



APPLICATION NOTE

ONLINE MONITORING OF WIND TURBINES

1 INTRODUCTION

Wind power or wind energy is the use of wind to provide mechanical power through wind turbines to turn electric generators and generate electricity. In other words, it converts the wind's kinetic energy into electrical energy.

Wind power plays a key role when it comes to renewable energy and is one of the fastest-growing renewable energy technologies today. The global installed wind-generation capacity onshore and offshore has increased by a factor of almost 75 in the past two decades, jumping from 7.5 gigawatts (GW) in 1997 to some 564 GW by 2018. According to the International Renewable Energy Agency (IRENA) in 2016, wind energy accounted for 16% of the electricity generated by renewable energy sources.

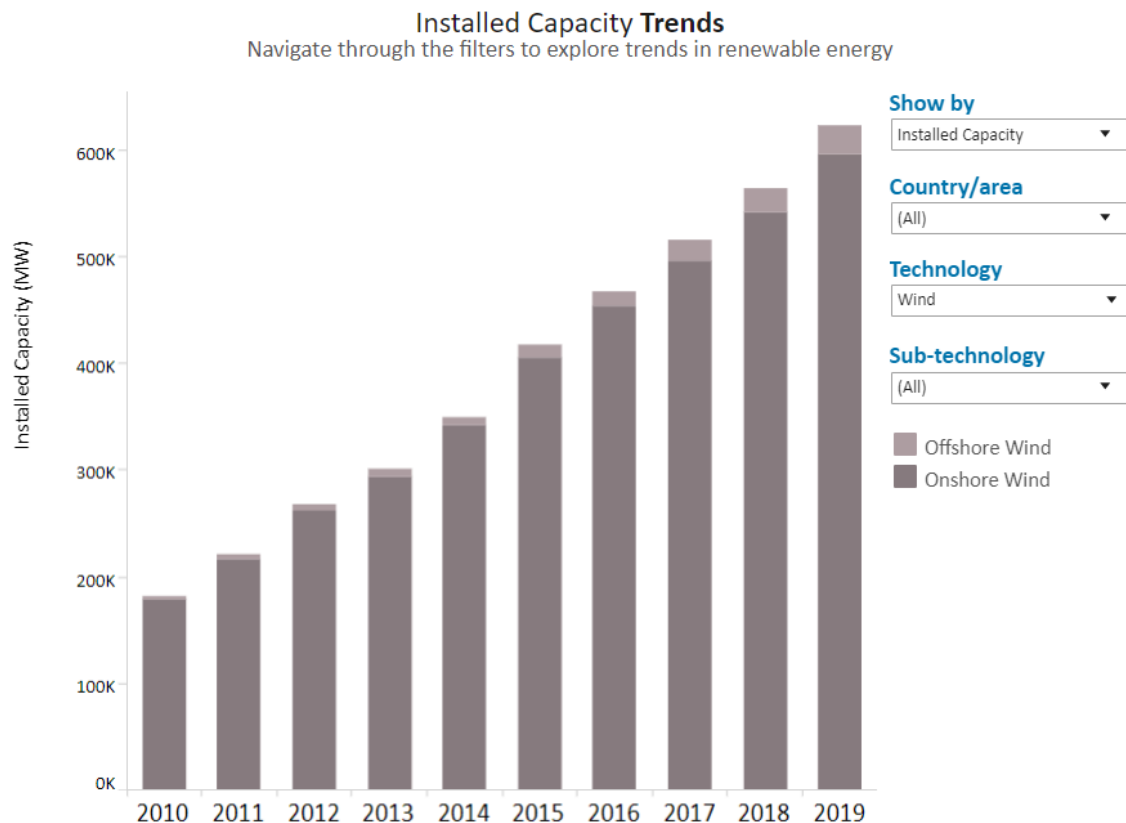
Arrays of wind turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels.

Wind turbines provide a clean energy source, use little water, emitting no greenhouse gases and no waste products. Wind power had the lowest relative greenhouse gas emissions, as compared to photovoltaic, hydro, geothermal, coal and gas. Over 1,500 tons of carbon dioxide per year can be eliminated by using a one-megawatt turbine instead of one megawatt of energy from fossil fuel.





As per IRENA, the total installed capacity of wind energy in the whole world is. 622,704 MW. China is the world leader in wind energy, with an installed capacity 221GW i.e. around a third of the world's capacity. The US is in second place with 96.4GW of installed capacity India with 37.5 GW in 2019 is no. 4 in the world. India is likely to install 54.7 GW of wind capacity by 2022 against the 60-GW target set by the government. Please see the below graphic for the year by year growth of wind energy worldwide.



The global wind turbine market was valued at \$81.2 billion in 2016 to reach \$134.6 billion by 2023 and is anticipated to grow at a CAGR of 7.2% from 2017 to 2023.

There are over 341,000 no. wind turbines on the planet and are installed both offshore and onshore from the turbulent seas and intense heat of the deserts to the green hilly areas. Wind turbines can be very large, reaching over 140 m tall and with blades 55 m long.

In the wind energy market, one thing above all counts: lowest generation costs or Cost of Energy (CoE). And these, in turn, require highly efficient wind turbines that run smoothly and without disruption. Structural health monitoring of the wind turbine and its foundations plays an important role to achieve this. It is also very important from the safety point of view as a turbine collapse can be catastrophic.

Encardio-rite offers a wide variety of sensors for monitoring foundations and towers of the wind turbines such as vibrating wire embedment strain gages, VW sister bars, soil and concrete interface pressure cells, electronic plumb lines, liquid level settlement system, tilt meters, multipoint borehole extensometers, etc. The sensors have a proven track record for reliability and long-term performance under harsh conditions. If used diligently, these instruments can provide important quantitative information about the behavior of the key structural elements of the wind turbines and provide an early warning of any impending failure.

