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Current challenges of assessing excess amplitude modulation character in wind turbine noise during EIA/planning phase

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Abstract

Increased knowledge of cause and effect of amplitude modulation in wind turbine noise has also increased the likelihood of using penalty scheme during noise verifications processes. In Finland, officials and research bodies are currently planning to set up such a penalty scheme for additional annoyance factors in wind turbine noise especially to be used during verifications process post analysis. However the use of such schemes after the commissioning of a wind farm brings additional, unknown risks to the project, which should be avoided by careful testing, planning and design. But the current state of international standards and recommendations gives no direct advice on how to estimate such risks especially regarding excess amplitude modulation (EAM) character.

This paper describes few risk assessment methods for estimating risks regarding EAM which could be used in noise assessment phase during the different planning stages of a wind farm. This includes a new way of using generally accepted sound propagation models for mapping visually the high modulation interference areas and estimation of possible EAM risks from the site specific wind measurement data. This type of data is typically available during the planning stage of the wind farm project and thus could be used by developers and/or consultants during that project stage.

Lowering the possibility of real EAM creation by using these additional assessment procedures before the wind farm erection could also increase the general acceptance of the whole project. However, due to the many factors which influence the formation on EAM character in wind turbine noise, without general and internationally accepted procedures, assessing it during the planning stage remains currently very challenging with high assessment uncertainty.

1. Introduction

In the end of 2013 there were 211 wind power plants in Finland, which capacity combined was 448 MW and produced electricity 777 GWh. Finland has agreed to increase the proportion of renewable energy production to 38 percent by 2020. Wind power production goal is set to 6 TWh and requires about 800-1000 turbines. According to the latest energy and environmental strategy the proportion would rise to 9 TWh by 2025. In 2014 the total capacity of announced wind power proposals was 10 000 MW. Only a part of them is

under active development. Some proposals have come to stop because of administrative obstacles and declining statements by the defensive forces. [1]

Environmental protection laws, land use and building laws in addition with health conservation laws apply to planning and operation of wind farms. In 2012 the reference noise level values were divided into wind turbine noise and rest of industry, for it was discovered that former thresholds lead to too great noise disturbance. In general residential areas the A-weighted equivalent L_{Aeq} noise level threshold is set to 45 dB during the day and 40 dB night-time. In areas used for holiday purposes outside the rural areas the thresholds are 40 dB day time and 35 dB at night. If the noise is excessively amplitude modulated (EAM) an addition of +5 dB is added to the calculated of measured value. Determination whether the noise is excessively amplitude modulated or not is not included.

As new studies have been published about annoyance caused by special characteristics of wind turbine related noise, new guidelines for noise assessments are about to be published. These guidelines would include a sanction procedure for excess amplitude modulation (Later “EAM”) and a definition how it is determined from measurement data. A proposal states that the EAM procedure would be based on modulation depth, which was defined in 2013 by Hünerbein et al. [2]. The threshold is suggested to be 3 dB. It is yet not certain whether the addition will always be + 5 dB, or would it depend on the severity of the perceived amplitude modulation.

2. Wind farm EIA and planning processes in Finland

The effects of a wind farm are greatly dependent on the location, size of the turbines and the environmental values of the surrounding area. Impacts on nature and on people are tried to be minimized by locating new farms on areas where existing operations can co-exist. Best wind conditions for power production are on the coast and on the hills of Lapland.

Basically every wind farm project has to go through an environmental impact analysis, if it has at least 10 turbines or the combined power is at least 30 MW. The actual two phased procedure starts with an evaluation programme. This includes a review on which projects alternatives will be evaluated and how the process will be carried out. In the second phase the actual impacts are determined according to the programme and a statement established by the local environmental authorities.

Sound pressure level estimation with modeling software is quite reliable nowadays. Nevertheless the most significant causes of annoyance are low frequency noise and amplitude modulation. When constant noise level can be fairly high without major concern, special characteristics of sound may induce annoyance even at relatively low sound pressure levels. The consideration of excess amplitude modulation in planning of a wind farm has not been possible yet.

