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Investigation, Prediction and Evaluation of Wind Turbine Noise in Japan

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ABSTRACT

While increasing in size and number, wind turbines in Japan are often located in quiet rural areas due to the country's lack of shallow adjacent sea and geographically unbalanced wind energy. Since a quiet environment makes wind turbine noise more noticeable, this location of wind turbines sometimes raises complaints about noise by neighborhood residents even if the noise generated by wind turbines is not very loud.

The Ministry of the Environment of Japan has developed an interim report on investigation, prediction and evaluation methods of wind turbine noise based on recent scientific findings, including the results of nationwide field measurements and related surveys in Japan. The challenges to be addressed are also identified.

Keywords: Wind turbine noise, investigation method, reference level
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1. Introduction

It is an important aspect of Japan's energy policy to accelerate the introduction of renewable energy. Among renewable energy sources, wind power generation is one of the important energy sources which emits neither air-polluting substances nor greenhouse gases and can also contribute to energy security because it can be done in Japan. The Basic Energy Plan of Japan (Cabinet decision in April, 2014) regards wind power generation as an energy source which can be made economically viable as its generation cost can be as low as that for thermal power generation if it can be developed on a large scale.

The number of wind power facilities installed in Japan started to increase around 2001, and 2,034 units have been installed by 2014 (as of the end of March, 2015) (1). According to the Supplementary Materials for the Long-term Energy Supply and Demand Outlook issued by the Agency for Natural Resources and Energy in July, 2015, approximately 10 million kW of wind power is expected to be installed by 2030, which represents a nearly four-fold increase from the existing installed wind power capacity of approximately 2.7 million kW (2).

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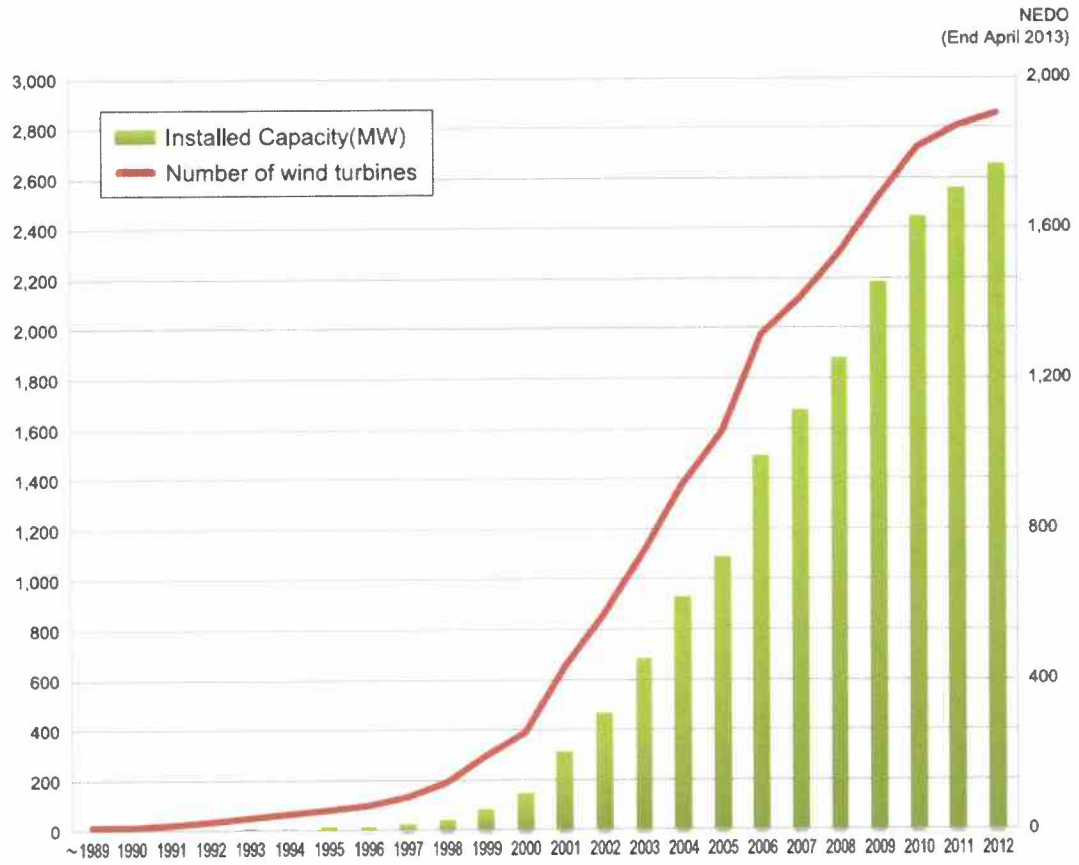

