TECH BYTES 2023 — Steam Turbine and Nuclear Solutions

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TECH BYTES

Steam Turbine and Nuclear Solutions

A sampling of technical content of interest to our customers in the nuclear and conventional power generation sectors.

TECH BYTES 2023

Tech Bytes is designed to give you just a taste of the high-quality content we publish monthly in the form of case histories, application notes, articles, whitepapers, and more – all designed to deliver the expertise we've accumulated over the last seven decades, allowing you to understand more about machinery monitoring technology, the machines it addresses, and the industries it serves.

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Your preferred partner for innovative and high quality monitoring solutions

The Meggitt facility in Fribourg, Switzerland, designs and manufactures complete condition monitoring, vibration monitoring, and measurement solutions for the energy and aerospace industries.

Since its foundation in 1952 as vibro-meter, our products and expertise have enabled superior solutions for the sensing and monitoring of vibration, pressure, air gap and other essential parameters in critical plants and equipment. Today, our solutions are trusted by major OEMs globally and have become standard-fit components on machinery used in Power Generation, Oil & Gas and other industrial applications.

Nuclear Product Coverage

Corresponding Measurements / Malfunctions	Unbalance	Misalignment	Oil Whirl/Whip	Steam Instability	Rub	Loose Bearing Pedestal	Blade Vibration /Off	Excessive Turb. Expansion	Uneven Turb. Expansion	Excessive Axial Force	Thrust Bearing Issues	Rotor Bow	Excessive Torsional Vibration	Electromagnetic Unbalance	Stator Windings Wear	Insufficient Bearing Lubrication	Stator Insulation Deterioration	Stator/Rotor: Out of Round, Concentricity	Valve Instability	Valve Vibrations	Valve Hydraulics
Relative Shaft Radial Vibration	*	*	*	*	*	*						*				*		*			
Relative Axial Vibration		*								*	*					*					
Axial Shaft Position										*	*				*						
Bearing Temperature	*	*	*		*					*	*					*					
Speed & 1/REV	*	*	*		*		*			*	*	*	*	*		*		*			
Bearing Absolute Vibration	*	*				*	*				*			*		*		*			
Expansion on Collar								*		*	*										
Expansion on Tapper								*		*											
Expansion w. Pendulum		*						*		*	*										
Differential Expansion									*												
Eccentricity												*									
Blade Tip Clearance	○	○			○		○					○									
Blade Tip Time-of-Arrival							○						○								
Generator Temperature															●		●	●			
Stator Bar Vibration															●		●				
Generator Partial Discharge														*	*		*	*			
Valve Pressure, Displacement, Vibrations				*															●	●	●

* Complete vibro-meter solution
● vibro-meter solution except for the sensor
○ Third-party solution compatible with VibroSight


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Steam turbines retain to this day an indispensable role in the world's electricity production as well as mechanical drive applications

Steam Turbine Monitoring

Many of our customers work in the disciplines of instrumentation and control (I&C), rotating machinery, and reliability. Few would consider themselves process professionals. For this reason, we start our discussion of steam turbines with a basic review of where they are used as summarized in Table 1.

Figure 1 shows the share of electricity production by type of generation between 1988 and 2021. Considering that steam turbines are used exclusively as the main generators in all coal-fired and nuclear plants, those plants alone tell us that steam turbines account for nearly half (46%) of the world's electricity generation. When we also consider that a large percentage of gas-fired plants utilize combined cycles, and that about 30% of the power in combined cycle plants is contributed by the steam turbine(s) therein, it becomes obvious that far more than half of the world's power is still attributable to steam turbines.