The online web-based monitoring service provided by Encardio-rite enables critical data at the client's desk with automatic alerts, to warns the related authorities in case any of the monitored parameters breaches its trigger value.

Encardio-rite also has expertise in advanced non-contact technologies used for safety monitoring and risk assessment of structures, such as automatic 3D deformation monitoring using ATS, laser scanning and survey using drones.

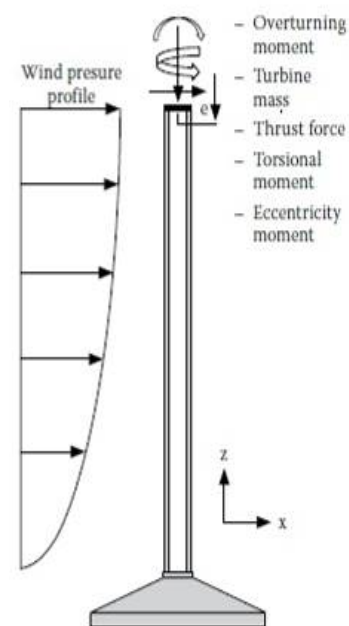
2 PURPOSE OF THE MONITORING SYSTEM

The structural integrity of the tower and its components is a critical element to ensure the lowest cost of energy and safety of the surroundings. With the stochastic nature of the load regime endured by a wind turbine a tailor-made structural health monitoring system is required to monitor the integrity of the concrete foundations supporting the tower and the tower itself.

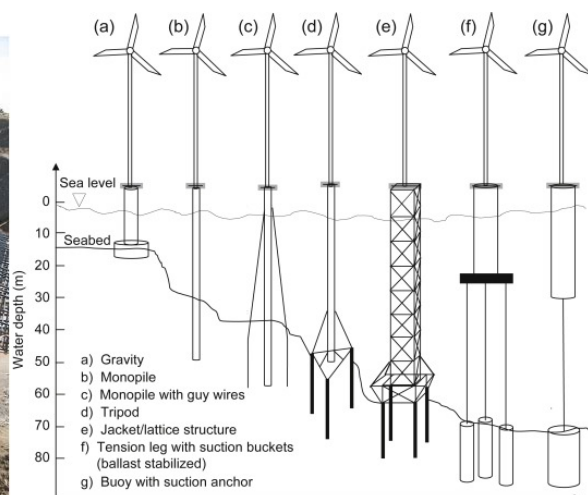
The figure given in the right shows the various loads acting on a wind turbine. The figures given below show various types of wind turbine foundations.

Purpose of monitoring a wind turbine are as follows:

- Verify the design and long-term performance of foundations.
- To get information on the current state of the rock-to-foundation interface during operation of its turbines
- Increase turbine performance, improve durability and decrease loads.
- Improve decision making and risk management process.
- Data to determine the effects of natural calamities such as earthquakes, cyclones, flooding, etc. on the wind turbine.
- Generating long-term reliable data.



Loads acting on a wind turbine



Types of foundations of on shore (left) and off shore wind turbines (right)