Figure 1. Installed Capacity and Number of Wind Turbines in Japan (Source: NEDO)

On the other hand, wind power facilities emit a certain amount of noise due to their power generation mechanism in which blades rotate by catching wind to generate power. While the noise level is normally not significantly large, there are cases where even a relatively low level of noise causes complaints as wind power facilities are often constructed in agricultural/mountainous areas which are originally quiet due to the need to choose areas which have suitable weather conditions including wind direction and velocity,. There have been not only noise complaints but also complaints of inaudible sound whose frequency is 20 Hz or less.

Against such a backdrop, as a result of the amendment of the Order for Enforcement of the Environmental Impact Assessment Act in October, 2012, the establishment of wind power stations came to be classified as relevant projects under the Act and discussions on the environmental impact assessment of wind power facilities have taken place. However, there are acoustic characteristics peculiar to noise generated from wind power facilities (hereinafter, "wind turbine noise"). It is thus necessary to develop methods relevant to the investigation, prediction, and assessment of wind turbine noise based on the latest scientific findings.

The Ministry of the Environment of Japan has set up an academic expert committee and examined ideas and issues about methods for investigating, predicting, and assessing wind turbine noise in Japan from 2013 to 2016, in light of the results of investigations and studies in Japan published so far as well. This paper reports the interim summary of the examination at the academic expert committee.

2. Extant findings

Surveys measuring wind turbine noise conducted in Japan from 2010 to 2012 revealed the following.

- In terms of spectral characteristics, wind turbine noise generally has a spectral slope of -4 dB per octave. Its 1/3 octave band sound pressure level in all parts of the super-low frequency range, which means 20Hz or lower, is below the ISO threshold of hearing for pure tones and the criterion curve for the assessment of low frequency noise proposed by Moorhouse et al. (Fig. 2). Super-low frequency range components of wind turbine noise are at imperceptible levels. Therefore, wind turbine noise is not an issue caused by super-low frequency range.
- In regard to the audible frequency range, in the range from about 40 Hz and above, the 1/3 octave band sound pressure level is above the said criterion curve and the threshold of hearing defined by ISO 389-7. Therefore, wind turbine noise should be regarded as "audible" sound (noise) in discussing it.

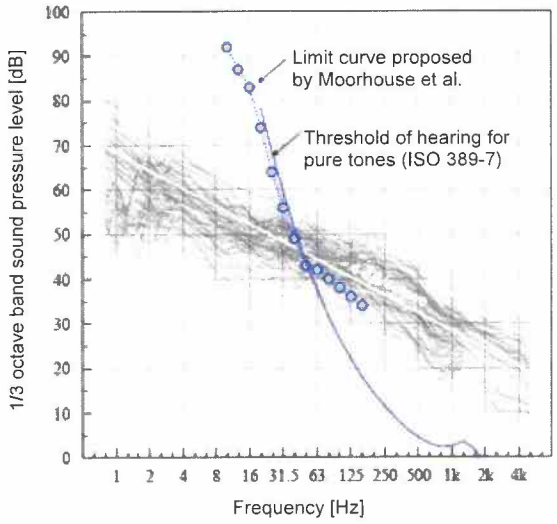

Figure 2. Result of the analysis of frequency characteristics of wind turbine noise (at 164 locations in the vicinity of 29 wind power facilities in Japan)

- Noise exposure levels of nearby residents from wind power facilities are distributed in the range of 26–50 dB in time-averaged A-weighted sound pressure levels. While this implies that wind turbine noise is not significantly higher than other types of environmental noise, it can cause serious annoyance to residential areas in the vicinity of wind power facilities located in extremely quiet agricultural/mountainous areas.
- In Japan, it is empirically known that the following relation holds between L_{Aeq}, which properly excludes non-relevant noise, and L_{A90}: $L_{Aeq} \fallingdotseq L_{A90}+2$ dB

It is also generally said that acoustic isolation is not always effective for noise from wind power facilities because it contains more low-frequency components. In a quiet environment with little noise of other types, it is relatively more easily heard than ordinary noise is.

