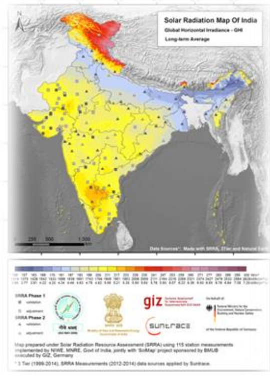

Fig.3 Web-GIS Solar (GHI) Atlas (niwe.res.in)

Action plans for research towards meeting national targets:

Existing capacity and needed growth dynamics:

As on date Wind capacity addition has crossed 32.287GW. With exceedance of target of FY2016-17 (Financial Year) already installed and assuming the balance of set target is likely to be achieved by FY2022, with repowering policies, hybrids of wind solar policies, higher technological interventions, 1GW of CTU(Central Transmission Unit) based BiT (Bid in tarrif mode as against the current mode of FiT) would mean (60-32.287-0.4) about 6.8GW/year as the annual target, from now on, as against 5.8GW/year, an year ago.

Action Plan of Research:1

Facilitation of several new megawatt class WTG manufacturers has been actively supported by Government of India, to make in India. New technology and new game changers are likely to add to annual capacity addition. While NIWE facilitates the OEMs to venture with new models of wind turbines, India specific design of wind turbines are really addressing the low wind regime (annual average wind speeds of 5-7 m/s), but attempts to extract more annual energy by increasing the rotor diameter (swept area, directly proportional power) and increase in Hub-height (increase in wind velocity and the wind power by cube of velocity times).

Action Plan of Research:2

Easy identification of Wind rich sites already made public with the active (Land Use Land Cover incorporated in GIS user-interactive maps) GIS Wind atlas made public at a grid resolution of 0.5x0.5km all over India at 100m above ground level (Fig.2). In parallel, NIWE worked with GIZ, Germany to release the Indian Solar Atlas as well (Fig.3). NIWE was able to make use of its decade long experience of bankable wind data collection and recently wind data resource through a network of high quality wind sensors simultaneously measured at various locations in India. The advantage has been the possibility of knowing upfront the capacity utilisation factors (CUF) possible with a mega watt class wind turbine at the site. {*CUF = (Energy generated in kWh) / (365*24*Capacity of the plant(kW))*}

Action Plan of Research:3

Solarisation of old wind turbines with hybridization involving load sensing adaptive smart converters for effective utilization of Grid and land infrastructure using externally integrated solar of fractional (of wind name plate) capacity of Wind turbine.

The recent desk top study completed [1] (downloadable pdf format report in NIWE's web site) with bankable 100m level data of 24 windy sites provide ready start projects for wind farms. If equal amount of wind and solar are deployed on an average of 61%MU, million units of electricity (kWh) would be realized from wind per MW and 39% MU would come from per MW of Solar(PV) per year, based on the limited production analysis. It is more than obvious that the complementary nature of wind+ solar would be the right road map for renewable development in the country. More so, with steady solar at a base level day power and the seasonal wind in any given year can be optimally used to easily meet the RE target of 100GW solar and 60GW wind just by tapping the low hanging fruits at the already identified locations, where 6-7 GW of wind and 18GW solar with less than 10% of land use can easily be deployed. This means 7GW of hybrid wind is easily possible per year which is more than the need of 6.8GW..

Fig. 4 Seasonal wind and steady solar promises Hybrid in India

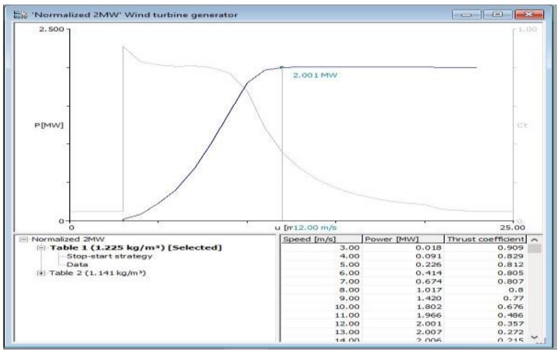

Fig.5 A hypothetical normalised power curve of 2MW wind turbine

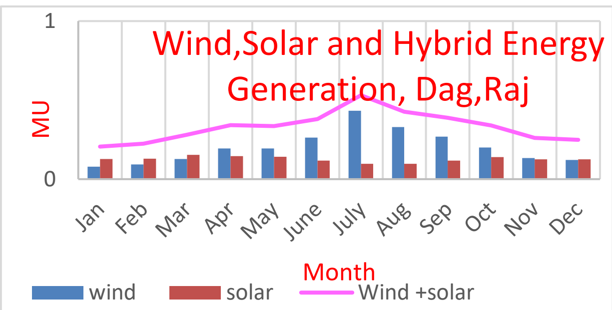

Fig.6 Relative increase of generation with wind solar Rajestan, India
Annual Energy Production/MW - AEP in Million Units
(Wind 24.4MU + Solar(SPV) 15.2MU Hybrid 39.6MU)