Steam Turbine Monitoring

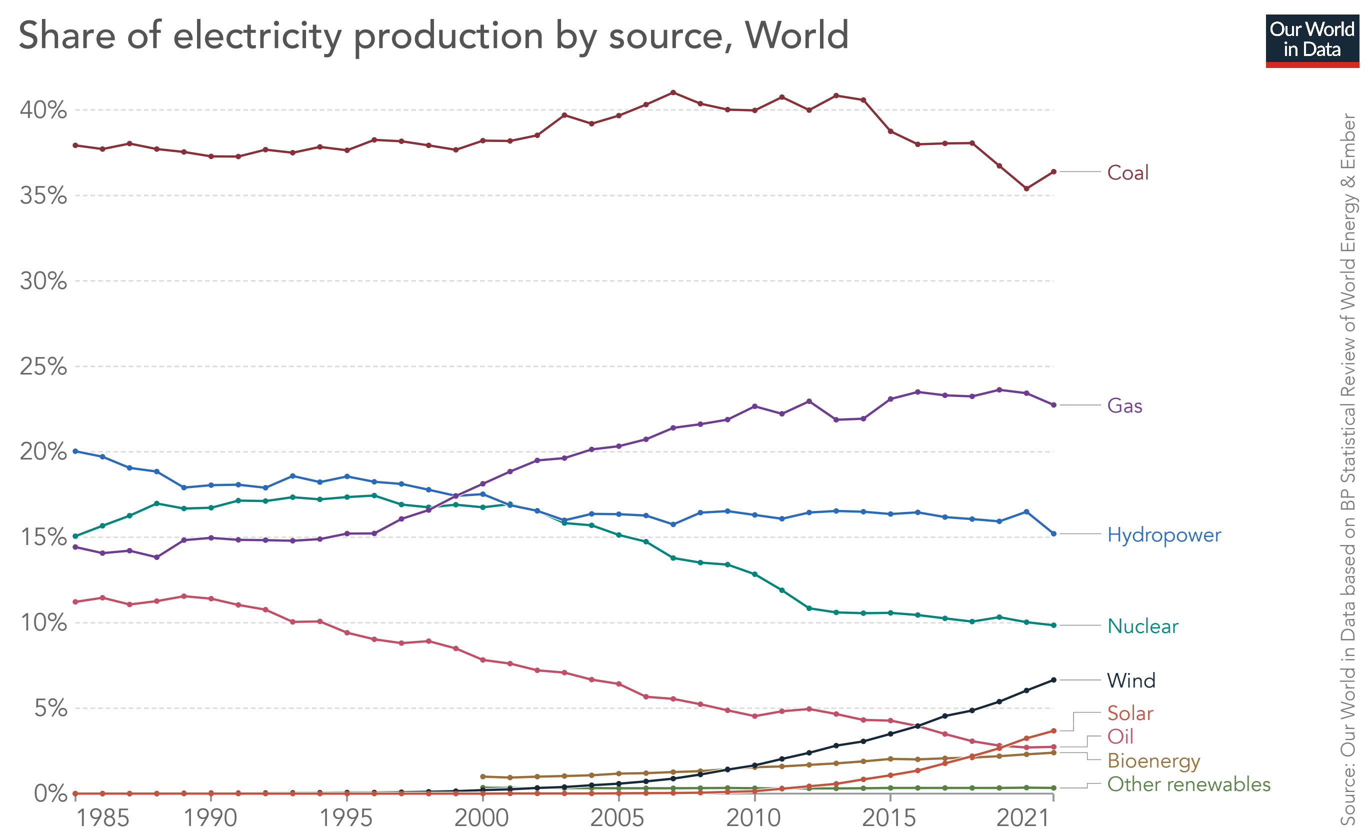


Figure 1: Global share of electricity production by source between 1985 and 2021. The contribution from coal (~36%) and nuclear (~10%) relies entirely on electricity produced from steam turbines while that from gas, oil, and solar relies partially on steam turbines. A large percentage of gas-fired plants use combined cycles where approximately 30% of the plant's electricity output comes from one or more steam turbines.

When we add in the tens of thousands of steam turbines used for mechanical drive applications globally where the driven machine is something other than an electrical generator, it becomes clear that steam turbines will be with us for the foreseeable future.

