

Support Through Design

An interview with ABB's global product manager

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John Shibutani, global product manager, Generators, at ABB.

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Editor's Note: The variability of renewable energy sources—especially wind and solar—and the trend towards real-time electricity markets mean there is a growing need for flexible grid support plants to balance power fluctuations. Generators used for power balancing need to operate reliably under very demanding conditions. *Diesel & Gas Turbine Worldwide's* Ian Cameron interviewed John Shibutani, global product manager, Generators, at ABB on the approach taken by the generator maker to design products that meet these challenges.



Ian Cameron (IC): How should supply variations caused by the increased amount of variable renewable energy be tackled?

John Shibutani (JS): One practical way utilities can compensate for fluctuat

ions in supplies is to operate balancing power plants. Facilities with multiple generating sets based on combustion engines and medium speed generators have proven to be a flexible and effective solution. A plant has recently been constructed in Estonia, for example, with a total capacity of 250 MW provided by 25 10 MW generating sets. Generators in this type of duty face a tough set of requirements. For these generators, 24/7 operation could mean 24 starts and stops in 7 days, or even just 7 hours. The generators may have to handle multiple starts and stops every day, rapid readiness for synchronization, and continuous load cycling. They must ramp



ABB generators on site in Estonia. The plant has a total capacity of 250 MW provided by 25 10-MW generating sets.

up from standstill to full load in just a few minutes, and ramp down even faster. The key aspect of this kind of operating profile for generator design is that the increased number of thermal and speed loading cycles cause stresses in the generator's components and structure. By simulating the thermal and speed cycles it is possible to study the stresses and their impact, and therefore obtain the information designers need to manage the stresses properly.

IC: How can cycles be investigated?

JS: To investigate the thermal cycles typical of grid support duty, our R&D team established a theoretical set of extreme operating conditions—the most unfavorable conditions a generator could be required to handle. They did this by analyzing real operating data from power balancing plants and by studying the ramp up and ramp down characteristics of the combustion engines that are typically used. Based on this research they created two extreme operating profiles. The first profile represents the maximum number of starts and stops (i.e. thermal and speed cycles) that a generator would have to cope with. The second profile represents a thermal cycle where the temperature gradient between the generator's winding and core comes close to its maximum value before cooling back down to ambient. The team then analyzed the impact of thermal cycles using the thermal network method. They produced plots showing how temperature differences between parts evolve over the two operating profiles. This work was done for both the stator – stator winding, core teeth and yoke – and the rotor. It showed the uneven temperature distributions which, together with the differing thermal expansion factors of materials like copper, steel and resin, cause stresses in generator components.

IC: How can the design challenges be helped?

JS: In terms of handling speed cycles in grid support operation, medium speed generators driven by combustion engines have characteristics that make the designer's work easier—especially when a common base frame is used. The common base frame ensures that vibrations are not transferred to surrounding structures, and the plant floor material does not have to be taken into consideration at all. The generators' relatively low rotational speed means that the design can always be sub-critical. At powers over 10 MW, the generators typically have 8-14 poles, which restrict twice-line vibrations, and makes the relatively short winding ends easy to design for high natural frequencies, and limits core-end heating when the generator is operated under-excited.

The main impact of speed cycles in grid support operation is on the generator set's vibration behaviour. As starts and stops dominate the operating profile, vibration analysis has to be done for ramp up and down as well as for nominal speed and power. Our work on speed cycles began with an analysis of the various excitation frequencies and amplitudes. The team created a finite element model of a complete generator set, and conducted a response analysis. This gave us the data we needed for an evaluation of fatigue strength based on steady state and transient deflection shapes. We then went on to verify our analysis by performing actual measurements.

IC: What are the implications for individual generator components?

JS: When it comes to applying the simulation and analysis to engineer generators for grid support duty, the designers can draw on ABB experience of medium speed motors and generators in other applications with variable operation profiles. These include synchronous motors for the metal processing and mining industries, and generators for the marine sector. As a result the designers do not have to re-invent the wheel. Looking at the insulation and winding, the important factor is that thermal cycles induce internal stresses – mainly in the insulation layers between the copper winding and steel core. Various methods—such as finite element analysis (FEA) and IEEE and IEC lifetime testing—are available to evaluate the effects on the insulation system. When we did FEA modelling, this confirmed that our existing insulation system based on vacuum pressure impregnation (VPI) provides superior capability to withstand the mechanical stresses caused by the thermal cycles. VPI involves impregnating the complete stator – and in some cases also the rotor – in an epoxy resin and it's a very well established technology. The end windings are affected by both thermal cycles and vibration. They are re-designed to enable even higher natural frequencies. 3D

modelling and FEA are typically used to support the design work, and the natural frequencies are measured to verify the results. Under-excited operation also has to be taken into account, as this can cause heating in the core-end region.

In the case of the frame, excitation and response depend on the engine and generator setup. Response analysis is therefore performed for the complete generator set, and all the details have to be taken into consideration in the re-design work. The frame is typically designed so that the natural frequencies are as high as possible and sufficiently far from the main excitation frequencies. Resonances cannot be completely avoided during starts and stops, however, so detailed analysis is performed and fatigue optimized designs used to ensure the stress levels are low enough. If welding does not provide an adequate lifetime, cast parts are used instead.

IC: What are the other challenges which are faced by designers?

JS: The rotor in these types of generators is sub-critical, which makes rotor design easier. However, we have to take thermal expansion into account, as with the stator. We generally use a jack-up system on the bearings to ensure there's sufficient oil pressure on start up to avoid excessive wear of the bearing shells. For cooling these generators have typically used an open design with shaft mounted fans. As an alternative, motor driven external fans can be used. This enables temperature variations to be minimized, or fan operation to be optimized for highest efficiency. We use CFD (computational fluid dynamics) tools to simulate the internal air flow. Generators for grid support plants have to satisfy tough requirements.

By applying advanced analysis techniques, backed by experience of applications with similar operating profiles, designers can engineer generators that will meet these requirements and provide long service lifetimes.

More information about the topic covered in this article can be found in a technical paper presented at PowerGen International, December 2015, Las Vegas, USA. The full paper is available for downloading [here](#).