Action Plan of Research:4

There has been increasing interest all over the world, to understand the atmospheric wind which is as a result of mere 2% of differentially absorbed solar energy on the earth's varied surface/terrain, so as to accurately predict the wind to assess in real time the available power (kWh) to manage the utility grid. NIWE has been providing high quality forecasting and Scheduling wind power in over 27% of installed capacity in India 7600MW in 108 SSs in TamilNadu, enabling not only conventional power management but also facilitating inter-state sale of excess wind power. A detailed discussion follows in the later section. This is in addition to ongoing Green Energy corridor to strengthen the evacuation infrastructure in the SLDCs (State Load Dispatch Centre). The practical commercial advantage is likely to attract more newer wind power projects.

Action Plan of Research:5

Half a decade from now there is a likelihood of over 2GW of offshore wind power in measured sites with bankable excellent offshore wind for over 10 months in a year with an annual mean wind velocity of 8.65m/s . An economic assessment of different types of towers and to identify the right location for a uninterruptible long term data collection was a key issue. While the wind has been predominantly from an offshore fetch off Tamil Nadu coast using a specially designed corrosion resistant marine quality steel guy supported 100m tall tower was a challenge.Today, over two years of data quality checked bankable wind resource potential has been made available. Attempts to design a LiDAR support platform and installation in the coastal Gujrat also was a big challenge and is on going interest.

Action Plan of Research:6

NIWE's vision plan of research proposals also include research infrastructure other than wind energy engineering such as LVRT (Low Voltage Ride Through), Blade testing and, dynamometer testing facility establishment in India in addition to the already established international accredited certification and type testing services. NIWE /MNRE is fully geared to keep pace with fast track growth path through need based research envisaged by the wind industry to meet the 60GW target.

Inter-Institutional Research

Request for proposals are entertained on thrust areas of wind energy research by NIWE as well as MNRE/GoI, scrutinized by either Research Council of NIWE or Selection committee of MNRE, and eligible projects are financed with progress being monitored periodically for the results as per the deliverable milestones and completion reports are hosted in the web site[1] for public use. Some of the interesting projects involving natural wind are described briefly :

- Development of a low cost laser based wind anemometer for multilevel wind velocity and meteorological parameters based on light back scatter analysis.
- Design and implementation of micro-jet at the blade tip to augment the developed torque to enable the wind turbine to operate under low wind using compressed air stored at the foot of the turbine support tower.

- Determination of drag and lift coefficients of aerofoils for various angles of attack using a wind tunnel.
- Remote continuous health monitoring of wind turbine components and towers during operating wind environment, and development of prognostic analysis and predictive scheduling of maintenance and performance monitoring.
- Design and establishment of wind and solar resource data network nation wide for simultaneous measurement and preparation of long term meso scale Model corroborated, web-GIS interactive Indian Atlases

Industry relevant developmental research in World Wind Energy

The primary goal of the wind industry over the last few decades has been reduction of cost of energy (CoE) per kWh using wind resource. Rather to the investor it is most often the Levelized cost of energy LCoE [14,15] for the useful or designed life of the wind turbine (usually 20-25 years). LCOE per kW system capacity [15]

is defined as, "$LCOE = w + f + c{\cdot}\Delta$, *(1)*

with w as the time-averaged variable cost per kWh, f as the levelized fixed operating cost per kWh and c as the levelized capacity cost of the facility per kWh. Δ is a tax factor that covers the impact of income taxes, the depreciation tax shield and investment tax credits"

Vestas has ventured into development of newer and efficient rotor aerodynamic blade profiles with significant improvements in energy production[3]. Longer blades with taller towers are essentially the proposed solutions for low wind regime like India, with a deeper concern and attention to detailing and developing wind farms with inclusive growth through CSR (corporate Social Responsibility) activities. Focusing on optimising aerodynamic performance using Gurney flap boosters and augmenting energy capture in existing rotors with vortex generators, realised the micro or incremental high Cp value in the power equation

$$P = \tfrac{1}{2} \, x \, \rho \, x \, V^3 \, x \, A \, x \, C_p \qquad (2)$$

The research outcome was able to provide energy efficiency through planned aerodynamic upgrades in multi-brand rotors of most of the wind turbine OEMs around the world, with an extended cut-out wind operation of the rotor avoiding abrupt stop or start of rotor in turbulent winds.

