Project Title: Application of wind measurement by remote sensing (Lidar) for wind turbine

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Project Necessity: Wind measurement with LIDAR and basically remote sensing offers two improvements compared to traditional wind measurement. First, wind measurement with LIDAR stands out where wind measurement with a mast and cup measuring devices is not economical or the installation of a mast takes time and sometimes has a higher cost. Secondly, in a wide space, all wind parameters are obtained with one device: speed, direction, turbulence and wind shear. It means that with one device we will have all the necessary data and its processing is easier.

Project Goals: The purpose of this report is to provide a solution for wind measurement without using an anemometer. Remote sensing is a simple way to determine wind speed remotely by observing the mass deviation marked in space from the ground. More clearly, the remote sensing method for today's wind energy applications includes the use of light wave propagation, sound and the detection of the reflection of this wave with tools called LIDAR, Sodar and satellites that analyze based on the reflection and scattering of waves. However, accuracy is an important factor in siting and evaluating wind resources regardless of the installation location, be it offshore or onshore. However, measurement errors of more than 1% are not acceptable for the bank and wind farm developers, as a 1% error in measuring the average wind speed will lead to an uncertainty of 3% in the average annual production power. Remote sensing techniques such as SODAR are based on atmospheric probing by sound emission, while LIDAR is based on atmospheric probing by electromagnetic wave radiation (microwave or laser light), and satellite remote sensing is based on Scattering of microwave and radar waves on the sea surface. However, the nature of calibration or validation and classification of each of these measuring devices may lead to different performance. These tools are suitable for measurement, but they face limitations in some fields. Obviously, wind turbines are getting bigger every day, it is not acceptable to say that measuring the wind speed at one height can introduce the wind speed in all diameters of the rotor. So with a mathematical simulation in the whole height including the diameter of the rotor at certain intervals, the wind speed is measured in the whole diameter of the rotor. The obtained power curve is different based on the wind speed at the height of the hub and the wind speed in the entire diameter of the rotor. In different parts of this report, we have tried to draw and present the LIDAR method which is more acceptable.

Abstract: Today, wind turbines are widely installed on land and sea. The development process of wind turbines is such that the dimensions have become much larger and the production power of wind turbines has increased significantly. Today, wind turbines with a rotor diameter of 150 meters and a power of 5 MW have been installed onshore and offshore with a rotor diameter of 200 meters and a power of 16 MW. Wind turbines with these dimensions will be exposed to high wind shear and turbulence at higher altitudes. Conventional anemometer method based on mast and cup anemometers, although they are approved by International Electrotechnical Commission (IEC), but nowadays they face a lot of limitations for accurate measurement of wind flow for large turbines. Therefore, experts are looking for new methods to replace the anemometer tower so that they can easily measure the wind speed up to a height of 200 meters. In the conventional anemometer method, taller and more expensive masts are needed for heights of 150 meters and above. Especially in offshore sites, we are facing huge problems of installing taller masts. Nowadays, wind measurement by remote method and especially LIDAR, which is developed in two types of ground installation or installation on the wind turbine nacelle, has been accepted by IEC standards. The first edition of the international standard IEC 61400-12-1 compiled in 2005 only approved the anemometer tower, but in the second edition compiled in 2017, the remote anemometer method was accepted. However, the strategy of measuring at several heights from 50 to 200 meters to measure the distribution of wind energy in the entire diameter of the rotor was noticed by the wind industry. For this purpose, remote sensing technology relying on Sodar, LIDAR and satellite methods was taken into consideration. Wind system energy and production power are affected by wind speed. As a result, anemometer with a good quality and high sensitivity, reliable and fully calibrated device is very necessary. Today, different types of anemometers with different accuracy are used, although until now the dominant method of anemometer has been the use of a cup anemometer with a mast. But the Sodar and Lidar methods for measuring wind speed have been able to overcome the limitations of the past tools one after the other and have quickly won the trust of experts and craftsmen and have proven that remote sensing of an issue Can be used in wind energy. In this report, as much as possible, an appropriate alternative to the anemometer tower based on the Lidar method has been discussed.

Steps and Methodologies: In this report, emphasizing the LIDAR device as a device for measuring wind speed in wind farms, it has been tried to explain the LIDAR well. Lidar can be divided into four categories in terms of installation mode and usage type:

1- Ground mounted LIDAR

2- Lidar on the nacelle of the wind turbine

3- Floating LIDAR

4- Lidar scanner

In this report, we focus on ground-mounted LIDAR and have examined it in detail in terms of technology and type of application in all cases. When the cup anemometer measurements of the meteorological tower are compared with the remote measuring devices, a multi-degree dispersion is usually observed. Some of these dispersions are caused by the sensitivity of remote sensing devices related to different environments (such as temperature and wind shear).

