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C-WET
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EDITORIAL

The apparent slow down in the wind power development in the Country is due to gradual realisation of profits by investors using Accelerated Depreciation (AD) in the post-recession, and not due to policies or capabilities. Further, to attract the "non-tax-liable" investors, Ministry of New & Renewable Energy (MNRE), Government of India has already officially launched the Generation Based Incentive (GBI) scheme in December, 2009 which is likely to augment wind power deployment in India.

But research & development in the area of wind energy needs to be done any way in India to bring down the cost per MW. Considerable efforts have been taken by MNRE, in setting up Research Institutions like C-WET and in sponsoring review, survey & research studies, to specialised institutions like World Institute of Sustainable Energy (WISE), Indian Institute of Technology (IITs), Indian Institute of Science (IISc) and Academic Institutions to sustain the growth of wind power development in India. MNRE has been regularly supporting HRD programmes, seminars, conferences, workshops and symposia interacting with other Ministries and through International Collaborations. In this context, it is important to build the infrastructure needed for carrying out research and C-WET is now in a position to undertake industry-specific research to improve performance and also to retrofit old wind machines to operate with full capabilities.

For instance, in this year, C-WET has installed successfully customised alternative controllers for all the nine 200 kW wind generators of MICON make in the R&D wind farm. During the last windy season all the machines were fully operational producing power. In addition to the existing 600 kW constant speed wind turbine, C-WET also has initiated purchase of a MW class variable speed wind turbine with an unconditional agreement signed with the Company to carry on research studies and testing/measurements on the machine.

C-WET's R&D infrastructure built at Kayathar along with sophisticated testing equipment will be used in the areas involving wake effects in wind farms, inter-cropping of higher capacity wind turbine in wind farms with low rated machines and re-powering existing wind farms with megawatt class machines with higher hub heights. Ministry has initiated two independent studies which indicate the potential of re-powering old wind farm, with lower Capital Expenditure (CAPEX) but with 30-40% higher wind energy production.

The R&D unit of C-WET has initiated a wind forecasting study to demonstrate the capabilities of forecasting and the realisation of wind power generation. The R&D unit has also engaged WISE, Pune to conduct a study involving strategic road map for developing the market for small wind turbines and wind solar hybrid systems in India, which is quite low as of now. One of the projects approved by R&D Council on power quality issues in grid connected wind farms has been initiated.

Wind Resource Assessment Unit has been very active in several projects including Meghalaya, Manipur and Himachal Pradesh involving wind monitoring, site validation and new wind mast installations. A few projects on micrositing and due diligence studies are also in progress in parallel.

A review of WRA programmes related to North Eastern Region was held at Shillong, Meghalaya to instruct the State Nodal Agencies (SNAs) to speed up the projects which are viable.

The Testing unit has been planning the installation, commissioning of Virtual Private Network (VPN) based Multi Protocol Label Switching network (MPLS) for remote data downloading from instrumented wind turbines in 2 sites. The system will enable downloading of measured/acquired data at C-WET, Chennai from remote wind turbine experiments, for interium analysis and periodical monitoring.

The Standards & Certification unit has reviewed the documentation and released the new updated RLMM list in December. The unit also organised an intensive hands on training to ten Scientists of C-WET on the "GH-BLADED" software. A team of experienced professionals from Garrad Hassan, UK were hosted at C-WET for imparting the training.

The ITCS unit for the first time organised a special international, self supported, training course on Wind Turbine Testing and Wind Farm Micrositing for Arab Organisation for Industrialisation (AOI), Egypt. The programme included systematic training on testing at Kayathar and demonstration of met mast erection at C-WET which was well received by the participants. The 8th National Training Course on Wind Turbine Technology was attended by 77 participants from Academic/Research Institutions, Industries, SNAs and consultants from various parts of the Country.

Under USAID/SARI Energy project, C-WET Scientists delivered a series of lectures to Srilankan Engineers under Indo-Srilanka Wind Energy knowledge exchange program co-ordinated by InWea. C-WET during the non windy season has been very active in carrying out this human resource development and information assimilation to various stake holders including young students from various engineering Colleges and Universities who keep visiting C-WET often.