Siemens [4] having merged with Gamesa wind turbines has been pioneer in IIoT (Industrial internet of Things) applications to digitally control production of wind turbine and wind farm operations. Research in these areas have been happening in several wind turbine manufacturers such as GE India [5,6], Envision [12], Vestas [3] ; some are already perfected and in operation, some OEMs use intelligence and Big data analytics to effect improved operations of their wind turbines/wind farms.

GE's Digital wind farm [5] is a generalised platform for several green field projects combining wind conditions derived from meso scale &microscale meteorological variations and managing the necessary control engineering to achieve enhanced annual energy production. Vestas, Chennai India has been monitoring Australian wind farms remotely with their R&D/O&M Engineers engaged in India. In India, sub megawatt wind turbine manufacturers have been rather reluctant to invest in digital technologies in the truly multi-disciplinary area of "Wind Energy Engineering" [13]. Experts argue that mere short term revenue goals may hamper vision of enhanced long term profitability with enhanced production.

Interesting developments are also happening [10], in the maintenance and inspection of long composite blades of wind turbine rotors by combining IIoT and robotics engineering using autonomous drones just as the driverless cars or remote internet executed medical surgeries which are gaining ground and getting accepted.

Gamesa[11] now with Siemens is also said (unconfirmed information through anonymous staff) to have made some break through in designing and manufacturing split blade techniques- which are interfaced (to original designed length) at site, for easy logistics in narrow or rural roads of India, and at hilly terrains.

RegenPowerTech's research[9] has already made India specific wind turbine designs of 2.8MW which is under going field trials as well as perfected an economical wind solar integrated converters by bringing Solar DC power in the core converter of wind turbine with full convertibility by AC-DC-AC system.

Rest of OEMs in India (over a dozen of them, including sub-mega watt class wind turbine manufacturers with limited export market) have very low market demand (in the absence of proactive demand for microgrids with solar and smart grids). They are also hampered by lack of technological design accreditation issues for LVRT, to comply with grid point interfacing as per the new regulations in vogue. The situation has forced these early investors survive with conventional O&M (operation and Maintenace) instead of new green field wind farm development.

Paradigm shift in Wind Energy Research :

In India, the IPR(Intellectual Property Right) focussed research in the wind Energy sector is quite limited. More research has been based on desk top studies on market predictions, policy stability and new improved, policy demands for repowering of existing wind farms, including intercropping, solarisation/hybridization of wind farms, and hybrid energy tariff determination, incentives for energy storage/auxiliary power backed wind farm operators. Developments in Europe indicates a paradigm shift from LCoE driven research in wind sector with a strong recommendation of revisiting science and engineering aspects of basic research.

Recently released publication by a high level multidisciplinary expert group of professors[14] and industrial experts on the needed attention in the wind energy research for the future with a long term vision, focusses the following areas:

"*1. Materials and structures*
2. Wind and turbulence
3. Aerodynamics
4. Control and system identification
5. Electricity conversion
6. Reliability and uncertainty modelling
7. Design methods
8. Hydrodynamics, soil characteristics and floating turbines
9. Offshore environmental aspects
10. Wind energy in the electric power system
11. Societal and economic aspects of wind energy"

with renewed interest to reduce the basic costs of engineering components exposed to ever challenging environmental natural resource, the wind i.e air in motion, much beyond CoE or LCoE over 20+ years. Thinking Wind Energy Engineering seems more appropriate since it is able to cater to multi-faceted science and Engineering from physics and atmospheric meteorology to "IoT and robotics driven technologies". While an elaborate treatment of all the proposed areas would be outside the scope of this conference, let us concentrate on the enlisted challenges which are directly relevant in the context of Wind Engineering (2&3, 4&10) and "as appropriately as applicable" way forward in India.

"Wind, Turbulence and Aerodynamics: Scientific Challenges [14]" and Way forward in India :

"To work out key parameters across scales that enable a rigorous approach to characterise wind conditions"

Mesoscale atmospheric events are in kilometres (geo spatially distributed), microscale needs are quite small owing to dissipation of energy from the large eddies(say mean winds/forward speeds of weather systems) to smaller eddies (say gust winds) (100s of meters in blades, fractions of millimetres in unsteady aerodynamics at the edges and tips of blades) .

In the context of Wind Energy exploitation there is a need to understand the effective spatio-temporal relationship to design more efficient blades suited to a specific site and environmental conditions. Over the years Government sponsored as well as private developer measured wind data is available for gaining the accuracy needed in identifying the sensitive or influencing parameters, involving data mining and analytics through research.