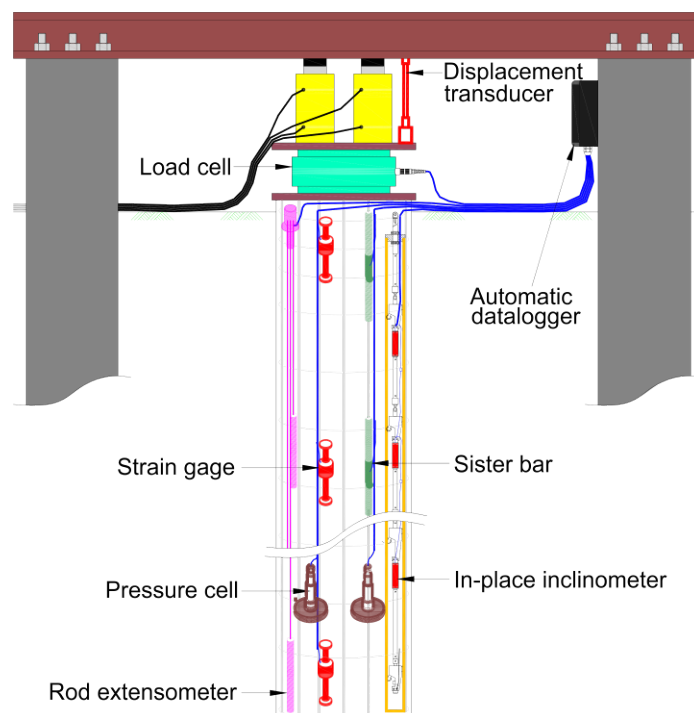


3 STRUCTURAL MONITORING SOLUTIONS

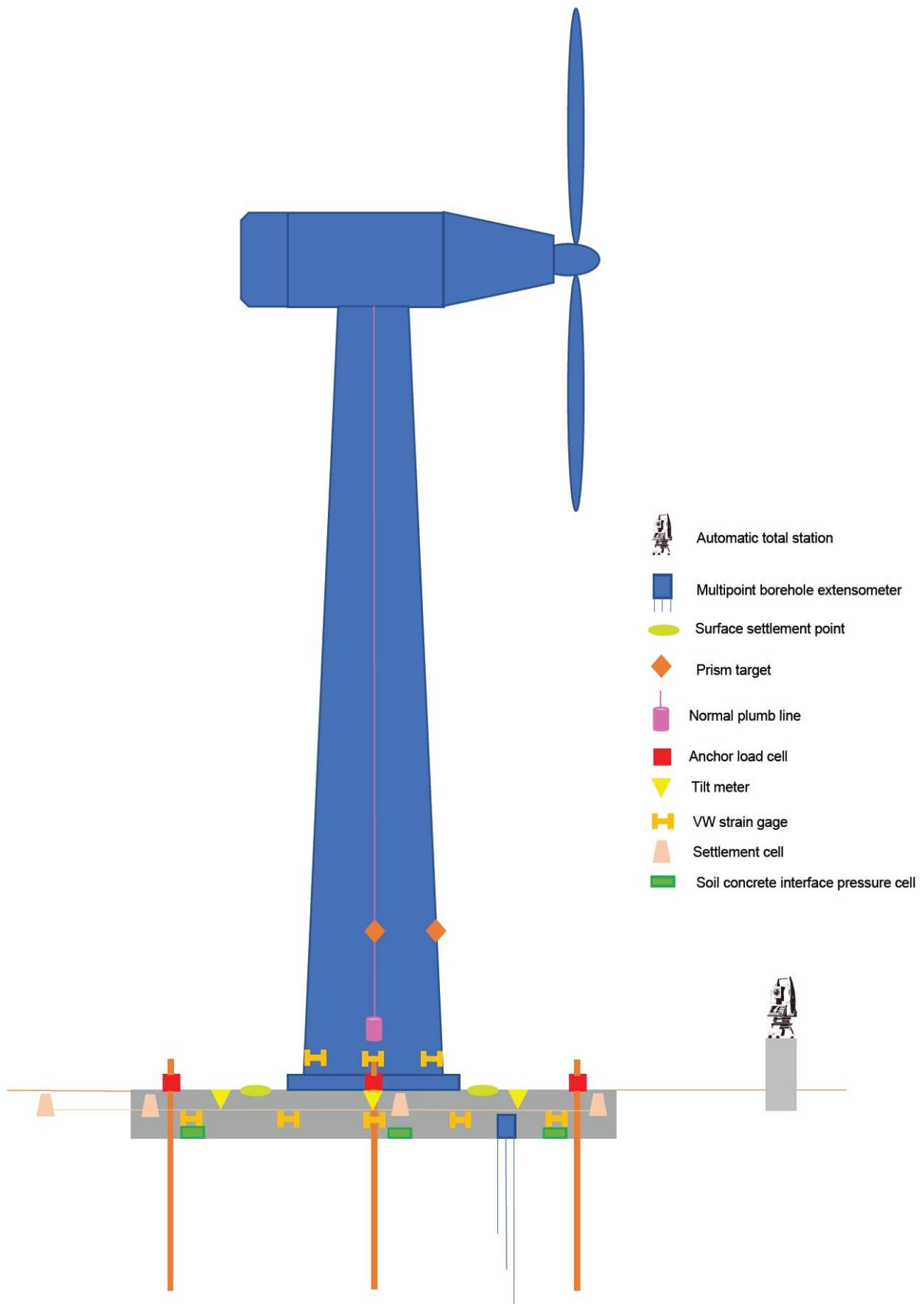
The following are the comprehensive range of sensors produced by Encardio-rite for performance and structural monitoring of wind turbines. These are for measuring vital parameters such as load distribution along the pile or raft foundation; effectiveness of lock-off bolts; tilting of the tower, movement between the foundation and the underlying soil/rock material foundation, settlement, etc.

Parameter	Instrument	Application area
Foundation's settlement (z)	Model EPS-12-60 topographical marker/surface settlement points monitored using a digital level with invar staves.	At the upper surface of the wind turbine's foundation
	Model ESM-30V vibrating wire liquid level settlement system	Fluid-filled vessels/pots of the system are embedded in the concrete foundation and the reference vessel is placed outside in the stable ground.
3D movements (x, y & z)	Model ERT-20P2 mini prism target monitored using a manual or automatic total station.	At the wind turbine's tower. The height of the placement of the prisms is mainly limited by the distance of placement of the ATS.
Lateral movement (automatic)	Model EAN-52M vertical in-place inclinometer system with several biaxial probes with SDI-12 output mounted vertically in a borehole. These are connected in a daisy chain manner with a single output cable for continuously monitoring sub-surface lateral movements	For measuring lateral movements of a pile foundation of the wind turbine during testing Can also be used for long term monitoring
Lub-surface lateral movement (manual)	Model EAN-26-MV manual inclinometer system comprising of a bi-axial digital inclinometer probe, operating cable on a reel with Bluetooth transceiver and a smartphone datalogger with inclinometer application	
Sub-surface relative settlements	Model EDS-70V vibrating wire type multiple point borehole extensometer	In the pile/raft foundation of the wind turbine. The head will be coupled to the wind turbine's foundation and various anchors will be grouted to a different stratum of the ground below. The deepest or the reference anchor has to rest in deep stable rock.
	Yield-point's d-EXTO Mk II multipoint borehole extensometer with up to six (6) Linear Variable Induction Transducers (LVIT). All rods are housed within a single fiberglass tube. The maximum diameter of the MPBX is 25 mm including the head assembly.	
Change in tilt	Model ESDL-30MT or EAN-95MW (RF) tiltmeters to record changes in the tilt of the foundation and the tower	At the upper surface of the foundation and the tower's body