Because completely uninhabited areas that have consistent enough wind conditions are extremely rare, it is needed to optimize the spread of noise close to dwellings. In that case any additions due to sanction procedures to the calculated or measured values would lead to exceeding the threshold noise level. Fixing the problem afterwards might end up being costly.

Since AM has been found to be a combination of wind profile, siting geometry and turbine design, the estimation and selection of optimal turbine for prevailing conditions would lead to more profitable farms and more seamless environmental impact assessments and follow-up.

There is no guideline for assessing EAM in the planning phase of a wind farm. So far it has only been possible to determine the existence from measurements of already erected turbines.

3. Estimating amplitude modulation in wind turbine noise

Noise assessments typically include a sound propagation model, where sound pressure levels are calculated to a digital terrain model. ISO 9613-2 [3] and Nord2000 [4] sound propagation model are used in Finland in all wind farm project development phase calculations [5]. After commissioning of the wind farm, noise measurements are sometimes conducted but it is not an obligatory part of the process if no noise complains arise after the start-up of the wind farm. The most important part of noise estimations are still conducted during the planning phase of the project, which is confirmed by applying a building permit [6] to it. Since EAM penalty sanctions may be included in the forthcoming statutory order of noise from wind turbines [1], an EAM risk assessment comes as a natural part of noise assessments.

Figure 1. New national good practice guides for wind farm project EIA/planning phase (published during 2012-2014) [5],[6],[7],[8]

Since EAM has multiple factors influencing its depth and overall strength, it was decided to split the main factors into three major factors from which the final EAM estimate should be assessed. These are 1) Turbine type depended EAM factors, which require either IEC type test evidence from the emission measurement or evidence from existing wind farms (measured results), 2) site depended factors mainly from the micrositing phase which include interference of AM from other turbines and 3) site environmental conditions, which may be the most important but also most difficult part of the assessment.

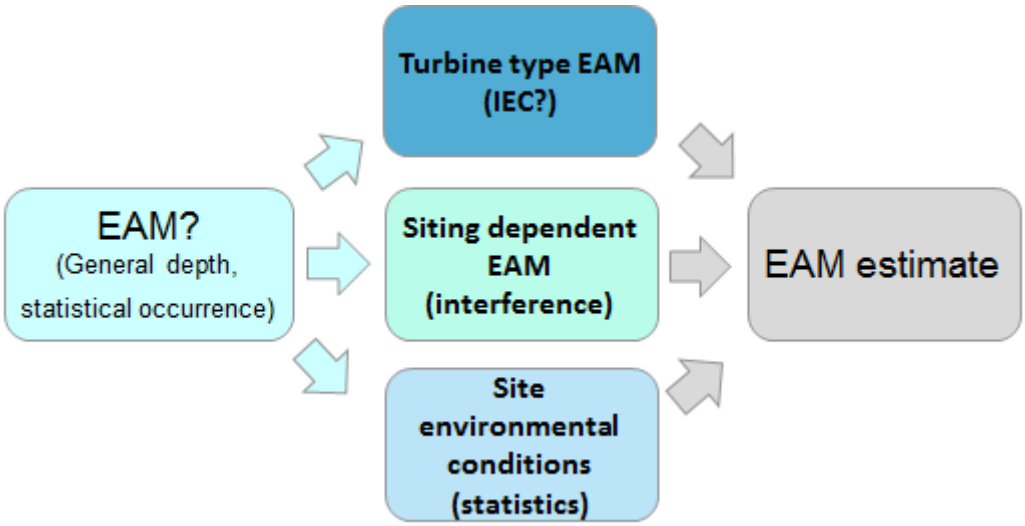

Figure 2. To estimate EAM in a real project, all three factors effecting EAM should be assessed

The processes presented above are discussed below in more detail and some new assessment methods are proposed by using publicly available environmental data and the same sound propagation models used in the current EIA/Planning phase.