"To understand small-scale turbulence for instationary atmospheric and complex orographic conditions."

In India NIWE/MNRE has already released a GIS wind resource atlas one of the best in the world, having maximum measured data validation at the CUF level (capacity utilisation factor with typical general wind turbine). Simultaneously measured temporal wind data exists for more than a year at 80 geographically located wind monitoring stations in India, which can be analysed with regards to spatio-temporal correlations. Infirmity prediction is a global challenge but data on accelerating and decelerating wind flows from measurements can be characterised by suitable analytics and uncertainty analysis.

"To be able to set up the correct reduced models based on the right scales to comprehend all important features of wind fields in space and time"

Reduced models with the right scale in relation to the physical entity in consideration is reproduced [14] in Table.2

Physical entity	Length Scale (m)	Wind Velocity scale (m/s)	Time Scale (s)
Atmospheric Boundary Layer	0.001	100	0.00001
Aerofoil	1	100	0.01
Rotor	100	10	10
Cluster	1000	10	100
Wind farm	10000	10	1000
Cluster of Wind farms	100000	10	10000

Table.2 Scale needs of wind turbine aerodynamics [14]

Forecasting and prediction with reduced level of models require insight and expertise, as knowledge of high frequency gust wind speeds in the atmospheric boundary layer is crucial and are by nature highly uncertain even few minutes/hours ahead and there is a limitation of a week or ten days beyond which forecasting the wind speeds are quite involved and is all the more difficult in complex or hilly terrains. However, in India suitable meso+microscale and hybrid models have already been validated and put to use in effective forecasting with reduced models which may need just fine tuning of local weather systems. India specific models are continually under improvement in simulation sustaining accuracy levels, for wind energy purposes.

"To work out rigorous methods in order to be able to exploit the growing computational power and experimental advances for clarifying challenging problems in aerodynamics."

India is blessed with state of the art computational hardware and hard core software professionals. With ever increasing availability of computing power at the desk top systems and cloud based shared systems, the once impossible CFD calculations even with multiple and parallel processor systems is now becoming available at ones desk top. Improved user defined turbulence models can be incorporated in fine tuned India specific tropical weather forecasting models to derive extreme meteorological scenarios for effective operations of individual wind turbines and cluster of wind farms. World over aggregation over a large geographical region has been one of the best methods for improved accuracy of energy forecasting, in which India/NIWE has taken pioneering efforts in a State, Tamil Nadu, discussed in later sections with greater details.

"To achieve an understanding of 3D flow pattern and their dynamics on rotor blades including emerging turbulence."

The modern wind resource assessment software systems, are not only based on statistical inference but also uses 3D flow pattern visualisation effectively incorporating orographic and topographical features in the fetch of wind as well as in the wind farm. In the beginning India had only a few institutes such as NIWE, and few private companies such as 3-TIER, AWS-Truewind, and Garrad Hassan to provide a detailed analysis with experience and insight. Today Indian OEMs have strong technical groups having trained wind siting Engineers, working with modern CFD based software environment enabling creation of user defined obstacles and study their effect on 3D flow and the associated turbulence in the field given the rotor and blade operating conditions well before the development of green field wind farm projects.

"To achieve a fundamental understanding of the aerodynamics of wakes and interacting wakes behind wind turbines."

There are practical limitations, in wind tunnel modelling of scaled wind turbines owing to several interlinked similitude compliance issues and realistic atmospheric turbulence modelling. Hence there is obvious issues/unresolved field problems of wind farm and the associated wakes behind wind turbines. Even though dependability of numerical wind tunnel (Computational Fluid Dynamics-CFD) and validation with wind tunnel or field experimental measurements are extremely difficult, it provides by far the more realistic/probable representation of the actual behaviour of wakes behind the wind turbine rotor blade tip. NIWE has measured wind velocity reductions behind a 2MW research wind turbine at its research wind farm and moderately corroborated with CFD simulations to understand near and far field wind velocity reduction and recovery with wake mixing with atmospheric turbulent flow. Many such wind field measurements are needed ; may be in the form of long term big data collection region specific projects to understand the unsteady flow in wake and wake effects.

"***To be at the forefront with the required knowledge to deal with new aerodynamic concepts***"

Earlier the industry's independent efforts to innovate and evolve new concepts of aerodynamic fine tuning of blade profiles, pitching logic has resulted in significant improvements in energy capture by wind rotors. In India great opportunities exist to understand and refurbish performance of existing wind turbines and wind farm with the use of these concepts. It's not only the comprehensive data acquisition and controls that will enable the required knowledge but a structured correlation must be established with wind and turbulence and the wind turbine performance.