Parameter	Instrument	Application area
Crack monitoring	Model EDJ-40V vibrating wire crack/joint meters for monitoring Model EDJ-40C2 Mechanical bi-axial crack meter	Across the existing cracks in the foundation
Tension in tie-down anchors for stabilizing the foundation	Model ELC-30S resistive strain gage type center hole load cell with 8 no. foil type strain gages or ELC-32V vibrating wire type center hole load cell with up to 8 no. VW elements	Between the locking nut or wedge plate of the tie-down anchor and the top of the foundation
The load applied on the foundation's pile during testing	Model ELC-150-SH high capacity compression load cell	At the top of the pile during testing.
Stress at the concrete soil interface	Model EPS-30V-I vibrating wire soil-concrete interface pressure cell	At the base of the wind turbine's foundation
	Model EPS-30V-J jack out pressure cell	At the base of the pile foundation
Strain in the foundation and the tower	Model EDS-20V-E embedment or EDS-20V-AW arc weldable strain gage or EDS-12V sister bar strain gage	Embedded in the foundation tied to the reinforcement cage or welded to the tower's structure close to the base and at other critical locations
Movement of the top of the tower relative to the foundation	Model EDS-50 normal plumb line with model EPR-01S telecoordinometer to monitor relative horizontal movements in x & y planes	Invar wire of the plumbline to be anchored to the top of the wind turbine's tower



Typical instrumentation scheme of a wind turbine pile foundation testing



Typical instrumentation scheme of a wind turbine

Encardio-rite provides two options to automatically log, store and transmit data to a central server from most of the above-mentioned electronic sensors:

- Model ESDL-30 SDI-12 data logger with an integral GSM/GPRS modem. Interface cards are available for conversion of sensor outputs to SDI-12 digital output, where the sensors do not have an SDI-12 interface output.
- Model EDAS-10 based on Campbell Scientific's CR1000 measurement and control module with GSM/GPRS modem.

Encardio rite provides a range of shielded armored/non-armored cables from 2 to 40 cores for connecting the above sensors to the readout devices/dataloggers. Necessary splicing kits, junction boxes, switch boxes, protective enclosures, and covers, lockable manhole covers are readily available to execute simple to complex instrumentation schemes. It also provides several solutions to reduce cable lengths by using multiplexers, SDI-12 interface and wireless transmission using the allowable RF band.

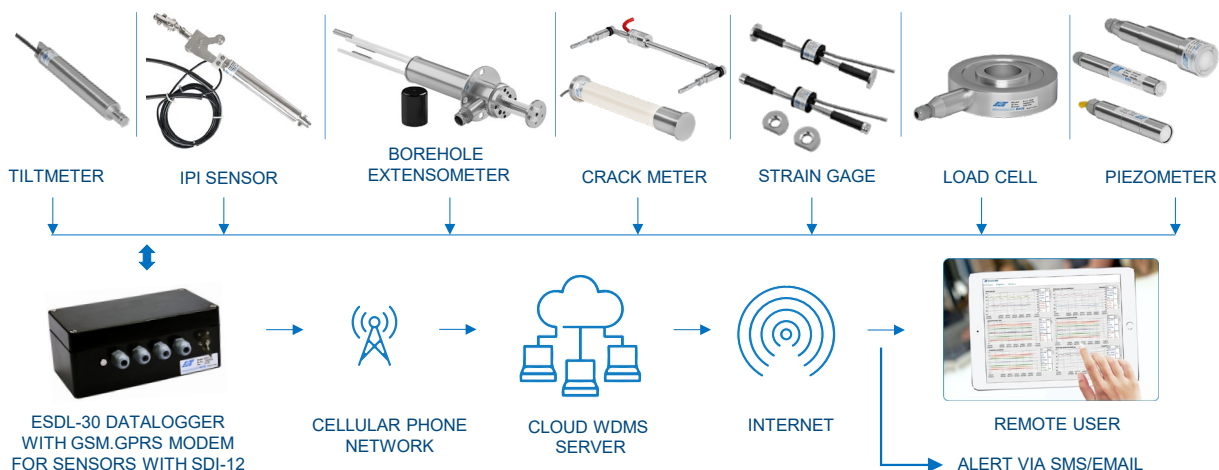
Lightning Protection: Field instruments are vulnerable to lightning damage in the areas with a high rate of lightning strikes. Although a tripolar plasma surge arrestor is inbuilt into most Encardio-rite sensors to protect these against voltage spikes across the input leads, an additional lightning protection system is recommended. It is preferable to engage a local agency specializing in earthing and lightning protection systems to implement the same.

For 24X7 near real-time data access Encardio-rite provides online web data monitoring service (WDMS) that presents the data of the above sensors as graphs, tables, overlaid on georeferenced maps, site plans, etc. It enables automatic alarms to the authorized users at different locations, on their computers/laptops. More details are given in the following section.

4 AUTOMATIC WIRED SENSORS MONITORING SYSTEM

Encardio-rite offers advanced automatic dataloggers with an in-built GSM/GPRS modem for data collection of geotechnical instruments with SDI-12 digital interface and transmission to a remote server. The dataloggers can be programmed to measure once every 5 seconds to once every 168 hours.

The measured data is stored, together with the current date, time and battery voltage, as a data record in the internal non-volatile memory of the datalogger. An alarm is triggered or SMS is automatically sent if any of the pre-determined trigger values are exceeded.



Remote real-time monitoring system with SDI-12 digital interface sensors and dataloggers

The advantage of the system is that only a single 3 conductor cable is required to interconnect all the sensors in a daisy chain configuration and eventually to the datalogger. SDI-12 is a multi-drop interface that can communicate with multi-parameter sensors.