3.3 Site environmental conditions

The local stall effect discussed in RUK AM study [9] and other sources [10] is one the main sources of EAM. The driver is of course a sudden and steep wind speed profile change which cannot be controlled easily by using the blade pitch controller due to the inertia and balancing of the system. Since many coastal areas in Finland may experience high wind gusts during high wind speed periods (forests causing turbulence, cold sea causing low level jets), it would be necessary to obtain information related to wind gusts, turbulence intensity and general wind shear statistics at the very early stage of development to support risk assessment of EAM. This however, seems to be completely missing from the overall good practices guides of wind turbine noise [5]. Wind developers usually have measured wind data before the final permitting phase, but planning and EIA studies may be done even before there's enough measured annual wind data available.

The Finnish Wind Atlas, a project developed by The Finnish Meteorological Institute, has a database of calculated values of many wind related parameters up to 400m height (250m and 2500m grids) from the whole country, like Weibull constants, turbulence intensity and even post-calculated wind gusts [11]. However, especially wind shear data or any data mentioned above are not split into day and night time statistics (like noise guideline values, $L_{Aeq,07\text{-}22}$ and $L_{Aeq\ 22\text{-}07}$) in Wind Atlas. The usable data and publicly available data that can be derived from the system is presented only as monthly average values.

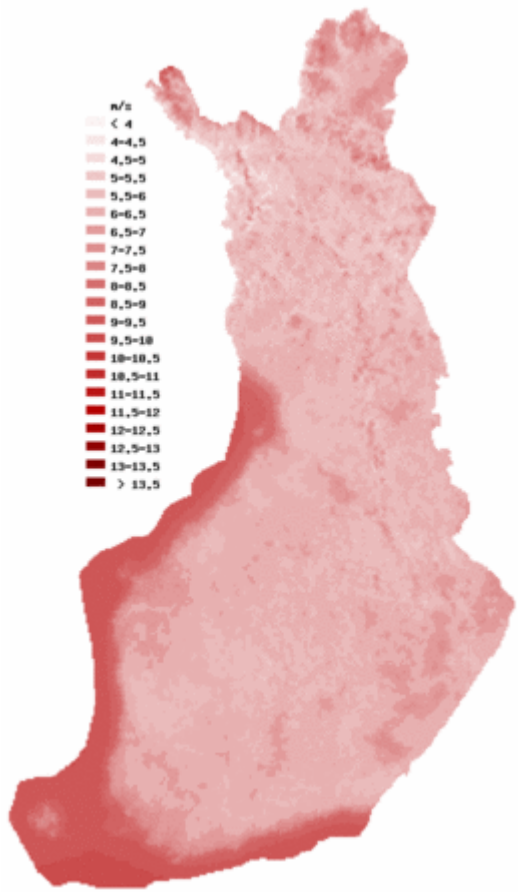

Figure 3. Example image from the Finnish Wind Atlas, wind speeds from 100 m height from the 2,5 x 2,5 km grid calculations [11]

Below is a graph presenting average monthly wind speed profiles from the Wind Atlas data on January in two different locations in Finland. In both locations, wind turbine noise measurements were performed including detailed analysis of AM and EAM. Case A represents a location with higher average wind speed but both locations are situated about 4km inland from the coast line each having over ten large wind turbines with 140m hub heights. Both locations are also surrounded by fairly dense spruce forests.

Logarithmic wind profiles can be calculated from the initial Wind Atlas data and the different between calculated “real” profiles seems to be very large and indicate a possible higher occurrence risk of either local stalling or EAM in general due to steep wind profile. This was also the measurement result in case A, which clearly revealed that the wind was more gusty in case A.