While with regards to wind, turbulence and aerodynamics the above referred scientific challenges are aptly identified after a background of status of development by highly knowledgeable cross disciplinary expert group [14], the discussions highlight contemporary trend in Indian scenario and the ample scope for development in the Indian wind industry to revisit the areas with greater rigor.

"*Control and system identification & Wind energy in the electric power system [14]" and Way forward in India:*

"To develop and integrate sensors, data processing, control algorithms and goals, such as reduction of damage actuators, able to handle competing control loads and maximisation of production equivalent via dedicated cost functions."

India is certainly lagging behind in the design and development of appropriate sensors at an affordable cost for robust and accurate field measurements of several physical and environmental parameters in static and in dynamic conditions of wind turbine and wind farm operations. At initial design stage if the health and condition monitoring has been vividly planned and sensors implanted prior to initial erection and commissioning of the wind turbines, the cost of such vital monitoring data would be a small fraction of the balance of plant(BoP) cost. Contemporary research in wind energy in India even in the OEMs has been cost reduction not only CAPEX, but also the operating costs, the OPEX. Often the older turbines lack an integrated approach to data collection. NIWE has demonstrated continuous health monitoring of its 2MW research wind turbine and has been collecting operational data for the past few years, for developing futuristic prognostic analysis and planned scheduling of maintenance of various components as the wind rotor experiences wind and associated turbulence. As the annual average mean wind speeds of most of the Indian sites being in the range of low wind regime (5-7m/s) higher turbulence levels inherent, beyond the design specifications given in IEC 61400 series and later versions.
Hence maximisation of production would be only possible with accurate measured data at site and taking conscious decisions for site-specific fine tuning of the pitch system management mostly by automatic means, which is still a grey area research using upfront dynamic wind capturing nacelle LIDARs and individual blade pitch with feed back controls.

"To integrate all relevant aspects, ranging from time-varying weather models to distributed sensing in the wind plant in a control-oriented wind plant model."

Typically time varying weather models are still a big challenge in a tropical country like India where high performance and high speed computing facilities with low through put time for each weather system simulation are moderate, Upon the geo-spatial orographic modifications close to the atmospheric boundary layer, further complication in modelling the local terrain induced turbulence is to be considered at design stage. The local or regional weather forecasting reliability even for automobile mobility has considerable scatter. With modern Properietary software tools such as "MeteoDyn", "WindSim", "Windfarmer", "WasP" higher versions, have provisions for wind farm or wind plant design with sophisticated micro-sitting of wind turbines minimizing wakes and wake effects and wake interactions. In India both NIWE like institutions as well as international wind energy service companies have adequate technical capacity built for wind farm designs with and without CFD tools. Not only siting of turbines, but also sensor driven network controls are now becoming possible to operate individual wind turbines (on/off/partial load) in the cluster based on prevailing or predicted local wind flow conditions. The contemporary practice of internet of Things (IoT) in wind farms have potential for further improvement using Digital Wind Farm techniques.

"***To determine precisely the stability of a network consisting of many sub-systems driven by sources and sinks with complex randomness like wind power***."

India is currently ranked fourth in the global wind energy league with over 32 GW of installed capacity. Presently, Wind energy installations in India are growing at 21% CAGR (Compound Annual Growth Rate). Tamil Nadu tops India's wind ranking, boasting 7.4 GW in 2015 - 35% of the then total installed capacity in the country. Spurred by the state's support for renewables, wind energy generation capacity in India could rise by 5 GW per annum over the next decade. Infirmity of wind and its implications in electrical sub systems is an issue to be solved. Penetration of wind generation is increasing day by day on interconnected power systems, system operators are facing with increased levels of variability and uncertainty. The integration of increasing amounts of wind into generation mix requires new tools and practices to ensure the continued reliable operation of the grid.

Indian Wind Power Association (IWPA) highlights that two to three billion units of electricity were lost each year in 2013 and 2014 because of wind farm downtime which is due to non availability of proper forecasting mechanism to predict wind power generation. The Indian wind industry faces several hurdles including transmission, scheduling and forecasting problems, resulting in wind turbines being taken off line because grid mangers could not accurately schedule wind power output on to the grid. Realising the need for Big Data such as electrical load measurements and accuracy of number of Million Units (MU, kWh) of power, the utility network is instrumented to stream data into centralised servers. The research and implementation challenges were not only technical but also socio-political. Extension of the success of NIWE with an international collaborator VORTEX from Spain, in the southern state of Tamil Nadu is now being extended to other windy states of India.