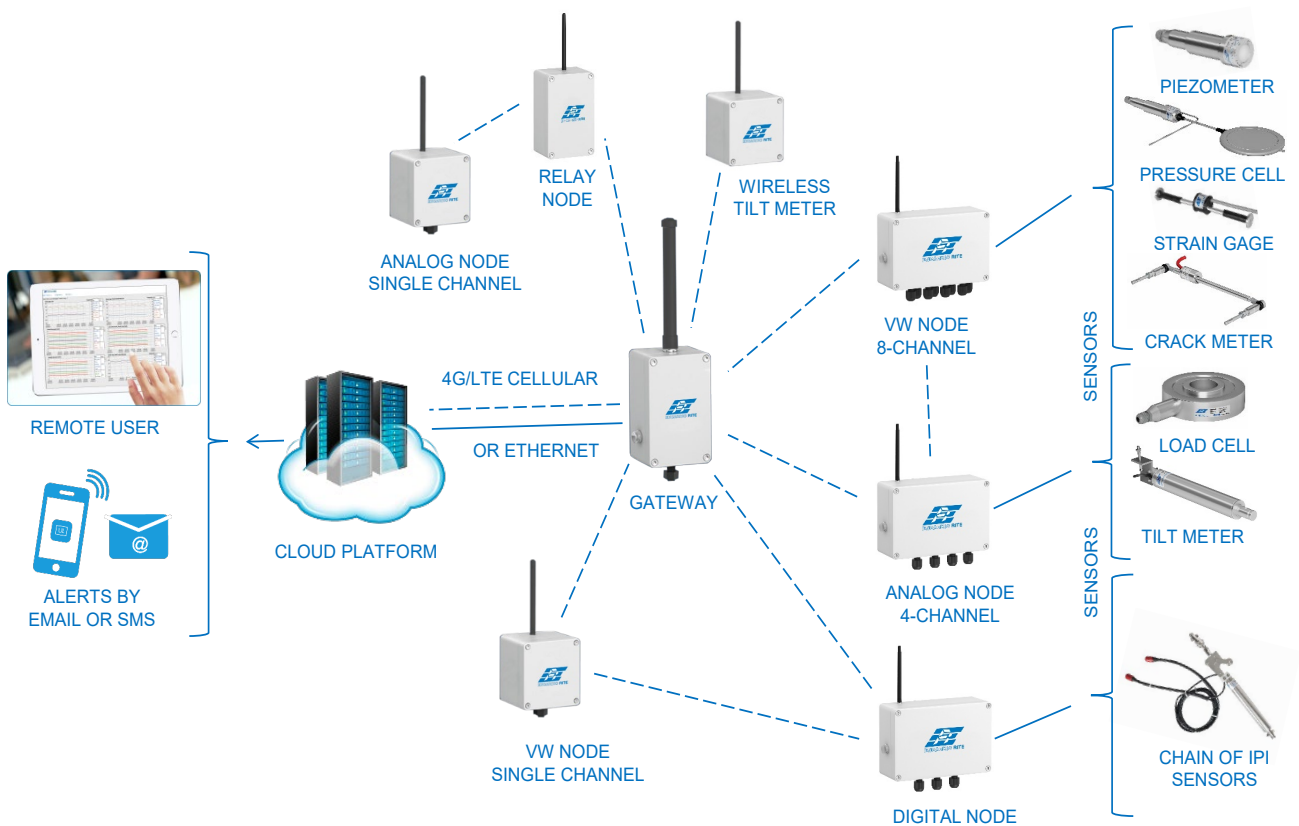
5 AUTOMATIC WIRELESS SENSORS MONITORING SYSTEM (RF)

Encardio-rite offers a state-of-the-art multi-hop wireless mesh network solution that allows real-time monitoring of geotechnical sensors in challenging projects, with reliable data transfer over long distances without any delay.

The system comprises sensors interfaced with the long-range, low power mesh network through nodes that send recorded data to the gateway with over 99 % reliability. The gateway uploads the collected sensor data to the central/cloud server.

The unique feature of our innovative mesh network is that even if a node cannot reach the gateway directly, it can send its data to the gateway via other nodes in the network. The mesh network allows all nodes to talk to each other, thus allowing them to relay data from other nodes to the Gateway. This ensures that data from all nodes are transferred to gateway (and hence cloud server) without any delay.