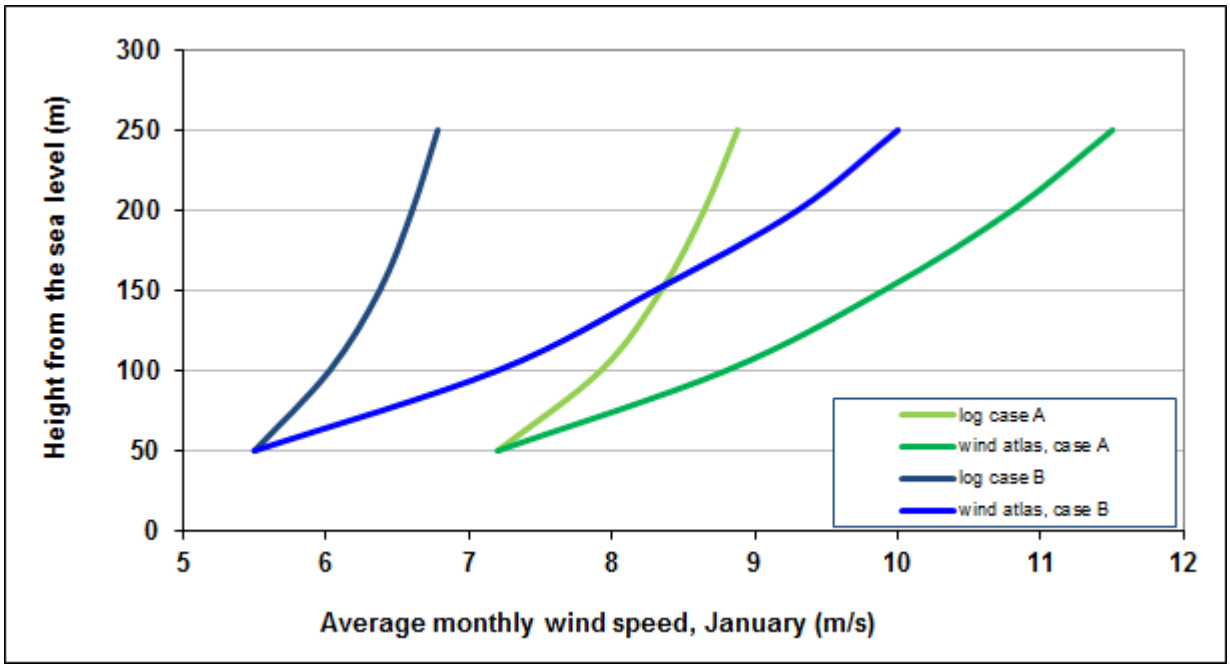

Figure 4. Wind profiles in two wind farm site from the national wind atlas database [x]

Despite the EAM measurement results from the field, Wind Atlas data surprisingly showed that wind gust factors may in fact be lower in case A during the most windy month. Weather prediction models do not automatically calculate wind gust values and these values were calculated only by Wind Atlas only to some particular heights and atmospheric stability states. Turbulence intensity is typically included in the models and a comparison indicates that case A should in general have lower turbulence intensity values indicating higher EAM [12] occurrence. This may also explain the results of wind gusts since those values are calculated directly from the turbulence kinetic energy, wind profile and from atmospheric stability distributions.[11]