"To use wind energy as far as possible to establish a system accommodating the power demand in combination with an efficient ancillary system to guarantee reliability of the power system."

Tamil Nadu's state-owned electricity generation and distribution utility, TANGEDCO, better manage the fluctuations in wind power output in the region. Wind power forecasting plays an important role in the allocation of balancing power. As a technical focal point of the entire spectrum of Indian wind Industry, NIWE has partnered with M/s. Vortex S.L, Spain to enhance wind forecasting initially in Tamil Nadu state. Indian Wind Power Association (IWPA) had approached NIWE to carryout forecasting of Wind power for the entire state of Tamil Nadu as per CERC (Central electricity Regulatory Commission) norms in vogue. Wind Turbines in Tamil Nadu are connected in 102

Substations and the same is being considered under the international research collaboration. NIWE / VORTEX Forecast service is based on a 3rd generation forecasting approach. Pioneering 1st prediction schemes were based on downscale-modeling and 2nd generation ones on statistical training only. NIWE approach takes the better of the two worlds introducing a new combined schemes. With forecast, NIWE enters the very competitive forecast market with a new, fresh approach: making use of our massive cluster (in charge of heavy Wind & Site calculations delivered every day) and an extremely interactive, easy-to-use user Interface.

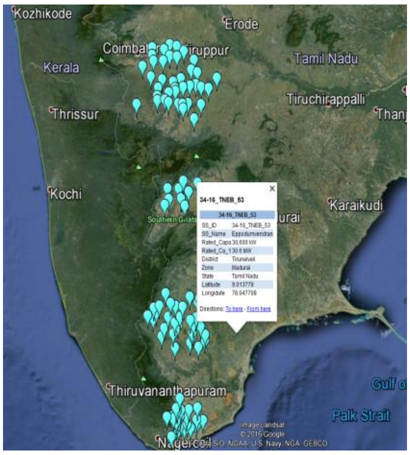

Fig.7 Geo-spatial distribution of Sub-stations of Wind power

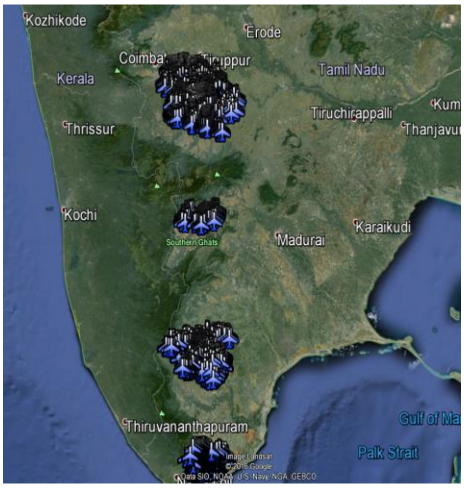

Fig.8 Wind farm clusters in the Tamil Nadu, India

NIWE has developed a new Forecasting service for the wind industry focusing its efforts on two main aspects: highly accurate results and highly customizable service. This is the first time the exercise is being attempted on a state-wide basis, allowing the grid operator in the state load dispatch center (SLDC) to exploit the forecast and real-time data on wind power generation at substation level to schedule evacuation of wind power.

"To optimise complex nonlinear networks for many different parameters and cases and to determine how to combine them."

India has implemented one of the largest cluster of wind farms aggregating to 7.4 GW in one single wind region for effective forecasting and scheduling with international collaborative research resulting in a business case solution in the state of Tamil Nadu. The wind forecasting used a mixed or hybrid model. As latest state of the art forecasting technologies, NIWE uses a mixture of physical and statistical schemes. NIWE generates forecast information by calibrating physical input from global and mesoscale numerical weather prediction models against historical wind farm observations (real or synthetic) with the use of advanced statistical techniques. The obtained calibration is used as learning information which can then be used to project to the future and thus generate forecasted information. NIWE makes use of several global numerical weather prediction atmospheric models, among which the European Centre for Medium Range Weather (ECMWF) Forecasting, deterministic model and the North American Global Forecasting System (GFS) constitute the two main inputs. Both models are used world wide on an operative basis and have been intensively validated. Besides the global models, NIWE / Vortex makes use of the WRF model in order to generate in-house mesoscale data that is also input to our forecasting system, to provide accurate day ahead / Intraday forecast with upto 16 revisions per day (Fig.9) . Forecasting is essential for scheduling wind energy primarily for the following two reasons: Energy should be consumed as soon as it is generated. Presently we do not have a storage mechanism, at the utility grid-scale. Wind energy is not only seasonal but is variable and discontinuous source. How much of wind energy is likely to be generated is difficult to assess in advance. NIWE have developed a technology to assess with a reasonable degree of accuracy of how much wind energy is likely to be generated in the 15 minutes ahead, one hour ahead, day ahead, a week ahead and 10 days ahead etc. The information regarding the likely generation of wind power, will help the SLDC (State Load Dispatch Centre) to schedule the power thus facilitating evacuation optimally.