I would like to thank the Industry especially Members of Indian Wind Turbine Manufacturers Association (IWTMA) for supporting C-WET's activities of training programmes by their valuable experience sharing, as faculty in spite of their busy business schedule, to educate the stake holders in the wind industry in India.

Once again, C-WET request your valuable feedback on our 'PAVAN' and suggestions to take on serious indigenous research providing you the needed solutions with the C-WET's expertise on all the areas of wind power generation, project development and due-diligence.

S. Gomathinayagam
Executive Director

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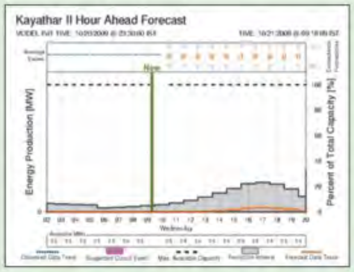
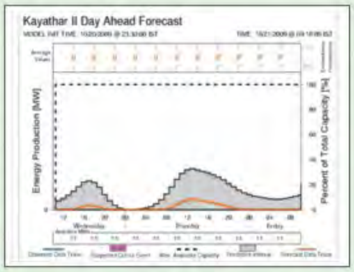
Editorial Board

Developments in R&D UNIT

Wind energy forecasting for the 600 kW R&D / experimental wind turbine – A technology demonstration project

The project was taken up with the aim of forecasting suitable and usable wind energy power that would be available for the 600 kW R&D/Experimental Wind Farm at Kayathar, Tamil Nadu on an hourly, daily and weekly basis and also predicting weather forecast for the site. The results will help in estimating the reliability of the forecasting system and act as a technology demonstrator to wind energy power generation companies.





A Strategic Road Map for Developing the Market for Small Wind Turbines and Wind-Solar-Hybrid Systems in India

The project was taken up to conduct an in depth study to assess the potential market and associated issues for small wind turbine systems in India with a view to utilizing them for providing electricity, water pumping services specially in rural areas.

Study on power quality issues in grid connected wind farms and identification of remedial measures

The project proposes to give recommendations for the appropriate integration of the new wind generation system foreseen for the Indian wind power based on measurements at site and simulation studies.

Move on in WRA UNIT

During the period of October to December 2009, 24 new Wind Monitoring stations in 5 states (Chattishgarh, Maharashtra, Meghalaya, Manipur and Lakshadweep) have been installed. Presently, 100 wind-monitoring stations are operational in 19 states and two in union territory under various wind monitoring projects funded by the Ministry and various entrepeneurs.

Projects on Verification of procedure of wind monitoring have been done for the folowing sites.

- 39 sites from Maharashtra for Maharashtra Energy Development Agency, Pune
- Sindgiri, Balambha, Varvada, Adodar, Gorsar Mocha for M/s. Suzlon Infrastructure Services Ltd, Pune
- Mundra for M/s. Tata Power Company Ltd, Mumbai and
- Agaswadi for M/s. Regen Powertech Pvt. Ltd, Chennai

WRA unit has also completed the following projects and submitted reports during this period.

1) Site Validation & Generation Estimate of Proposed wind farm projects at 50.4 MW wind farm projects at Khandke, Ahmednagar District in Maharashtra for M/s. Enercon India Limited, Mumbai, Sindhgiri & Hearada in Karnataka for M/s. Suzlon Energy Ltd, Pune and 1.65 MW wind turbine at Gudepanchgani, Sangli District in Maharashtra for M/s. Kalani Industries Private Limited, Indore.
2) Performance Guarantee Test of 10.5 MW Wind Turbine Generator at Udyathur site in Tamilnadu for M/s. Suzlon Energy Ltd, Pune.
3) Micrositing of wind farm project at Guledagudda, Kappattaguda in Karnataka for M/s. Karnataka Power Corporation Ltd, Bangalore.

Meeting & Training

A meeting of the WRA programme for the North East region was held on 22.10.2009 at Shillong, Meghalaya to review the progress of the WRA activities in the Northeastern States.