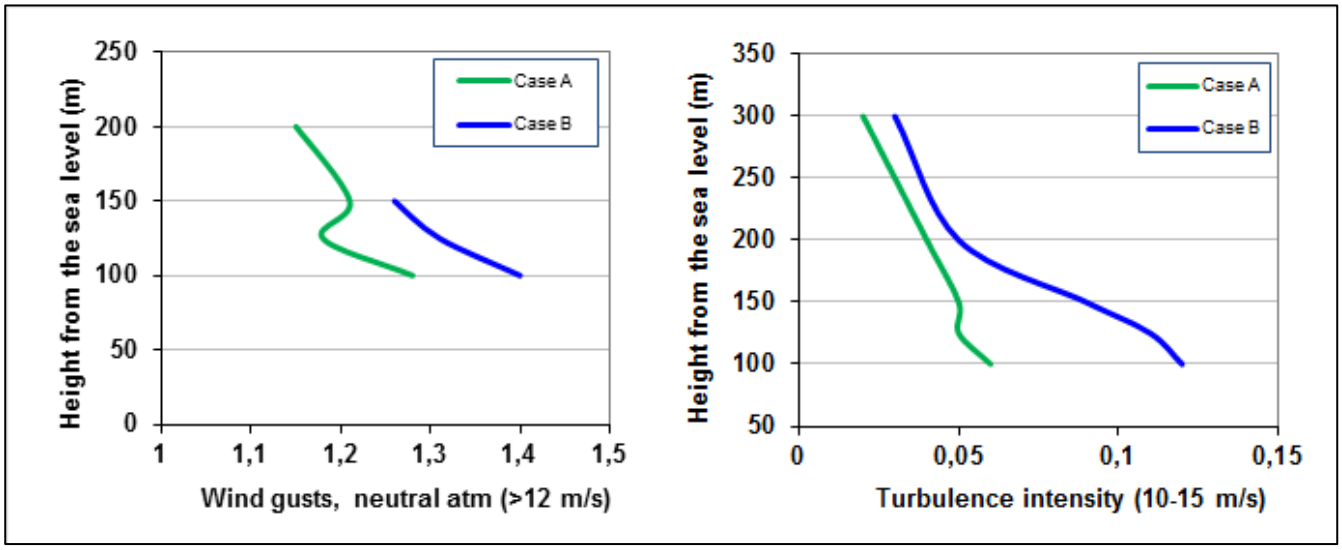

Figure 5. Wind gust and turbulence intensities from the national wind atlas in two wind farm sites [x]

Wind Atlas mainly gives the frequencies of the wind speeds at several heights from the average ground height from the site. Below in a graph is presented calculated downwind situations to both cases at 150 m height and to wind speeds exceeding 8 m/s. Downwind

situations are previously been discovered to be important part in EAM detection and strength. [12], [13].

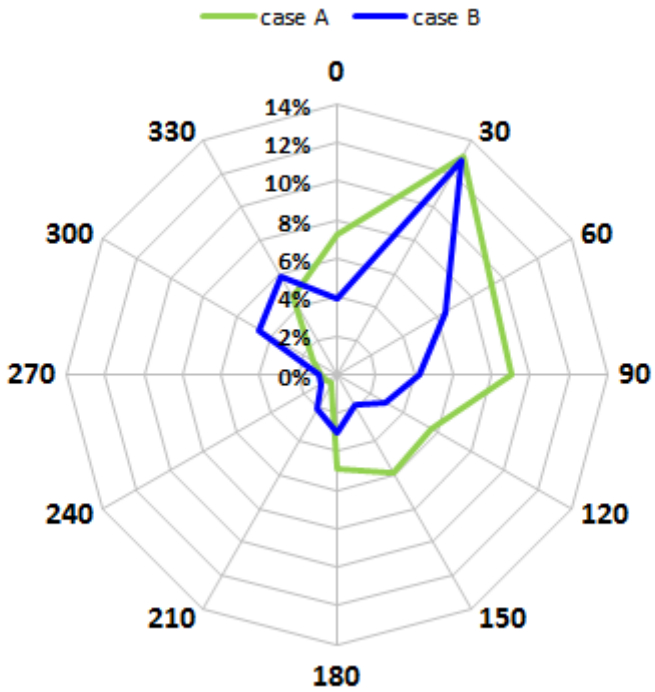

Figure 6. Calculated downwind statistics (from the national wind atlas of winds > 8 m/s at 150m height, January [x]

A conclusion from the publicly available wind data from the Finnish Wind Atlas would be that EAM occurrences may be very difficult to predict simply by using monthly average values of wind profiles or turbulence intensities. Therefore EAM risks should always be, if possible, calculated from the measured wind data which gives more freedom to separate the diurnal statistics and stability occurrences at the site. This however clearly increases the complexity and time consumption of the noise calculations as it brings meteorology related information to the process which also may require involvement of such professionals in the assessment phase. For large projects this is probably not an issue to be taken into account but may be problematic for many small sized projects with lower level of detailed engineering in the EIA/planning phase.

