Wind Turbines

Wind power is popular. The market for wind turbines is expanding rapidly and with it is an increasing demand for turbines to be installed in urban areas. This can be problematic due to turbulence and the lack of consistent wind and means that they need to be located above the city on the roofs of buildings or other structures.

Placing wind turbines on roofs has a number of challenges such as;

- Access
- Capacity to support the applied forces
- Anticipated requirement for specialised support structures for stability
- Proximity to high spec building use such as penthouses
- Risk of resonance in the building structure
- Vibration isolation performance is very dependent on the turbine type, the building design, and building use

Each turbine design has its own operating characteristics and more importantly each roof structure and potential mounting arrangement will vary meaning that a bespoke system needs to be designed based a number of factors and must include: Structural Integrity vs Vibration Control vs Operating Performance vs Practicalities.
Design Consideration 01

Shock and Vibration affecting operating performance

Roof structures tend to be light in weight and strength and therefore are good transmitters of vibration. Usually specialist wind turbine support frames need to be designed to provide sufficient strength by connecting the frame to the main columns from the building which in turn creates a direct transmission path from turbine to the main building structure.

Vibration from wind turbines can either generate vibration or, worse, resonate parts of the structure causing vibration and reradiated noise disturbance within the building.

The vibration of the turbines can come from two sources:

- Unpredictable mechanical friction, unbalancing of the rotor, wind gust related. Depending on the maximum rotor speed, these vibrations will tend to be below 10Hz.

- The second type of predictable vibration is linked to the generator operation, and micro pulses due to the electronics of the turbine. These vibrations will range from ~100Hz to ~400Hz (varying with the rotor speed). Depending on the stiffness of the mounting system, 2nd and 3rd harmonics can appear on the vibration spectrum. Therefore, we need to consider the complete range of vibration from 100Hz to ~1.2kHz (400Hz*3rd harmonic). However, the energy from the 2nd and 3rd harmonics are a lot lower than the first one.

Most human ears can hear sounds of frequencies ranging between 20Hz and 20kHz. However, the frequency response of the human ear is such that low frequency sounds appear less loud than high frequencies. This is commonly accounted for by weighting the sound pressure level. A-weighting, for example, provides a relatively accurate measurement of perceived loudness. Vibration transmission from wind turbines into a building is undesirable because it can be heard.

Farrat has a significant amount of experience in the successful design of vibration control systems for roof mounted wind turbines. The solutions in each case were driven by the constraints but generally resulted in a bolted through or full decoupled push-pull connection using high damping elastomeric materials.

Factors to consider in obtaining a solution are:

1. Positioning - Since structural integrity is critical and such support frames cannot be avoided then vibration control needs to be incorporated somewhere between the turbine mast and the building structure. From a structural point of view they need to be located to ensure that the structure retains sufficient stiffness. The forces from the wind turbine can lead to torsion and shear loadings. From an acoustic point of view they should be above the roof which will be the most efficient transmitter of vibration energy as noise into the building and from a practical point of view they should not be affected by, or affect the insulation and waterproofing systems on the roof.
Shock and Vibration affecting operating performance (Cont)

2. **Allowable movement** - A primary constraint in vibration control of wind turbines is allowable movement. A small movement at the base of a turbine will be amplified at the top of the mast so a first question to consider is how much movement can be permitted at the top of the mast and then what is the max allowable movement at the point where the vibration control solution is to be applied. Often this value will be very low and therefore means that, high resilience, low frequency solutions such as springs or pads cannot be used. Adding mass by way of an inertial block is a very effective way of reducing vibration disturbance (2x mass = 0.5 vibration), increasing stability by lowering the centre of gravity and allowing the use of lower frequency isolators but as we know roof structures are lightweight and usually cannot permit significant addition of mass.

3. **Modelling** - The entire system needs to be considered as a 3d model rather than a simple mass on springs isolation model. Rocking and modal behaviour of the turbine structure have to be considered. For any roof mounted wind turbine application it is very important to establish the operating frequencies of the turbine as well as the natural frequency of the mounting, roof and building structure to see what the combined effects might be. This usually needs to be done with modelling. Dynamic modelling of the entire system is also important when you consider that once resilient materials have been incorporated into a connection the natural frequency of the frame will alter. The natural frequency of beams and masts will decrease once they are resiliently connected as opposed to if they were rigidly connected.

4. **Natural frequency** - is derived from mass of system rather than applied wind loads (wind load should not be considered as a mass) so the dynamic spring constant of the bolted through (push pull) connection is critical to real performance. Dynamic natural frequency does not necessarily equate to the calculated (mass spring) natural frequency.

5. **Damping** - Damping plays a crucial role in wind turbine isolation as it dissipates energy in a vibrating system and converts that energy to heat. It is essential to control the potential high levels of transient vibration and shock, particularly if the system is excited at, or near, to its resonant frequency. Damping is required where movement of the supported equipment must be minimised especially at resonance and when shock is to be absorbed.

6. **Light weight but high forces** - Roof mounted wind turbines tend to be very light whilst peak wind speeds are significantly higher (6–7x) than typical wind speeds so it is difficult to design a mounting system that can provide suitable resilience at normal wind speeds whilst still being able to accept peak wind loadings. The isolation connection design should be pre-compressed to ensure that as the connection deflects or up-lifts it does not lose tension in the connection. Pads must stay in contact with frame even under peak load (6–7x normal load). This puts an extra emphasis on the anti-vibration material to be able to withstand very high loads whilst still offering resilience at low loads.
Shock and Vibration affecting operating performance (Cont)

7. Bespoke vs off the shelf – Many off the shelf wind turbine isolation systems are designed for installation on the ground or concrete and brick structures (which are very good to damp vibration) which means they may not offer adequate vibration control performance for steel structures.

Example of Farrat’s success and experience in designing high performance vibration control solutions for roof mounted wind turbines we were asked to provide an alternative design to an existing application where a competitor’s solution was installed but not providing adequate performance.

The following is an exert from the conclusions of the vibration consultant’s findings;

“The 8 hour average results demonstrate that the typical background vibration levels fall well below the ASHRAE guideline levels for Residential (good environmental standards) of 2.032e-4m/s (8000µin/s). In addition, over the key frequency band of 10–15Hz that was seen previously to be responsible for vibration issues, the modified system design coupled with Farrat Isolation resulted in a 53.8% and 72.5% reduction over the February 2011 and September 2011 surveys respectively.”

In another example the findings were as follows;

“Levels of vibration in the flat immediately below the turbine was well below that known to cause nuisance or discomfort. The turbine’s control panel dominates the vibration measured in the flat in the X, Y and Z directions. Furthermore they did not show any correlation to wind speed.

No measurable impact on noise levels both externally and within the flat due to operation of the turbine Vibration levels within the flat are well below the comfort criteria for 24hr working.”

Solutions

Farrat Damping Pads (NBR, Squaregrip, IMBR)
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