A review meeting on WRA comprising official from MNRE, C-WET and SNAs were held during 10th & 11th November 2009 at C-WET, Chennai to review the progress of WRA projects in 20 states and 2 union territories.

Steps forward in TESTING UNIT

- Shri S.A.Mathew, Scientist and Unit Chief Incharge, had shared the dias as a key note speaker and delivered a lecture on "Wind Turbine Technology in India and its Impact" in the International Conference - Green Power-VI held on 18th November 2009 at New Delhi.
- Load calibration for Safety and Function Testing of 1000 kW wind turbine of M/s. WinWind Power Energy Pvt. Ltd has been carried out.
- Final reports of Safety and Function Testing of 1000 kW wind turbine of M/s. WinWind Power Energy Pvt. Ltd. have been issued.
- Power Curve Measurements reporting of 1000 kW Wind Turbine of M/s. WinWind Power Energy Pvt. Ltd. has been completed and final reports have been issued to the customer.
- Review of procedures as per requirements of ISO 9001:2000 and ISO / IEC 17025: 2005 has been completed.

Marching ahead in S&C UNIT

Documentation / information have been obtained from the wind turbine manufacturers for updating the Revised List of Models and Manufacturers (RLMM) of Wind Electric Generators / Wind Turbine Equipment. Reviewed the documentation and organized the RLMM meetings and the updated RLMM has been issued on 29.12.2009.

S&C unit organized a five day training programme on "GH Bladed" software, provided by M/s. Garrad Hassan Partners Limited at C-WET during 30th November to 4th December 2009 for C-WET Engineers.

GH Bladed Software Training Participants

The certification projects, taken up as per TAPS-2000 (amended) are under progress.

The continual improvement and maintaining the Quality Management System (QMS) are ongoing.

Highlights from ITCS UNIT

Special International Training Course for AOI Engineers

Information, Training and Commercial Services Unit had successfully organized a special International Training Course on "Wind Turbine Testing and Wind Farm Micrositing" for Arab Organization for Industrialization (AOI) Engineers during 19th to 28th October 2009. Five Engineers from Egypt representing the AOI attended the program and learned about Testing of Wind Turbines and Wind Resource Assessment in a detailed manner.

The objective of the training programme was to transfer knowledge and to develop special skills needed by the wind energy personnel working in the technical and operational fields and to share the experiences from the lessons learnt over the past two decades. This course has provided invaluable platform for dialogue and open exchange of views and experiences.

The AOI Engineers at the WTTS, Kayathar

The training addresses the following topics:

- Overview of Sustaining Wind Energy as Green Power
- Introduction to Testing of Wind Turbines Measurement Techniques
- Introduction to Instrumentation required for Wind Turbine Measurements
- Facilities of WTTS, QMS of Testing Unit and Introduction to IEC Standards IEC TS 61400-13
- Power Curve Measurements
- Load Measurements
- Safety and function Testing
- Operation and Maintenance of Wind Farms
- Power Quality and Yaw efficiency Measurements
- Grid Integration of Wind Turbine
- Introduction to Wind Resource Assessment
- Wind Structure, Statistics and Energy Analysis
- Wind Measurements and Instrumentation
- Wind Resource Assessment by using Remote sensing instruments
- Meso and Micro scale models for wind resource assessment
- Micrositing

AOI engineers participating 35m met mast erection

The total course duration was ten days covering tutorial lectures, exercises and manufacturing facilities & wind farms visits, to give a complete picture of the know-how and how to go about setting up a coordinated wind energy programme at an international level. The course started on 19th and ended on 28th October 2009. The course was appreciated by the participants.

National Training Programme

The ITCS unit had successfully organized the 8th National Training Course on "Wind Turbine Technology" during 9th – 11th December 2009 at C-WET, Chennai. Eighty participants have registered and 77 participants attended the training course from academic institutes, industry, State Nodal Agencies, developers and consultants from various parts of the country. The duration of the course was three days extended by a day due to the demand of the participants in the previous training programmes. The training course was inaugurated by Dr. M. A. Atmanand, Director, National Institute of Ocean Technology after the address of Dr. S. Gomathinayagam, ED, C-WET.