3.4 Interference of other turbines

Interference patters of modulation from several turbines may give sudden rise to abnormal SPL peaks or also may develop over short periods of time to the maximum SPL and then fade away. These patterns are typically chaotic in nature and vary from location to another. van den Berg realized in his study from 2007 [14] that the highest peaks or highest probability of occurrence would be created if receiver location is more or less situated in the middle of a turbine row.

Modern turbines are nowadays mostly pitch regulated variable speed turbines which may complicate the interference pattern in time domain, but does not necessarily completely remove its effect. Since turbine SPLs are calculated by using sound propagation models, it became logical to expand the propagation modelling processes to visualize locations, where individual wind turbine SPLs are close to each other in a more complex terrain areas.

Below is an example graph (figure 7) from a real wind farm location, where wind turbine noise and AM related measurement were performed few years ago [13]. The site has all together five stall regulated turbines but these example calculation situations has maximum three turbines each in a row at the top of a small hill about 300 meters above the far field terrain level.

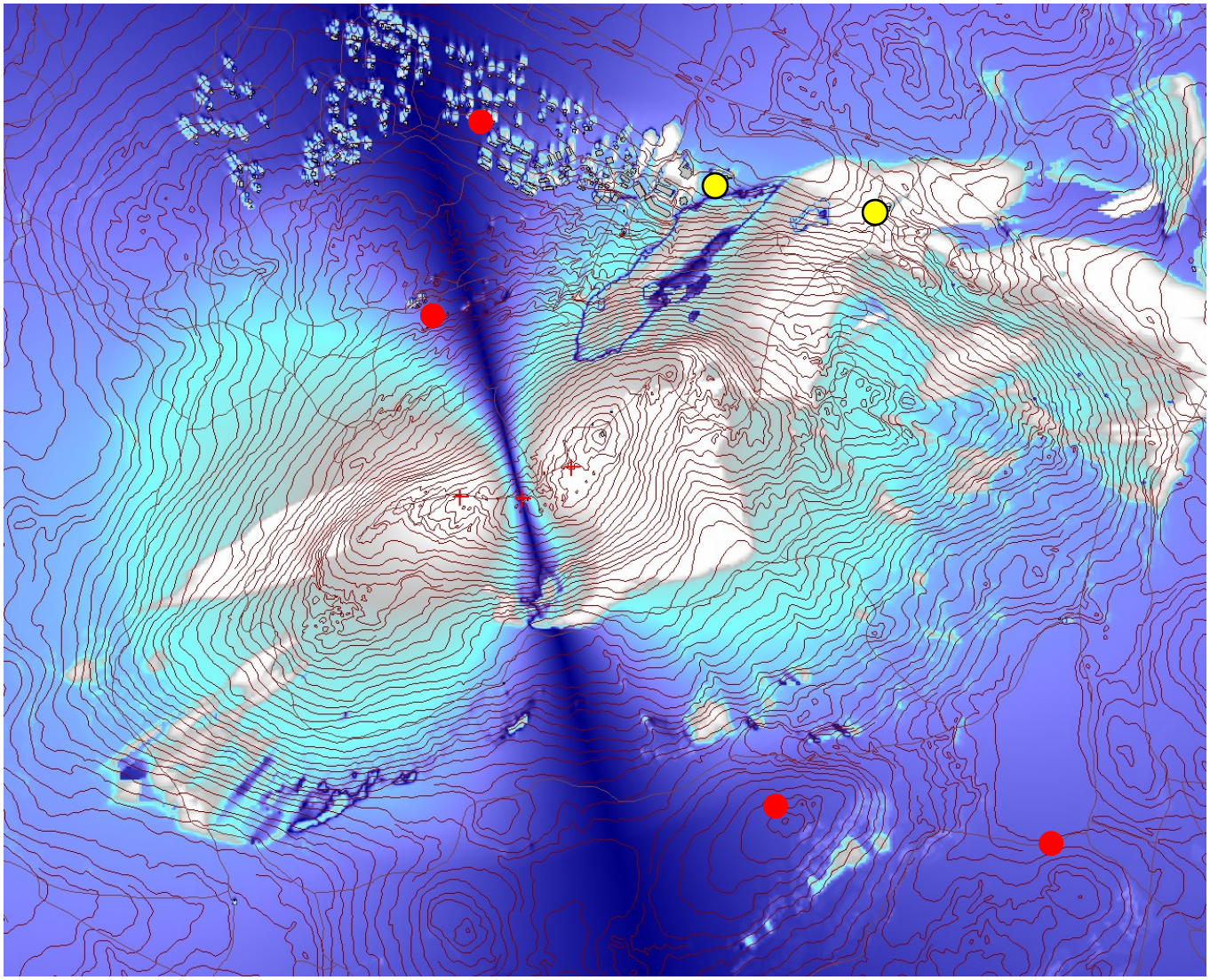

Figure 7. First three turbines

This graph above represents locations in darker colours where 2-3 turbines have sound pressure levels close to each other. These images also reveal locations (no colour), where a single turbine is dominating the SPL levels and this way may create enhanced EAM effect due to the lack of other turbines destructive interference (only a single AM pattern is perceived). A second possibility was calculated with 3 other turbines in the same turbine row in a graph below.