NIWE / Vortex has developed a Forecasting system by combining the most recent and innovative numerical tools with the know-how and experience accumulated by the wind industry along the past two decades. That is, a very fresh and modern state of the art framework which can be easily adapted to the fast-changing and demanding wind industry sector. NIWE is aware of the several wind industry forecasting needs depending both on the final user profile as well as the electricity market characteristics for each country. By taking very much into account the referred wide range of forecast customers, NIWE offers a fast, reliable and transparent solution.

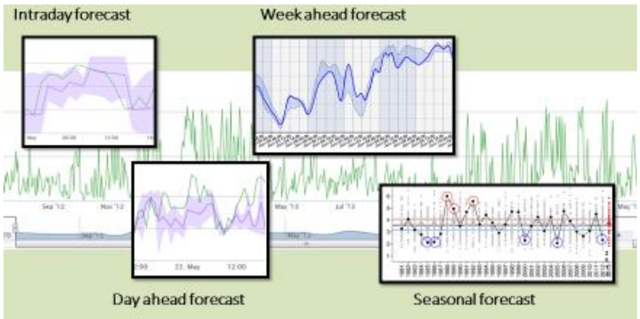

Fig.9 Wind Power Forecasting uses wind data simulations and wind energy generation in non linear distribution net works.

NIWE needs the following three essential inputs to train the forecast model:

- Accurate Historical Generation data of each pooling stations (11kV, 33kV, 66kV
- Real-time wind power generation data from each pooling stations
- Architecture of each pooling stations
- Pooling station wise details of the connected wind turbines/win farm clusters

Currently Indian meteorological weather models are getting improved with satellite or spatially distributed micro level measurements for validation and fine tuning for wind energy applications and to reduce the cost of energy forecasting using commercially traded results of foreign model simulations. The continued research in this direction will facilitate utility grid operators more reliable space-time constrained forecast for higher wind energy penetration.

Summary and Conclusions

The invited paper is continuation of Wind Energy Country report with reference the APCWE, Chennai, India. India is today world's second largest renewable market with second largest wind energy equipment manufacturing capability, in which wind energy has sustained its lead role in the utility grade energy mix.

To be specific, research and development in Wind Energy in India has been based on the business competition among all global players who are mandated to manufacture in India with international accredited design and quality standards (IEC: International Electrotechnical Commission). Basic level "IPR quality" product development research infrastructure is yet to be full fledged and focussed in India, more owing to lack of motivated skilled manpower engaged/deployed in research not for want of adequate research grants.

In line with European plan of eleven carefully identified areas which needed to be studied in detail and to be promoted in the interest of Global community and targets of Climate Change by serious reorientation of resources (manpower, Laboratory and field computational and IoT infrastructure) by dedicated and integrated efforts of industry along with Government of India. It may be authentically stated that, of the decades of experience the resource mapping and wind power forecasting with scheduling, have been closer to that of international quality standards, and results are out of best practices in spite of the anticipated barriers for orderly development in a multi-cultural,multi-religious,socio-political largest democratic economy with over a billion population living with difficulties to showcase unity in diversity.

The Government, Industry,Academia/research Institutions need to force themselves to work harder, together in prioritized areas to achieve wind target of 60GW/ renewable target of 175GW in order to provide 24x7 continuously (on demand) power for all the people of India and extend 'Wind Energy Engineering' technologies to deprived communities elsewhere in the world. Wind Energy today is one of the matured and proven technologies in the world to get started in an orderly way towards a **S**ustainable **G**lobal **E**nergy **T**ransition: **S'GET** with contemporary understanding and advancements of Wind Tunnel or Full scale testing as well as Computational simulations in the area of Wind Engineering.

Disclaimer

The scientific and technical discussions and suggestions have been the author's own opinion based on published or public domain knowledge[1-15] and a decade of interactive industry-institutional experience in the sector [16-20] and is certainly not of that of any State of India or Central (Republic) Government of India.

Acknowledgements

The author, acknowledges with profound gratitude to Professor Richard G.J. Flay, Chair 9th Asia Pacific Conference on Wind Engineering, Auckland, December 2017 for his kind consideration as a keynote speaker in the conference and encouraging me all the support needed to participate in the event and to his team for their excellent follow up and effective coordination.