This national training course had addressed all aspects of wind power harnessing, starting from wind resource assessment to project implementation and operations & maintenance in a focused manner.

The Chief Guest inaugurating the course

The course topics were structured in such a way that would be both beneficial for the freshmen in the industry as well as for refresher to the experienced. The course content was well organized and appreciated by the participants. The people who had offered the presentation / lecture for these three days were scientists and professionals with years of experience in the wind turbine industry.

Shri. R. Sellamuthu IAS, Additional Chief Secretary / Development Commissioner, Planning & Development Department, Govt. of Tamil Nadu was the Chief Guest for the valedictory function and he had been kind enough to distribute the course certificate to the participants.

Shri. R. Sellamuthu IAS distributing the Certifiate

C-WET campus visit

The following visits have been organised, where in the C-WET activities, services were explained and the facilities available in the campus were shown.

- Energy auditors, as part of the training course organized by National Productivity Council visited on 29th October 2009.
- Post Wind Day celebration by IWTMA (Certificate distribution and C-WET facility visit for the Winners - School Children) organized on 18th November 2009.
- Professor Kishor Mehta who has been instrumental in establishing wind science and engineering division at Texas Tech University, USA visited on 16th December 2009 and addressed the C-WET scientists, technicians including project staff about the curriculum development activity in the University.
- 20 Students along with two faculty members from Alpha Matriculation School, Chennai visited on 27th November 2009.
- Sri Lankan Engineers visited on 6th November 2009 as part of the 'India-Sri Lanka Wind Energy knowledge exchange program coordinated by Indian Wind Energy Association (InWea).
- Dr. Hassan Younis, Minister for Electricity and Energy, Egypt visited on 18th November 2009.

Egyptian Minister discussing with
the Executive Director, C-WET

WIND RESOURCE ASSESSMENT USING REMOTE SENSING INSTRUMENTS

K.Boopathi, Scientist, Wind Resource Assessment Unit, C-WET

INTRODUCTION

Renewable sources of energy have been contributing a part of the energy requirements of the world. Among the other renewable energy sources, wind energy is the most economic and the most rapidly growing source of energy for the generation of electric power. The Power available in the wind energy is directly proportional to the cube of the wind speed. Accurate measurements of wind speed and turbulence structure of boundary layer at the height of turbine rotors is very essential as the height of commercial wind turbines increases above 150 m. The measurement of wind profiles by instrumented meteorological masts used in the wind energy field are expensive to deploy especially in complex terrain and the extrapolation of the data to higher altitudes is not very reliable and does not accurately reflect the true vertical structure of the wind speed. To overcome these disadvantages, remote sensing techniques can be used as an alternative measurement technique. Most promising remote sensing techniques are: SODAR (SOund Detection And Ranging), LIDAR (LIght Detection And Ranging) and Satellite. SODAR is based on sound propagation, LIDAR is on Laser Doppler principle and Satellite is on microwave scatterometry and Synthetic Aperture Radar (SAR) methods

WHAT IS REMOTE SENSING?

Remote sensing is the use of instruments such as cameras, telescopes, radar and satellite imagery to capture the spectral and spatial properties of objects and materials observable from a distance. Remote sensing technology expands the capabilities of human sight by allowing us to see a multitude of physical and human features over vast areas of hundreds or even thousands of square miles or kilometers.

SODAR

What is a SODAR?

SODAR is an instrument for the measurement of wind speed, remotely, from the ground. It operates by transmitting a short pulse of sound which is refracted by the small scale turbulence in the atmosphere. This turbulence is transported by the wind, and the radial velocity of the air can be determined by measuring the Doppler shift of the sound being refracted from the turbulence. The range of the turbulence is determined from the delay between the transmission of the acoustic pulse, and the reception of the refracted signal. By repeating this process in three different directions, each direction having a large component being orthogonal to the other two directions, the three dimensional wind field can be calculated.