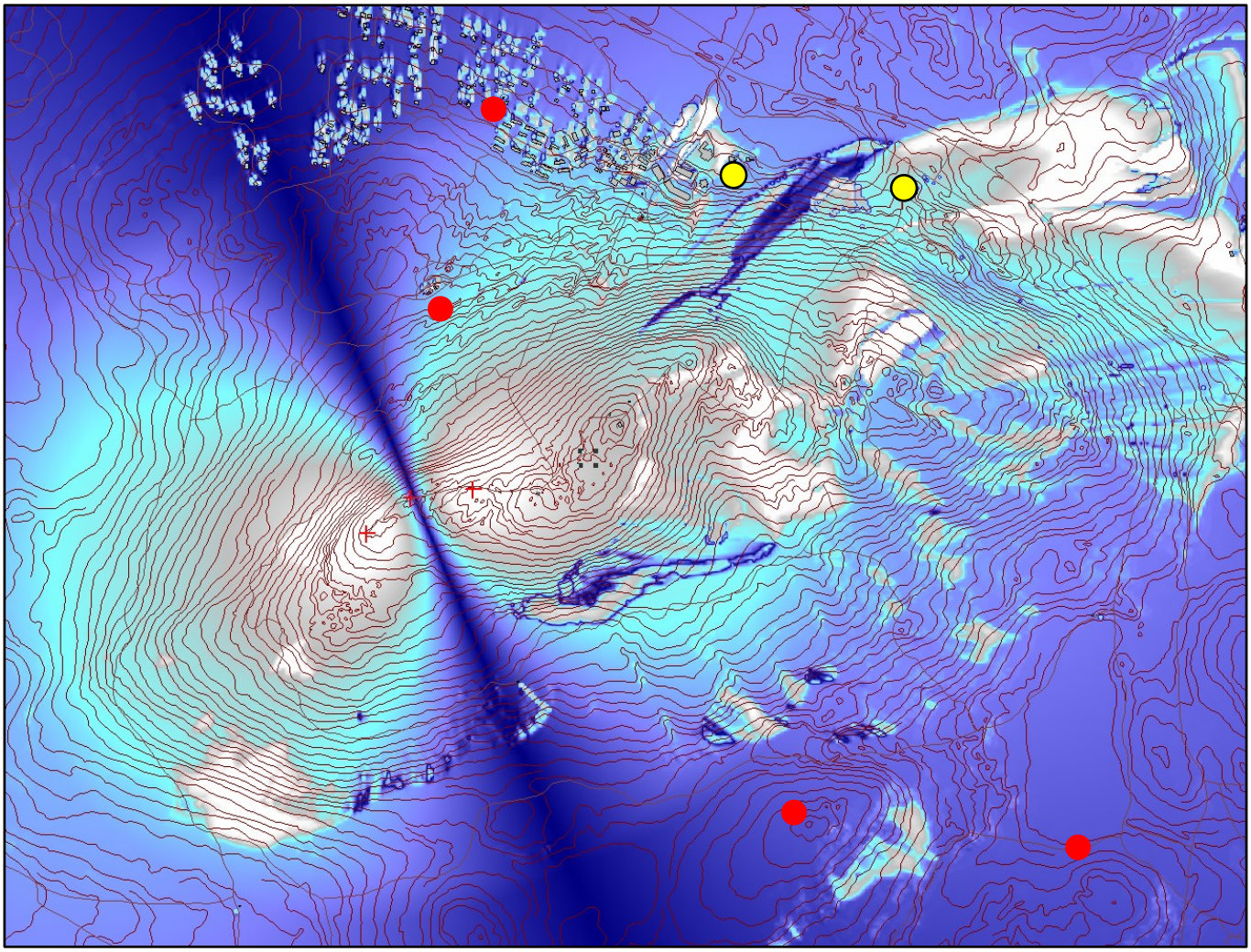

Figure 8. Next three turbine group

One can make calculation to N number of turbine groups but it may be wise to optimize the number to 2-3 turbine groups due to the separation distance and placing of individual turbines inside the single row. Both options (same or single SPL results) can be useful when searching interference and thus EAM risk areas in the surrounding areas.

This type of modelling, developed in Pöyry, is still under some development, but will be implemented in the future noise assessment projects if found to be useful. The example project modelled above had encouraging results from the real world measurements and points marked as red dots had clearly enhanced AM compared to yellow dot locations with hardly detectable AM. The modelling also revealed locations which can be difficult to predict by simply using geometrical separation distances calculated directly from the turbines.

3.5 OAM from noise emission data

Noise emission measurement results either from IEC 61400-11 measurements [15] or guarantee verification measurements typically from national level best practice guides/manufacturers own guidance [7] provides the basis for sound power level and tonality assessments. Current IEC standard revision however does not specify any methodology for EAM detection nor penalty scheme. This leaves all EAM related information to be assessed only during the commissioning phase of the wind farm.

National level best guidance, like in Finland [5-8], may advice AM penalty to be added to the reference sound power level if modulation is found to be EAM. This situation creates a conflict between national level requirements and the IEC test based noise guarantees. When noise assessment are conducted during the EIA and/or permitting phase, AM or EAM information is typically not implemented to the emission levels in sound propagation models unless there is clear evidence from a particular turbine model type problem found from previous studies [5]. A penalty level, like +5 dB, used in the current Finnish noise legislation [16], would be added to the measured sound power level if EAM is found. This situation would then lead to environmental permitting phase and possibly also costly noise optimization processes. This can be seen clearly as a risk factor in the wind farm siting processes and should be avoided by careful planning and micrositing work phase.