3. Methods for investigating and predicting wind turbine noise, a perspective for its assessment, and responses against it

In light of the findings described in section 2, the issue of wind turbine noise should be taken not as one of super-low frequency sound below 20 Hz but as one of "audible" sound (noise), and it should be basically measured at the A-weighted sound pressure level. We here summarize matters to be noted in conducting an investigation and/or prediction of noise before and after installing wind power facilities and a perspective for wind turbine noise assessment.

3.1 Investigation and prediction before installation

3.1.1 Matters to be noted upon an investigation

In selecting a method for investigation, it is necessary to collect various kinds of information in light of business and regional characteristics to a necessary extent in order to conduct prediction and assessment appropriately. Particularly with regard to wind turbine noise, it is important to distinguish and discuss three major issues:

(1) Sound source characteristics

It is necessary to pay attention to:

- information on the wind power facility concerned, including its specifications, manufacturer, model number, hub height, rotor diameter, rated wind velocity, and power generation;
- the sound power level of the generated noise;
- the A-weighted overall value and frequency characteristics (including the 1/3 octave band sound power level) of the sound power level at the rated (maximum) output (to grasp the situation of maximal environmental impact);
- A-weighted overall values and frequency characteristics (including the 1/3 octave band sound power level) of sound power levels under different wind velocities;
- pure tonal frequency components (to be determined in accordance with IEC 61400-11:2012); and
- existing data pertaining to the same model in operation.

(2) Propagation characteristics

In Japan, wind power facilities are often installed in agricultural/mountainous areas. Sound waves emitted from a wind power facility installed in an agricultural/mountainous area are affected by various factors before propagating to a sound receiving point (assessment point), in comparison with one installed on a large, flat piece of land such as a plain or desert. Its noise level and frequency characteristics tend to change due to phenomena including reflection, absorption, transmission, refraction, and diffraction. It is therefore necessary to pay attention to:

- phenomena such as the reflection, absorption, or diffraction of wind turbine noise due to undulating terrains or ridges,
- the state of the ground surface (including rivers and lakes), and
- meteorological information such as wind conditions including wind direction, velocity, and frequency.

(3) Information on a sound receiving point (assessment location)

With regard to locations where an investigation is conducted, focusing on the daily life and activities of residents in the vicinity of a wind power facility, it is necessary to pay attention to:

- the configuration of establishments particularly requiring consideration for environmental conservation such as schools and hospitals and the outline of housing configuration (including the structure of each house), and
- the state of the acoustic environment (degree of quietness) of the area in question.

(4) The specific method for investigation

In measuring residual noise in a given area, it is necessary to pay attention to the following.

a. Sound to be excluded

Sounds of the types given below should be excluded. Since wind power facilities operate when wind is blowing, noises caused by wind such as sound of rustling leaves are not excluded. ("Wind noise" generated by wind hitting a sound level meter's microphone is excluded, however.)

i) transitory noise such as the sound of automobiles passing nearby and aircraft noise
ii) artificial sound not occurring regularly such as sound generated by accidents/incidents, vehicles driven by hot-rodders, emergency vehicles, etc.
iii) natural sound not occurring regularly such as sound generated by natural phenomena including rain and defoliation, animals' cries, etc.
iv) sound incidental to measurement such as the voice of a person talking to a measurer, sound of tampering with measuring instrument, etc.

b. Surveying and other equipment

As the wind is generally strong in areas around wind power facilities, it is indispensable to use a windbreak screen in order to avoid effects of wind noise as much as possible in measuring residual noise. Several kinds of urethane spherical windbreak screens with different diameters are commercially available. In general, the larger the diameter of such a screen is, the less likely a sound level meter inside the screen will be affected by wind noise. Installing a windbreak screen can reduce the impact of wind noise up to the wind velocity of around 5 m/s.