DOPPLER SHIFT

Doppler shift is a change in the frequency of a signal caused by a moving source or target. Imagine a target (a patch of turbulence, for example) moving in the direction of propagation at a speed u and the speed of sound is c, as shown in Figure 1

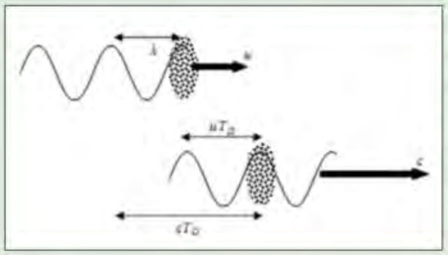


Fig.1. A turbulent patch moving with speed u in the direction of sound propagation. The lower plot shows the distance moved by the patch in time TD, and the distance moved by the acoustic pressure wave in the same time.

At time t = 0, an acoustic pressure maximum is at the target, and the next pressure maximum is a distance away. If this next pressure maximum reaches the target at t = TD, the target has moved a distance uTD and the pressure maximum has moved a distance cTD = λ+uTD. So the period between two maxima at the target is TD = λ/(c-u). The frequency of the sound at the target is therefore

$$f_D = \frac{1}{T_D} = \frac{c-u}{\lambda} = \frac{c}{\lambda}\left[1-\frac{u}{c}\right] = f\left[1-\frac{u}{c}\right] \qquad \text{Eqn.1}$$

The Doppler frequency f_D is less than the transmitted frequency , as sensed by the target If the sound is reflected by the target back toward the source, successive pressure maxima are separated by a larger distance, as shown in Figure 2

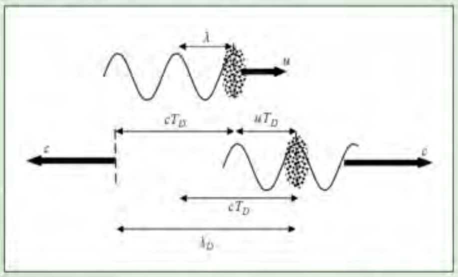


Fig.2: Reflection of sound from a target moving in the direction of sound propagation. The dashed lines show positions of reflected pressure maxima at a time TD after the first pressure maximum reaches the target patch.

Now

$$\lambda_D = (c+u)T_D = \frac{c+u}{c-u}\lambda \qquad f_D = f\,\frac{c-u}{c+u} \approx f\left[1-2\frac{u}{c}\right]$$

So

Eqn. 2 & 3

The change in frequency is approximately 2(u/c)f. This frequency change is used to determine the wind speed components carrying turbulent patches

OPERATING PRINCIPLE

A SODAR antenna emits short acoustic pulses into the atmosphere. The acoustic waves are scattered at temperature in homogeneities in the air. The antenna receives the backscattered signals. Since the temperature inhomogeneities move with the mean wind, a Doppler frequency shift emerges. The frequency shift reveals the wind speed. The amplitude of the backscattered signals supplies information about the thermal turbulence. The duration between emission and reception of a pulse provides the measurement height. By emitting multiple beams into different directions, vertical profiles of three dimensional winds and the turbulence structure are derived. The operating principle and set up of SODAR is as shown in Fig3.

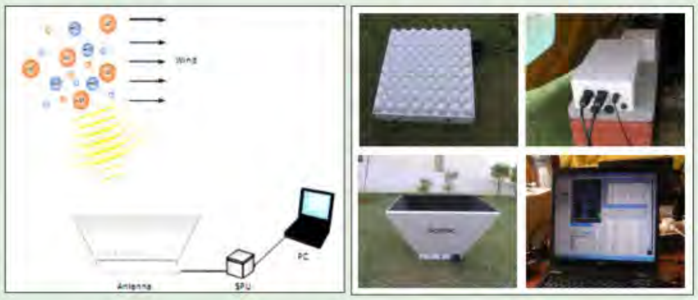


Fig 3.Operation principle and set up of SODAR instrument

OPERATING REQUIREMENTS

SODAR should be operated at a site for a sufficient period of time to collect a representative and statistically robust sample of meteorological conditions for the desired range of wind speeds and directions.