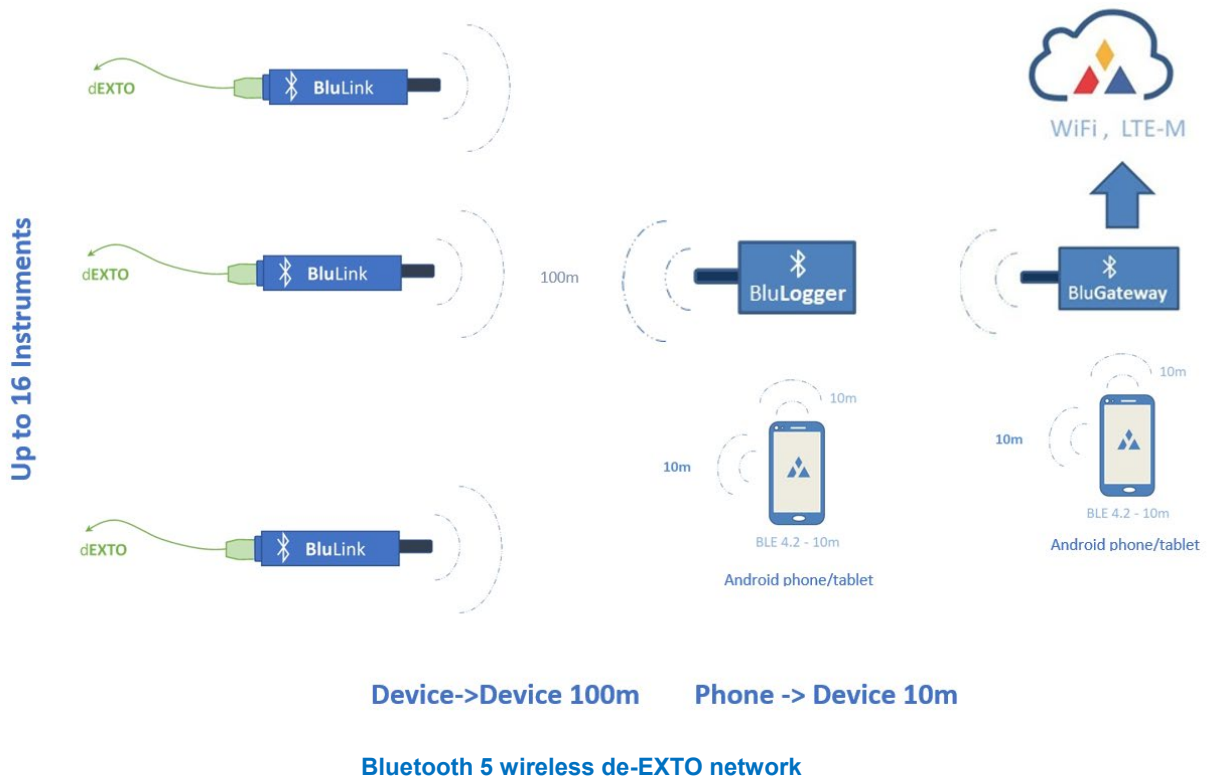
The wireless system eliminates the need for running lengthy cables, thus offering benefits such as convenient installations, cost & time savings, remote monitoring of hard to access locations and easy maintenance.



Remote real-time monitoring system with wireless (RF) nodes and gateways

6 BLUETOOTH 5 BASED WIRELESS SENSOR NETWORK

YieldPoint's d-EXTO digital MPBX can be wirelessly networked in a star topology for data retrieval and transmission using an extremely low energy data transfer technology, based on Bluetooth 5. It features the same low power features like Bluetooth Low Energy (BLE) but with 4 times its range (100 m). The Bluetooth devices of the wireless network include BluPoint which enables Bluetooth connectivity to the digital MPBX, BluLoggers, and BluGateways. The above Bluetooth device also allows the site personnel to take the latest readings with an Android phone or tablet installed with BluPoint App. From a distance of around 10 m. BluGateways can autonomously collect data from BluLink or BlueLogger and transmit it via a WiFi or LTE-M network to a central server. BluLoggers can also be fitted to vehicles to wirelessly collect readings from sensors with BlueLink during a drive-by. The above Bluetooth devices run on lithium or alkaline batteries. With 1 reading/hr the alkaline batteries will last 2-3 years, and lithium batteries over 4 years.



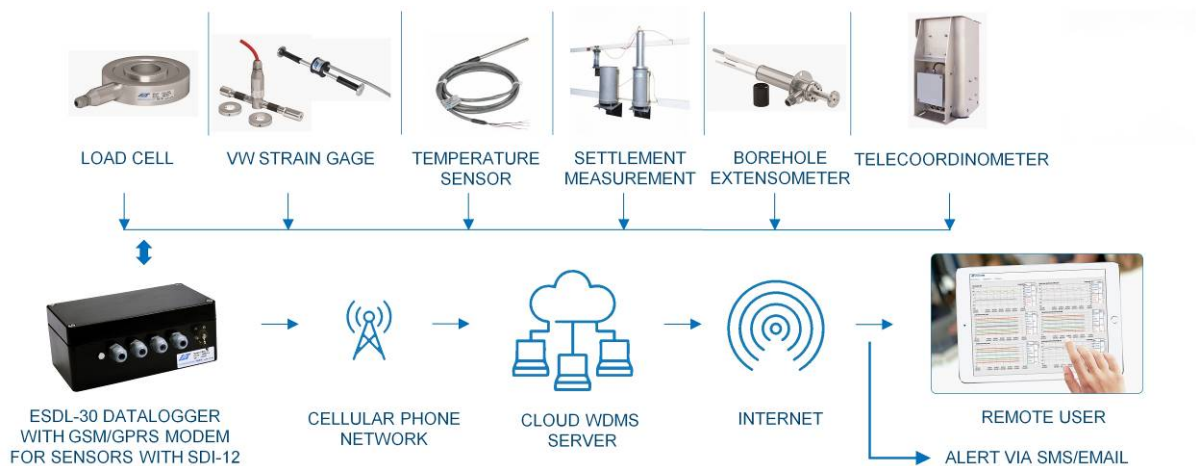
7 PUBLIC CLOUD-BASED WEB DATA MONITORING SERVICE (WDMS)

The heart of the online structural health monitoring instrumentation system is a Public Cloud-Based Web Data Monitoring Service based on Encardio-rite's Drishti software for retrieving data from the field data loggers, archiving the data in a SQL database, processing the data and presenting the processed data in tabular and most suitable graphical forms for easy interpretation. The tables and graphs related to any site or sites can be accessed by authorized personnel who can log in to their site using the supplied login ID and access password from anywhere in the world over the internet.

The web browser interface is very simple to use and intuitive. Any user who is only interested in viewing the data and reports will take just a few minutes to get familiar with the operation of the system.

Data from Encardio-rite cloud-based web monitoring service can be accessed from just about any type of device that supports a standard web browser like a desktop or laptop PC, Tablet, Smartphone or most other mobile computing devices. No special software is needed for accessing the user sites as the information can be viewed using most standard and popular web browsers like Microsoft Internet Explorer, Mozilla Firefox, Google Chrome, etc.