c. Survey areas and locations

In light of the propagation characteristics of wind turbine noise, the survey targets areas susceptible to an environmental impact by wind turbine noise, such as residential areas in the vicinity of a wind power facility (generally within a radius of about 1 km from a wind turbine). An area in which a quiet environment should be conserved such as hospital premises may be included in them. In selecting specific survey locations in the survey areas, in addition to locations where a wind power generation facility is planned to be installed, such locations are to be selected that are immune to local impacts of particular sound sources where the average level of noise in the relevant area can be assessed, including residential areas around the wind power generation facility. Measurement is to be performed at an outdoor location 3.5 m or more distant from a reflective object excluding the ground.

d. Survey period and hours

In order to grasp conditions throughout the year accurately, a survey is to be conducted in each period of the year for different typical meteorological conditions under which a wind turbine operates (for instance, each season if meteorological conditions vary greatly by seasons).

The period of a single survey should be appropriately determined in consideration of time variation of noise due to the impact of meteorological conditions and other elements. As measurement values may be unstable depending on wind conditions, a survey should be performed for three or more consecutive days in principle. The survey should be conducted both during the day (6:00–22:00) and at night (22:00–6:00) hours.

3.1.2 Matters to be noted in prediction

As mentioned above, in Japan, wind power facilities are often installed in agricultural/mountainous areas. In comparison with cases where such a facility is installed on a large, flat piece of land such as a plain or desert, sound waves emitted from a wind power facility installed in a mountainous area diffuse in a more complicated manner as they propagate due to the influence of geological states, vegetation, meteorological conditions such as wind conditions, etc. In addition, it has to be noted that the propagation of wind turbine noise is extremely complicated as it is subject to attenuation by distance, reflection and absorption by the ground surface, reflection and diffraction by acoustic obstructions, attenuation by atmospheric absorption, etc.

Among the prediction methods used, while "ISO 9613-2 : 1996" allows incorporation of more detailed conditions, prediction calculation according to it is rather complex. Furthermore, there is a problem of how the reflection rate should be calculated in cases where the effect of reflection by the ground surface becomes an issue, as is the case with a wind turbine installed in a ridge.

On the other hand, the New Energy and Industrial Technology Development Organization (hereinafter, "NEDO") published a prediction method for the environmental impact assessment

ofwind power generation in July, 2003 (revised into the second version in February, 2006). This models wind power facilities as sound source points and uses sound power levels provided by manufacturers of wind power generators. This method takes into account distance attenuation due to sound diffusion in the propagation process and attenuation by atmospheric absorption. While this method can be used easily, it is difficult to consider meteorological effects, etc.

It is necessary to pay full attention to such characteristics of methods in making prediction.

3.2 Survey after the installation of a wind turbine

As stated in section 3.1, predicting wind turbine noise involves elements with large uncertainty such as emission characteristics of noise from the source and effects of meteorological conditions as well as terrain and structures in the propagation process. Predicted values before the installation of a wind turbine and measured values after installation may sometimes differ greatly.

We here summarize matters to be noted in a survey after the installation of a wind turbine.

(1) Conditions of measurement

It is necessary to grasp the conditions of measurement and other relevant local matters that may impact the propagation of noise. At least, one should grasp wind direction and velocity at the nacelle height, the variation of power output, and meteorological data required for calculating the attenuation by atmospheric absorption (wind direction and velocity, temperature, and humidity).

(2) Survey method

Wind turbine noise varies greatly by wind conditions, and a wind turbine often starts and suspends operation repeatedly. Therefore, measurement should be performed in appropriate hours in light of the state of operation of the wind power facility in question. For example, a method is conceivable that measures the average level in a 10-minute period in which wind turbine noise is stable (10-minute equivalent noise level: $L_{\mathrm{Aeq,\ 10\ min}}$) and regards it as the representative value. If the relevant wind power facility operates steadily for long hours, it is effective for obtaining robust data, for instance, to measure noise for 10 minutes every hour on the hour and calculate the average energy over the entire period of time.

For measurement locations, period, etc., refer to what is noted for a survey before the installation.

(3) Survey Results

The representative value of a survey after the installation of a wind power facility should be taken as the A-weighted equivalent sound pressure level measured over a period of time in which the effect of wind turbine noise is at its maximum and in which the effect of background noise is low(e.g. during night time). It is also required to confirm whether there is any pure tonal component.