Because the backscattered sound measured by SODAR is dependent upon spatially distributed turbulent temperature fluctuations, and these fluctuations are not necessarily evenly distributed within a height interval (i.e., range gate), very short measurement periods (less than a few days) are generally not very useful. Temporal averaging will smooth out the variation and provide better reliability and comparability with other measurements. Initial evaluation of the quality of SODAR data generally depends on at least 12 hours' data, preferably when wind speeds are 4 m/s or greater at the height level of interest (e.g., wind turbine hub height).

HEIGHT DETERMINATION

In time, t, the sound travels a distance, Ct. If the antenna beam is vertical, the height, z, between the transceiver and the scattering inhomogeneity is (DIN- DVI, 1999):

$$z = \frac{Ct}{2} \qquad \text{Eq.4}$$

Where t is the elapsed time between transmitting and receiving. The minimum measurable height depends on the finite switchover time between transmit and receive modes.

For an antenna whose beam is inclined at an angle to the vertical, it is valid

$$z = Ctcos\,\frac{\phi}{2} \qquad \text{Eq.5}$$

Fig. 4 shows the relationship between travel time of the sound and the target height. The slope of the straight lines is the speed of sound C. It also illustrates that SODAR does not make point measurements, but measurements over a small volume. The radial resolution is determined by the transmission time and the receiving time

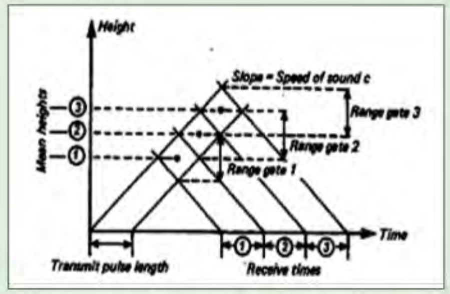


Fig. 4: Schematic showing relationship between travel time and measured height (DIN- DVI, 1999)

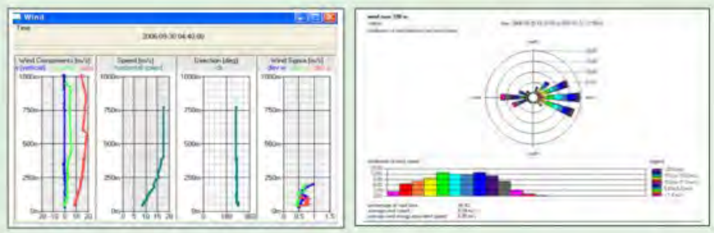


Fig.5 Vertical wind profile u,v,w components and wind rose diagram

Fig 5 illustrates that the vertical wind profiles and wind rose diagram which are obtained from the SODAR measurements

HORIZONTAL WIND VECTOR CALCULATION

Horizontal wind speed WS, and wind direction WD can be directly calculated for each measurement cycle from the wind components:

$$WS = \sqrt{u^2 + v^2} \qquad \text{Eq.6}$$

$$WD = tan^{-1}\frac{u}{v} \qquad \text{Eq.7}$$

However, the standard deviation of these single shot wind speeds can exceed 1 m s^{-1} (or) m/s due to finite beam width, finite pulse length, Hanning shaping and other effect.

ADVANTAGES AND DISADVANTAGES OF SODAR

SODAR system have been used to facilitate research in a number of areas of atmospheric Science, microwave propagation, civil aviation and various other direct applications like wind resource assessment studies

The main advantages of SODAR are

- Easily installable at any place even with non experts
- Continuous operation and measurement without human intension
- No intrusion into the space being sampled
- Low labour cost for measurements
- Very high resolution three dimensional measurements (Height, Time and Intensity) image of the lower atmosphere with three components of wind(zonal, meridional and vertical)

And moreover SODARs can be used for,

- Characterization of local micro climate
- The wind monitoring at airports and parachute drop zones
- Wind power assessment
- Blast notice monitoring, prediction and minimization

Disadvantages are

- Range: Sound is attenuated in the atmosphere. Attenuation increases with increasing frequency. With increase in temperature and /or lower the relative humidity the attenuation of sound increases.ie. The height performance of a SODAR in a hot dry desert may be only 60 % of the same instrument in a cool damp location.
- Audible sound: Because of use of audible sound SODAR use may be limited in built up areas.
- Back ground noise: The back ground noise can limit the SODAR performance. Therefore SODAR should not be used in areas where the noice level (at the frequency of operation of SODAR) is high
- Local structures: SODARs should not be installed near structures (or vegetations) which can produce fixed echoes.