References

[1] India Web sites :Ministry of New and Renewable energy, mnre.gov.in; National Institute of Wind Energy, niwe.res.in (2017)

[2] Gomathinayagam S., APCTT-UNESCAP, Asian and Pacific Centre for Transfer of Technology of the United Nations – Economic and Social Commission for Asia and the Pacific (ESCAP) : India Renewable Energy Report, November (2012)

[3]Web info (accessed on 26 Oct 2017) //http://nozebra.ipapercms.dk/Vestas/Communication/Productbrochure/ProductImprovements/AerodynamicUpgrades/

[4] Web info (accessed on 26 Oct 2017) //https://www.siemens.com/content/dam/internet/siemens-com/us/home/company/topic-areas/digitalization/documents/cg-mc-digital-future-of-us-manufacturing-en.pdf

[5] Web info (accessed on 26 Oct 2017) https://www.gerenewableenergy.com/content/dam/gepower-renewables/global/en_US/downloads/brochures/digital-wind-farm-solutions-gea31821b-r2.pdf

[6] Web info (accessed on 26 Oct 2017) https://www.gerenewableenergy.com/content/dam/gepower-renewables/global/en_US/downloads/brochures/wind-powerup-gea30967-r2.pdf

[7] Web info (accessed on 26 Oct 2017) http://www.suzlon.com/pdf/media_kit/S97-S111_ProductBrochure.pdf

[8] Web info Acciona-Nordex (accessed on 26 Oct 2017) www.nordex.online.com/.../Nordex_Delta4000_Brochure_en.pdf

[9] Web info (accessed on 26 Oct 2017) http://www.regenpowertech.com/

[10]https://www.youtube.com/watch?v=2otIJKRkroo ; Luleå University of Technology**,** Sweden (accessed on 26 Oct 2017)

[11] Web info: http://www.gamesacorp.com/en (accessed on 26 Oct 2017)

[12] Web info (accessed on 26 Oct 2017) http://www.envision-energy.com/latest/

[13] Pramod Jain,"Wind Energy Engineering", McGraw Hill, (2011)

[14] G. A. M. van Kuik, J. Peinke, R. Nijssen, D. Lekou, J. Mann, J. N. Sørensen, C. Ferreira,J. W. vanWingerden, D. Schlipf, P. Gebraad, H. Polinder, A. Abrahamsen, G. J. W. van Bussel1,J. D. Sørensen, P. Tavner, C. L. Bottasso, M. Muskulus, D. Matha, H. J. Lindeboom,S. Degraer, O. Kramer, S. Lehnhoff, M. Sonnenschein, P. E. Sørensen, R. W. Künneke,P. E. Morthorst, and K. Skytte "Long-term research challenges in wind energy – a research agenda by the European Academy of Wind Energy", Wind Energ. Sci., 1, 1–39, (2016)

[15] Comello, S., Glenk, G. and S. Reichelstein (2017). Levelized Cost of Electricity Calculator. URL: http://stanford.edu/dept/gsb_circle/sustainable-energy/lcoe

[16] Ali M. Abdelsalam, K.Boopathi., S.Gomathinayagam, S.S.Hari Krishnan Kumar, and Velraj Ramalingam, “Experimental and numerical studies on the wake behavior of a Horizontal axis wind turbine”, International Journal of wind engineering and Industrial Aerodynamics, 128 (2014) pp54-65.

[17] Marko Schwandt, Kaushal Chhatbar , Richard Meyer , Indradip Mitra , Ramadhan Vashistha , Godugunur Giridhar , S. Gomathinayagam , Ashvini Kumar, “Development and Test of gap filling procedures for Solar Radiation data of the Indian SRRA measurement network” - Energy Procedia 57(2014) pp 1100-1109

[18] Marko Schwandt, Kaushal Chhatbar , Richard Meyer , Indradip Mitra , Ramadhan Vashistha, Godugunur Giridhar , S. Gomathinayagam , Ashvini Kumar “Quality check procedures and statistics for the Indian SRRA solar radiation measurement network” - Energy Procedia 57(2014) PP 1227-1236

[19] A.Kumar, S. Gomathinayagam , G.Giridhar, I. Mitra , R. Vashistha , R. Meyer , M. Schwandt , K. Chhatbar “Field experiences with the operation of solar radiation resource assessment stations in India” - Energy Procedia 49(2014) PP 2351-2361

[20] Linkedin Profile: https://www.linkedin.com/in/drgoms-dr-s-gomathinayagam-35a9b913