A graphic like a map, ground plan or a photograph of the plant can be put on the opening screen marked with the position of installed sensor/sensors with a square dot or hotspot near its symbol. As soon as the mouse pointer is brought over the hot spot location the corresponding sensor details like sensor identification tag, last recorded sensor reading, and the values of the programmed alert levels pop up in a box. If any of the alarm levels are exceeded the sensor location turns to a red dot. Clicking the pop-up table with the mouse brings up an associated data window where the sensor data can be seen either as a table or as a graph



Remote real-time monitoring system with SDI-12 digital interface sensors and dataloggers

Site administrators can set two alarm limits which are generally considered as “alert level” and “evacuate level”. Alarms can also be generated in case the data upload time limit is crossed for any sensor. It can also be programmed to send the health status of the system to selected users. Other users can only view the data and alarm status but cannot make any changes.

The WDMS can also be programmed to send SMS alert messages or e-mail to selected users as soon as any sensor data crosses its predefined alarm levels, either while going above or going below the alarm level or if data upload time limit is exceeded.

The panel view gives summarized information about site variables update, alarms status and last updated data and the statistical view provides site data variables minimum, maximum and average over a particular duration.

The dynamic chart of the software is handy when analyzing the correlation between readings from two or more sensors or comparing parameters between different sites.

It is simple to download data from Drishti web interface to the users' computer. to a text, .csv and excel file which can be used for further engineering analysis like calculation of rotational stiffness.

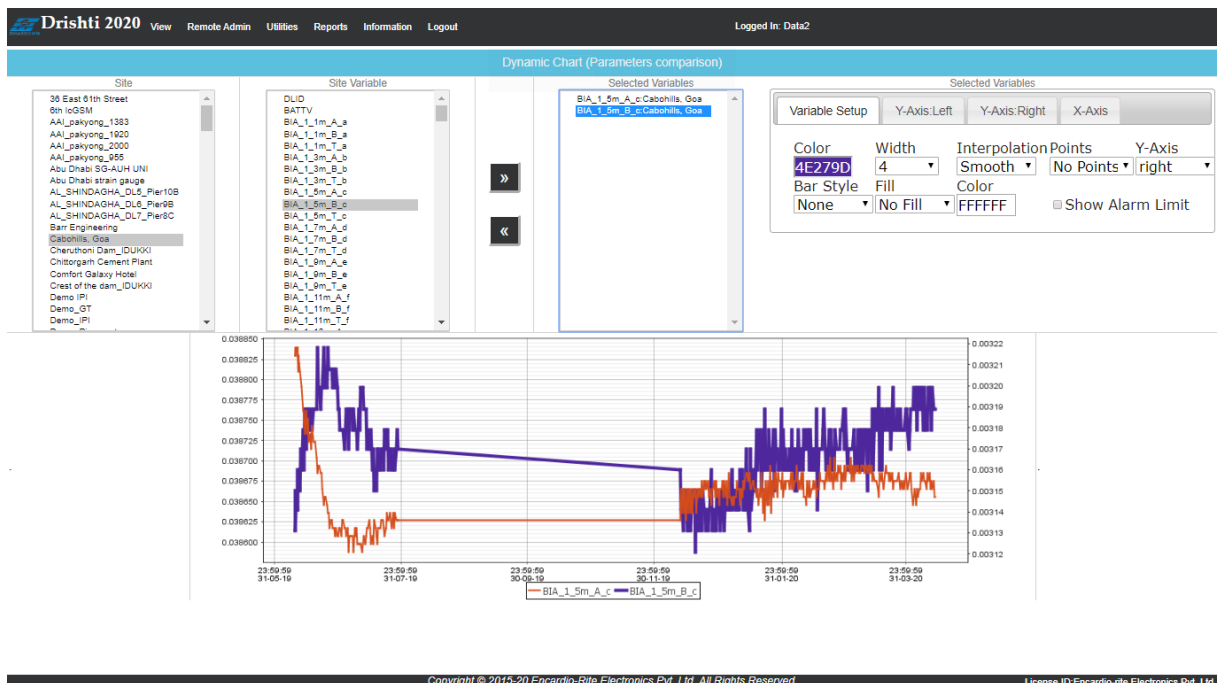
The reporting feature of the software allows users to generate parameter summaries (average, max, min). The reports can be exported as a delimited text file or in Microsoft excel format.

Users can also upload documents and files to Drishti and make them available to other online users.



Documents can include Images, Users' Manuals, Calibration Certificates. The supported file formats are PDF, MS Word & MS Excel.

Encardio-rite cloud services work on a rental model. The user has to pay a small setup fee for the first time and then a monthly rental has to be paid for accessing the data over the cloud as long as required.



Data viewing options in Drishti

8 NON-CONTACT METHODS OF MONITORING

Encardio-rite group of companies and the Moniterra group of affiliated companies are associated together to offer a complete solution for safety monitoring. With our combined experience in online structural surveys and monitoring, we are today one of the most formidable companies in the world in this field.

8.1 Laser scanning

Laser scanning is an advanced method of surveying and conducting geometric profiling of wind turbines that are generally difficult to reach or gain access to. Recent developments in the laser scanners and software have made it one of the fastest, convenient and cost-effective tools to accurately monitor wind turbines in three-dimensions. Drone mounted laser scanners are best suited to scan these very high machines.

The advantage of laser scanning is that the measurements are not limited only to specific prism spots, but covers all the exposed surfaces. Completion of the fieldwork results in a geo-referenced point cloud which, due to its great density and its ability to bear information on the reflectivity and/or the color of each point, comes close to the term, “**virtual reality**”.