LIDAR

What is a LIDAR?

LIDAR is an acronym of LIght Detection And Ranging. It is a technique to measure the distance between the sensor, a laser source of light and an object. By precisely timing of the round trip return time of a pulse of light backscattered from the target, its location can be calculated. With a solid object, the return pulse of reflected light will be sharp. With a diffuse object, such as a forest canopy, there will be many return pulses reflected by different elements of the canopy. Using high speed and precise timing of the return pulse, information about the 'depth' effect can be determined.

A LIDAR consists essentially of five subsystems: (1) a transmitter, in all practical cases a laser, mostly, but not necessarily pulsed; (2) a transmitter optics; (3) a receiver optics; (4) a detector; and (5) an electronic system for data acquisition, processing, evaluation, display, and storage (Figure 6).

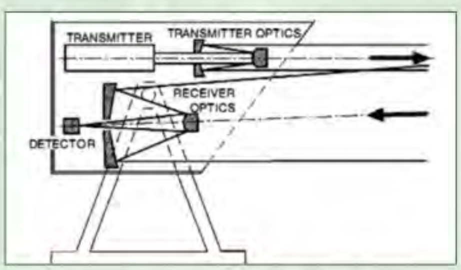


Fig.6 LIDAR setup and operating principle

Most LIDARs have additional components that differ considerably according to type and purpose of the LIDAR. These can be one or more additional lasers; one or more additional receivers; optical fibers in the transmitter or receiver optics; passive wavelength-selective devices such as absorption cells, filters, monochromators, and spectrometers; active devices for wavelength selection and adjustment; polarizing and polarization sensitive components; some kind of beam-steering gear;manually operated or automated alignment aids; one-way or interactive diagnostic systems for long-term unattended operation; protective shutters; and some kind of shelter or housing often called "platform" with an infrastructure that provides power, temperature control, operator accommodation, displacement possibilities, orientation stability, telemetry, etc., as the case may be. LIDARs range in size from a shoe box to a 40-ft container, and beyond. LIDARs are by definition monostatic, that is, the transmitter and the receiver are at the same location. They may be coaxial, with the axes of the transmitted beam and receiver field of view coinciding, or side by side or biaxial, with the two axes parallel or near-parallel, but not identical. The transmitter optics of a lidar serves the dual purpose of expanding the laser-beam diameter in order to reduce the area density of the laser pulse energy and of reducing the divergence of the laser beam. The receiver optics collects the backscattered light and focuses it onto the detector. Suitably programmed, the associated electronics takes the signals from the detector, extracts and conditions the relevant information, processes the signals to convert them to the physical quantities of interest, and displays, recombines, and compresses the data for long-term storage.

LIDAR Techniques

There are five basic LIDAR techniques which make use of specific interaction processes of the emitted radiation with the atmospheric constituents and which are:

(a) elastic-backscatter LIDAR (b) differential-absorption LIDAR (c) Raman LIDAR (d) fluorescence LIDAR (resonance) and (e) Doppler LIDAR.

Scan Techniques

As pulsed Doppler lidars measure profiles of the line-of-sight wind velocity, vertically pointed systems directly provide the profile of the vertical wind velocity. For the horizontal wind, the LIDARs must be tilted out of the vertical. In this way the horizontal wind produces a line-of-sight component to the LIDAR signal, and with appropriate scanning schemes the three-dimensional wind vector can be inferred. A necessary assumption is horizontal homogeneity of the wind field over the sensed volume. Vertical homogeneity, however, is not required.