Current situation, where noise guarantee data does not give any information related to the occurrence of EAM at any situation, does not support the national guidance and increases the risk/demands for automatic implementation of the 5 dB penalty without even recognising the generally lower LAeq noise limits for wind turbine noise at the residents.

4.0 Conclusions

This paper describes three basic assessment methods for estimating risks regarding EAM which could be used in noise assessment phase during the different planning stages of a wind farm in Finland. This includes a new way of using generally accepted sound propagation models for mapping visually the possible sound interference areas, estimation of possible EAM risks from the site specific wind measurement data and finally turbine type dependent noise guarantee data for general AM, which is currently not available internationally.

Accurate EAM depth levels or occurrence statistics cannot be estimated by using the methods presented in this paper, however some degree of EAM risks may be revealed. Since the current statutory order of noise from wind turbines in Finland is still under governmental decision making process, there is no full certainty if the EAM penalty scheme is going to be included in the Finnish legislation. If fully implemented (as a +5 dB penalty), EAM measurement methods and modeling principles need to be revised. However EAM risk assessments are typically never included in such national levels guidance and therefore this assessment is only given directly to the project developers during the planning phase by consultants. It is therefore important to find a common EAM risk assessment methodology for professionals used in future wind farm projects to lower the risk of wind turbine related noise nuisance and to increase the reliability of wind turbine related noise assessments in general.

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