The equivalent noise level during operation can be estimated by adding around 2 dB to the noise level exceeded for 90% of the measurement period (L_{A90}).

3.3 Assessment of wind turbine noise

In assessing the impact of noise resulting from the installation of a facility, the procedure of environmental impact assessment performed before installation examines "whether such noise is avoided or reduced to an extent feasible" and, if applicable, "whether it is intended to be consistent with standards or criteria given by the Japanese government or local municipalities from the perspective of environmental protection."

For the former examination, the extent to which the impact of noise resulting from the implementation of the relevant project is avoided or reduced is assessed by comparing multiple countermeasures in terms of the structure, layout, output, the number of units, and technical noise reduction measures in accordance with the maturity of the project plan. The assessment can also be done by examining to what extent better feasible technology can be incorporated, etc. Specifically, assessment is made from such viewpoints as whether the local noise level will not be significantly raised, whether the layout plan for the project secures a sufficient distance between the facility and residences, etc.

On the other hand, no standards or criteria specific to wind turbine noise have been set from the

perspective of environmental protection by the national government.

4. Future agenda

4.1 Actions to be taken by operators and manufacturers of wind power facilities

Operators and manufacturers will continue to be expected to accumulate survey data after the installation of wind power facilities, implement technical measures, such as developing low noise blades or implementing additional soundproof measures, and maintenance measures intended to reduce noise, etc. Furthermore, they are also expected to examine and develop technology supporting the broad promotion of efforts for noise control including the examination of an aerodynamic sound propagation prediction model reflecting locational conditions.

4.2 Actions to be taken by administrative agencies (the government of Japan and local municipalities)

4.2.1 Collecting and sharing information on wind power facilities, raising awareness

It is necessary to develop and improve manuals for appropriately responding to complaints concerning wind power facilities. At the same time, it is necessary to examine a framework for sharing knowledge of technological countermeasures implemented by operators which can be applied to other facilities, to administer education and training programs to enhance local municipality officials' expertise further, to promote understanding by local residents through the dissemination of precise information on the auditory impression of wind turbine noise and similar matters as well as raising their awareness of such information, etc.

It is possible that not only the magnitude and properties of sound but also visual elements are related to complaints about noise from wind power facilities. It is necessary to continue to gather knowledge on the impact of elements other than noise and examine responses.

4.2.2 Perspective for the assessment of wind turbine noise

At present, no standards or criteria specific to wind turbine noise have been set from the perspective of environmental protection by the national government. In light of the fact that wind power facilities are often installed in quiet areas, possible annoyance caused by amplitude-modulation sound (swish sound) and, if applicable, pure tonal components of wind turbine noise, it is necessary to examine a certain reference level for assessment of noise in consideration of the impact on the sound recipients.

Furthermore, with regard to the sound environment in quiet areas, it is necessary to consider all facilities, not limited to wind power facilities, located therein. It is necessary to examine what methods for investigating, predicting, and assessing the sound environment in quiet areas in Japan should be like while surveying examples in other countries.

4.3 Actions to be taken by all parties concerned

When it comes to wind turbine noise, it is important to facilitate communication among relevant stakeholders including operators of wind power facilities, manufacturers, local municipalities, local residents, in light of issues unique to sensory pollution. It has been reported that annoyance caused by wind turbine noise is low among residents who perceive wind turbines positively so that receptivity to the installation of a wind turbine facility is higher among them. There are cases where actions for maintaining a favorable relationship with local residents actually reduced complaints. Such actions include a wind power facility operator's holding briefing sessions, creating an optimal business plan based on the comprehensive analysis of the distance separating residences and the relevant establishment in conjunction with the installation and layout of a wind power facility, continuing to deal with complaints, and concluding an agreement with local residents and municipalities. It is necessary to enhance communication among the parties concerned in this light.

REFERENCES

1. New Energy and Industrial Technology Development Organization (NEDO). NEDO offshore wind energy progress Edition II. [Internet] 2013. p.5. Available from: http://www.nedo.go.jp/content/100534312.pdf?from=b
2. Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry. [Internet] 2015. p.47. Available from: http://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/mitoshi/011/pdf/011_07.pdf