Sizes and Bearing Types

Steam turbines in power generation service can range in size from as much as 1800 MW in nuclear plant service to less than 10MW when used for on-site power generation as part of a process plant. However, the vast majority are greater than 2 MW in size and for this reason use fluid-film bearings rather than rolling element bearings.
Steams turbines in mechanical drive service can range in size from single-stage units as small as 0.1 MW to multi-stage units as large as 200 MW. As noted above, however, once they exceed approximately 2 MW in size, fluid-film bearings are almost always used. Thus, most steam turbines encountered in practice will utilize fluid-film bearings and are most appropriately instrumented at their radial and axial (thrust) bearings by means of proximity probes.

Sensors and Measurements

Although most steam turbines employ fluid-film bearings, smaller units in mechanical drive service incorporate rolling element bearings and are thus monitored with seismic sensors mounted on the bearing caps as shown in Figure 2. Their driven machines are likewise small and usually also employ rolling element bearings and are thus also monitored by means of bearing cap seismic sensors.

Although some customers monitor larger steam turbines that have fluid-film bearings with seismic sensors, this is not recommended because the diagnostic data available from such sensors for condition monitoring purposes is rarely adequate. While rolling element

Primary applications of steam turbines

Table 1

Type	Steam Turbine Applications	Steam Production Method
Nuclear	• Main Turbine Generators • Mechanical Drive for auxiliary equipment	Steam produced via nuclear fission
Thermal Power	• Main Turbine Generators • Mechanical Drive for auxiliary equipment	Steam produced in a boiler via burning of fossil fuel
Combined-Cycle Power	• Main Turbine Generators	Steam produced in a Heat Recovery Steam Generator (HRSG) using hot exhaust from gas turbine
Combined Heat & Power (aka: Cogeneration)	• Main Turbine Generators	Steam produced as in a combined-cycle plant or as in a conventional thermal plant
Concentrated Solar Power (CSP)	• Main Turbine Generators	Steam produced through concentrated sunlight that heats water directly or indirectly via a working fluid (such as molten salt)
Geothermal Power	• Main Turbine Generators	Steam produced through concentrated sunlight that heats water directly or indirectly via a working fluid (such as molten salt)
Mechanical Drive	• Prime mover for pumps, fans, compressors, etc.	Usually, a byproduct of an exothermic process in a process plant, or sometimes directly via a fired boiler if steam is needed for the process

bearings generate characteristic frequencies based on the make/model of bearing, its internal geometries, and rotative speeds, the same is not true of fluid-film bearings and a true shaft-observing transducer (eddy-current proximity) is necessary for proper diagnostics.

Although a seismic transducer can arguably provide radial vibration protection if the machine shakes severely enough, it cannot provide thrust bearing protection because this is fundamentally a position measurement – not a vibration measurement.

Also, for radial measurements, the forces transmitted from the rotor through the fluid film and subsequently to the bearing cap undergoes damping and may or may not reflect an appreciable amount of casing vibration for a given amount of rotor vibration. Lastly, there can be problems such as misalignment that manifest as radial position changes – not just vibration changes – that won't be detected by a seismic sensor such as an accelerometer or a moving-coil velocity transducer.

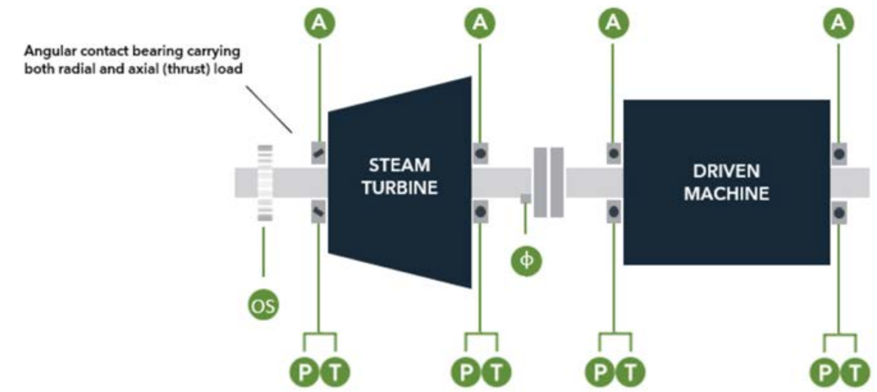


Figure 2: Small steam turbines in mechanical drive service typically use rolling element bearings and are monitored as shown here via absolute (A) seismic sensors mounted on the bearing housings. The vibration measurements are often augmented with lube oil pressure (P) and bearing temperature (T) measurements. Overspeed (OS) and phase trigger (ϕ) measurements should also be included.