VAD (Velocity Azimuth Display) Technique

When a conical scan is carried out with the apex of the cone at the LIDAR scanner as depicted in Fig. 7 and, for a given height or distance, the velocity signal is displayed as a function of azimuth angle, a plot as the one shown in.8 is obtained. From this display of velocity versus azimuth the technique got its name of velocity-azimuth display, or VAD. In the ideal case of a homogeneous atmosphere the measured LOS component shows a sine-like behavior (Fig.8)given by

$$\upsilon_r = -u \sin\theta \cos\varphi - \upsilon \cos\theta \cos\varphi - \omega \sin\varphi \qquad \text{eq.8}$$

u- The west–east component,

υ- The south–north component,

ω- The vertical component,

θ- The azimuth angle, clockwise from North, and

φ- The elevation angle.

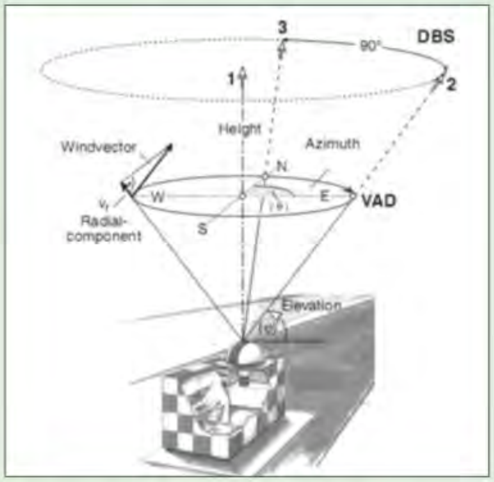


Fig.7 Schematic of the scan technique of a Doppler LIDAR Lower part: VAD scan upper part: DBS scan

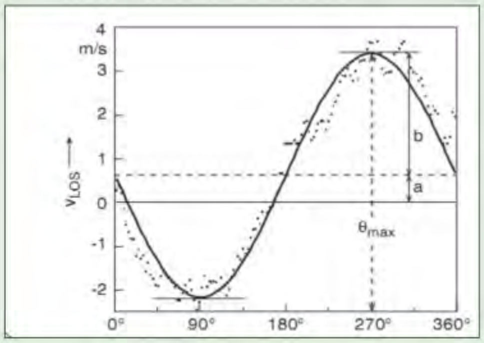


Fig.8 Example of sine fitting of the radial wind velocity simulated with the use of the VAD

If we fit this to a function of type

$$\upsilon_r = a + b\cos(\theta - \theta_{max}) \qquad \text{Eq-9}$$

With offset a, amplitude b, and phase shift θ max, we immediately gets the three-dimensional wind vector

$$\boldsymbol{u} = (u, \upsilon, \omega) = (-b\sin\theta_{max}/\cos\varphi, -b\cos\theta_{max}/\cos\varphi, -a/\sin\varphi) \qquad \text{Eq-10}$$

With this, the horizontal wind speed uhor is

$$\boldsymbol{u}_{hor} = (u^2 + \upsilon^2)^{1/2}, = b/\cos\varphi \qquad \text{Eq-11}$$

The horizontal wind direction dd, as westerly wind, i.e., blows from the west,

$$dd = \theta_{max} \qquad \text{Eq-12}$$

vertical wind velocity ω, defined as positive for wind up, is

$$\omega = -a/\sin\varphi \qquad \text{Eq-13}$$

and total wind speed is

$$|u| = (u^2 + \upsilon^2 + \omega^2)^{1/2} \qquad \text{Eq.14}$$

For a VAD scan, a separate sine-wave fit is done for each height interval. From each of

those one set of data a, b, ¸max and, consequently, u, v, w is obtained for each height interval.

Conclusion

Remote sensing technologies can be used for atmospheric studies and for the assessment of the wind resource needed for the wind industry. These technologies can be used where the standard instruments (cup anemometers & wind vanes) need met masts for their mounting and the cost associated with the erection and instrumentation of the met masts increases rapidly with height and the place (complex terrain) where the met mast cannot be installed.

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