Standard power transformers are generally considered as source of noise and vibration during service, thus their emissions can be evaluated to improve surrounding equipment mechanical design. Land-installed transformers are sometimes subjected to external vibrations during earthquakes. Particular precautions have to be taken by manufacturers to let transformers withstand such events, which remain however of short duration, meaning that long term fatigue doesn't need to be assessed.

When implemented inside a nacelle of a large wind turbine, power transformers are subjected to important external vibration which can't be ignored at design stage. Two main phenomena are responsible of this harsh environment:

- The rotor blades excitation, which is corresponding to rotational motion of the rotor, plus the blade passing frequency which is three times the rotor frequency (for three blades wind turbine). The frequency range of this excitation is comprised in the [0;2] Hz range.
- The wind turbine tower and nacelle rear frame natural frequencies, which are excited by aeroelastic loads. The frequency range of this excitation is comprised in the [1;9] Hz range.

These low-frequency loadings oblige wind turbine designers to take care of the dynamic behavior of each component on the long term, in determining damage level in all the structure for wind turbine lifetime. Technical specification of the transformer consequently comprises three main criteria that needs to be verified at design stage:

- Transformer main flexural eigenfrequencies should not coincide with wind turbine ones to avoid drastic amplification of stresses. A frequency ratio of two is recommended between wind turbine and transformer eigenfrequencies (as safety factor), meaning that the first flexural modes of the transformer shouldn't be lower than 18 Hz;
- Maximum stress applied to the structure shouldn't exceed materials' elastic limits in all parts of the transformers for transport and service conditions;
- Fatigue cumulative damage ratio should remain below 1 over representative period for transport and service conditions.

Main flexural eigenfrequencies of any transformer are directly related with overall mass and main dimensions. In the case of a 14 MVA transformer having a compact design and weighting around 20 tons, main flexural modes are naturally higher than the forbidden frequency range (below 18 Hz), so it can be considered that the dynamic amplification of stress due to transformer modes is kept within reasonable limits. Transformer rigid body modes are located in lower frequency range (comprised between 5 and 15 Hz) but are not assessed to be too severe for the structure as they imply acceleration to the whole structure without selectivity (amplification of acceleration levels in specific areas), unlike flexural modes.

Important stress and damage levels due to transport and service conditions are determined in several parts of transformer, notably around fixations to nacelle rear frame, fixations of the active part to the tank, conservator and conservator fixations, all pipes (oil and water), accessories attached to tank wall (control cabinet…) and openings (cover, manholes). In consequence, the mechanical design of transformer needs to be finely revised and adjusted to avoid stress and damage in these hotspots, which is a challenging exercise as the global mass and footprint are at the same time strictly limited.
Among relevant mechanical design practices, following solutions can be proposed:

- Adjustment of design to smoothly distribute stress in transformer fixations to nacelle and in active part fixations to transformer tank, and avoid at all times stress concentration in most fragile parts (welds and bolted openings);
- Adjustment of weld types according to damage results;
- Usage of high tensile steel when other solution is not suitable;
- Enhancement of supportive elements and usage of flexible pipes to reduce bending, elongation and torsion at connection locations;
- Adjustment of the number of bolts and material grade to reduce risk of failure or sliding for bolted openings;
- Reduction of conservator altitude at the maximum and enhancement of conservator support feet structure and welds areas;
- Usage of soft cables for lead exit connections, to avoid stress in this critical area;
- Increasement of all fixation systems stiffnesses to prevent resonances corresponding to excitation frequencies.

Another challenging activity for transformer manufacturer is the determination of damage levels corresponding to dynamic loadings. While fatigue determination can be realized manually for simple objects for static loads, large structure such as power transformer and the consideration of dynamic excitation and structural response imply to use finite element (FE) model coupled with statistical determination tool for fatigue. The calculation of damage levels should follow these steps:

1. Computation of transformer modal base (numerical modal analysis), up to maximum frequency of interest. For large offshore wind turbine application, there is no use to include in the analysis modes higher than 100 Hz.
2. Excitation of the structure using random vibration methodology. In order to consider real excitation, vibration amplitude and frequency distribution can be described by Power Spectral Density (PSD) function, which can be directly measured inside wind turbine nacelle for service conditions. PSD permits to describe efficiently the magnitude of vibration intensity for defined frequency range without considering time history signal. This can be considered as the average vibration spectrum, on which a gaussian distribution is applied to reproduce long term efforts seen be the structure. PSD is expressed as squared acceleration per frequency range.
3. Computation of structural response and determination of stress levels in all parts of the transformer, considering all frequencies.
4. Computation of cumulative damage ratio in all the structure, following stress levels determined with FE model, number of cycles (for instance 25 years for service conditions) and combination of acceleration levels in three directions, for all the material categories (fatigue strength curves, known as “S-N” curves).
5. Finally, results are analyzed considering damage plot for each material category, where applicable. A particular look is required when checking damage levels in the welds. Indeed, this is the most fragile structure (compared to plain matter), and presence of angles can virtually exaggerate damage level. In damage hotspot location, specific interpolation methodology can be used to conclude about robustness of results.

Fatigue damage results can’t be predicted using simple models. This leads mechanical designers to adopt trial and error process with complex FE models up to demonstrate full compliance of transformer structure with specification. This extends the duration of mechanical design activity compared to land-installed transformers, which can become very challenging when considering that transformer is only one component among many to be validated before manufacturing and installation inside offshore wind turbine nacelle.