The task is to evaluate the test classification to identify and quantify these sensitivities for a number of discrete heights that cover a range of the desired measurement. Like the cup anemometer, it is assumed that these sensitivities require a specific type and test classification to be done for each type of remote sensing device for at least two devices of each type and in at least two positions. The remaining scatter is considered as random noise in the cup anemometer comparison. This test is a comparison of the measurement of remote sensing devices with calibrated cup anemometers on the weather tower that includes a set of heights. Usually, the power curve test is performed in different positions and at different times and according to environmental conditions with different distribution. Depending on the sensitivities identified during the test classification, different environmental conditions affect the performance of remote sensing devices. The increase in uncertainty is determined in the test review. By making sure of at least one common measurement height, it is possible to evaluate how the uncertainty in the classification is obtained and check the test with remote sensing devices during the continuity power curve test. If a discontinuity is detected from this monitoring, the corresponding uncertainties used in the power curve test are increased. The power performance characteristics of the wind turbine are determined by the measured power curve and the estimated annual energy production (AEP). The measured power curve is determined by the relationship between the wind speed and the output power of the wind turbine. We have here the list of standards related to wind measurement, i.e. IEC 61400-50 series, related to the measurement of wind speed based on anemometer tower, as well as remote sensing methods until 2023 that have been published:

IEC 61400-50-1 Guide to measuring wind with an anemometer.

IEC 61400-50-2 Guide to the measurement of ground-mounted remote sensing.

- IEC 61400-50-3 Lidar guidance on nacelles.

- IEC 61400-50-4 Guide to using floating LIDAR.

Having accurate measurements of wind flow in the atmosphere is a fundamental parameter for improving the design of wind turbines and anemometer sites. Therefore, an important factor for making wind energy cheaper is to improve the reliability of wind speed measurement. The use of LIDAR depends on the type of LIDAR, and the issues that we discussed in different parts of this report can be discussed in more detail in four classifications for two modes of continuous LIDAR and pulsed LIDAR. Pulsed LIDAR in practical modes of installation on the nacelle and lidar with scanner mode in two positions of short range and long range where the light beam can be controlled and steered are commercially available today. The point that we should emphasize here is the rapid development of LIDAR and its acceptance in the wind and standard industry. In the offshore sector, LIDAR has been accepted almost independently for site evaluation, and in the performance test and power curve section, it has also been accepted with some considerations. In the field of flat lands, LIDAR has been accepted as a standard by performing calibration. There is still a problem in complex terrains, and research in this field continues, and maybe with the help of LIDAR fluid analysis software, it will be accepted independently in this type of terrain in the future.

Main Results (technical outputs, patents, papers, books, reports, etc.):

The IEC 61400 12-1 2017, which introduces the procedure for measuring the power performance of a wind turbine, has accepted wind measurement by remote sensing method. Among the remote sensing methods, the Sodar method was explained first, and then the Lidar method, which is now accepted as a practical method, was explained. The measurement of wind speed with Sodar technique is based on the propagation of sound waves with frequencies of (2000-4000) Hz, which are transmitted in three directions and the reflection of the waves is received and processed by the receiver. This method was operationally started in 1980 to measure wind speed and was initially used for environmental measurement and air pollution control and then developed in the field of wind energy. The sound wave is emitted by the transmitter device and then the sound return, which is the result of temperature changes and atmospheric disturbance, is received by the receiver microphone. In standard atmospheric conditions, the transmitter sends sound waves at a speed of 340 meters per second to a detector at a height of 170 meters, then the return pulse is received after 1 second. It sends three components of sound waves in the vertical direction and two diagonal directions, to form the three-dimensional vector of the wind, including speed, direction and deviation. The accuracy of SODAR measurement is determined based on the acceptable limit of the carrier-to-noise ratio (C/N). This limit is compatible with the layout of the transmitter and receiver and whether the Sodar device is single or multiple. Dual stick shaping has more advantages than single propagation shaping, i.e. it has a better carrier-to-noise ratio. Most of the SODAR devices that are made today do not have the necessary accuracy to work in the scope of wind resource assessment and site-measurement and are more suitable for a cheap pre-measurement than other remote sensing methods in a short time. Most Sodar systems equipped with solar panels are required to provide electrical power and require very little maintenance. When working with Sodar devices, this limitation should be taken into account that they are sensitive to acoustic reflection from nearby objects. Measurement at a height above 100 meters in Sodar faces a limitation, and another limitation at high wind speeds, i.e. more than 15 meters per second, has problems in separating sound from noise and has low accuracy. We should know that all remote sensing devices face measurement errors in complex terrains. The errors are much larger for hilly terrains. In the fields where the disturbance is severe, Sodar has more error than the anemometer tower equipped with cup anemometer. Therefore, nowadays, especially from 2010 onwards, the banks providing loans to wind farms require a detailed evaluation of the site. In this way, Sodar has been left out of the world wind industry and has given the field to Lidar, which is much more accurate. Having accurate measurements of wind flow in the atmosphere is a fundamental parameter for improving the design of wind turbines and anemometer sites. Therefore, an important factor for making wind energy cheaper is to improve the reliability of wind speed measurement. The use of LIDAR depends on the type of LIDAR, and the issues that we discussed in different parts of this report can be discussed in more detail in four classifications for two modes of continuous LIDAR and pulsed LIDAR. Pulsed LIDAR in practical modes of installation on the nacelle and LIDAR with scanner mode in two positions of short range and long range where the light beam can be controlled and steered are commercially available today. The point that we should emphasize here is the rapid development of LIDAR and its acceptance in the wind and standard industry. In the offshore sector, LIDAR has been accepted almost independently for site evaluation, and in the performance test and power curve section, it has also been accepted with some considerations. In the field of flat lands, LIDAR has been accepted as a standard by performing calibration. There is still a problem in complex terrains, and research in this field continues, and maybe with the help of LIDAR fluid analysis software, it will be accepted independently in this type of terrain in the future.