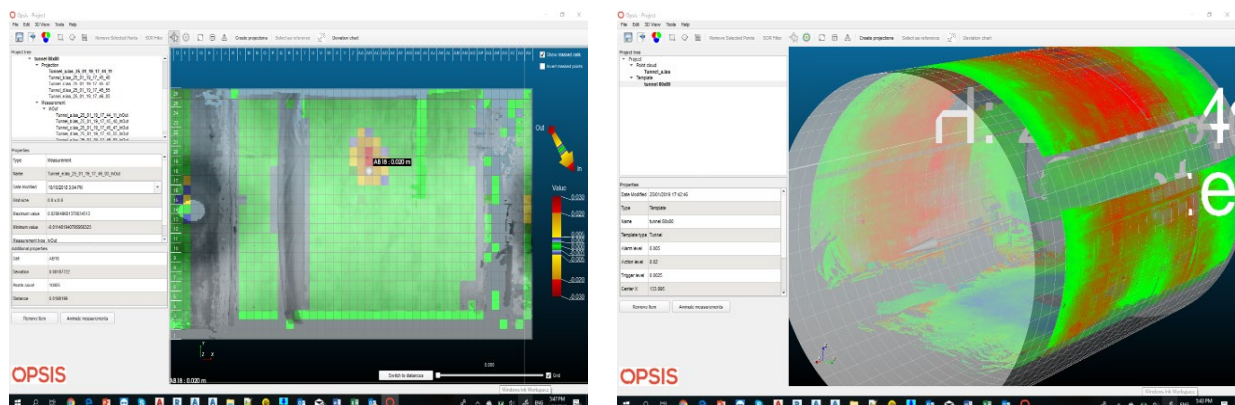
OPSIS is a software developed to overcome the impediment caused by the vast amounts of data LiDAR generates. The idea within its core is to perform operations over the raw data from the LiDAR to obtain a significantly smaller data set to carry out the analysis.

The task of monitoring the deformations or displacements of the scanned objects to perceive possible changes using OPSIS comes down to processing the subsequent point clouds obtained in different epochs using the same projection surface and grid obtained as the best fit for the initial point cloud. If significant changes in the object's geometrical form occur, variations of the cell's mean values and color will make them easily detectable.

What makes this approach unique and better than other commonly used existing software is the feature that it not only gives a point cloud pair comparison but it also provides a linear diagram visualization of the deformation history of each grid cell. Due to the lighter nature of the new software, it takes significantly lesser time to process the results and make the same available online, almost in real-time.

To summarize, the results of laser scanning gives us:

- Surveying of current state and of «as constructed» state
- Virtual reality creations; Virtual tour videos
- Geometric documentation of the structure
- Creation of 2D & 3D products (sections, facets, 3D models, etc.)
- Identification of deformations



Deformation monitoring using OPSIS software

8.2 Aerial Mapping using Unmanned Aerial Vehicles (UAV/Drone)

Inspection of huge structures like wind turbines requires a high degree of analysis but at times are difficult to reach or gain access to. Use of Unmanned Aerial Vehicles (UAV)/Drones is best suited for such applications.

UAVs/Drones are unmanned and remotely-piloted aircraft that follow a pre-programmed path for takeoff, flight, and landing. These aircraft are equipped with HD/IR/Thermal cameras that capture images and videos. Using UAVs/drones to video, model and scan for cracks, erosion, corrosion and defects in wind turbines, that would otherwise require the inspector to use a rope/harness or erect access scaffolding, is safer, faster and smarter choice. This technology is useful during the construction process also-as the development occurs, managers have difficulty maintaining a true picture of the site. With UAV-based mapping at regular intervals, this information gap can be closed.



Wind turbine inspection using drone

8.3 Automatic deformation monitoring system (ATS)

The near real-time 3D-deformation monitoring system is a systematic tracking of any alteration that may take place in the shape or dimension of a wind turbine's tower as a result of stress, load, aging, etc.

The above deformation monitoring system consists of a high accuracy automated total stations (ATS) that have the ability of auto-target recognition (without any human interference). Each ATS has a dedicated control box that includes a computer running special software. This control box manages the total station and schedules the frequency of the measurements, the addition or subtraction of monitor benchmarks, the filters of acceptance or repetition of each measurement, the atmospheric corrections in distance measurements, the calculation, and repositioning of the total station, etc.



Structural monitoring using ATS

The whole system can be controlled/re-configured remotely after installation at the site. The on-site system transmits the collected raw data to a remote server/computer via GPRS/GPS. Raw data is processed into meaningful results by specialized software. The system has the facility of alert notifications through SMS and (or) e-mail to the authorized team for any result exceeding present alarm and critical levels.

The system provides an accurate, continuous, real-time data, eliminating any human error/delay in manual data. The raw data is processed, analyzed and the result is majorly used for predictive maintenance, alarming for safety.



9 CONCLUSION

The data observed from the sensor-based and non-contact structural monitoring solutions for wind turbines described above play a vital role in safeguarding its structure, nearby communities and environment at large, providing timely warnings to take corrective measures. The cost of the monitoring solutions describes above is not expensive compared to the losses incurred in case of any wind turbine failure.

Owing to the critical nature of the above renewable energy generating units, the instruments used and the manpower deployed for installation, monitoring and maintenance of instruments have therefore to be top quality and reliable. Encardio-rite group of companies with experience in manufacturing and monitoring of almost half a century are one of the best manufacturer and service provider in the field.

Cloud-based data management solutions offered by Encardio-rite do the processing and analysis of the collected raw data and provide rapid dissemination of meaningful information to the concerned personnel and stakeholders located anywhere in the world.