For all of these reasons, vibro-meter recommends proximity probes whenever the machine has fluid-film bearings. As will be discussed later in this article, seismic sensors can augment the data from proximity probes on extremely large and/or compliant machines via so-called dual-probe and shaft-absolute measurements, but they should only be used in addition to (not in lieu of) proximity probes.
When steam turbines use fluid-film bearings (and the vast majority do), they are monitored with conventional X-Y proximity probes at radial bearings and dual-voting axial probes at thrust bearings as shown in Figure 3. This complement of transducers (when a phase trigger is also installed) provides both adequate machinery protection and diagnostic / condition monitoring capabilities for machines up to about 30MW in size. Occasionally, seismic sensors are also mounted on the bearing caps to allow both shaft-relative and bearing absolute

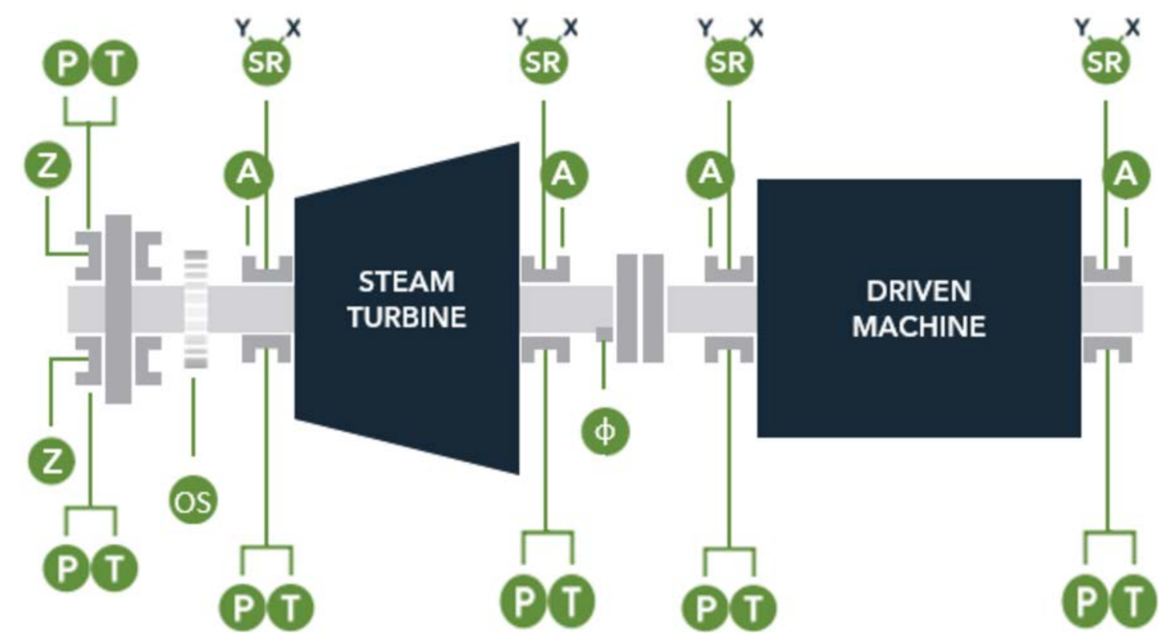


Figure 3: Up to approximately 30MW, steam turbines with fluid-film bearings can be addressed with only conventional measurements of shaft-relative (SR) vibration using X-Y proximity probes, axial position (Z) using dual-voting proximity probes, and a phase trigger (ϕ). As with smaller units, lube oil pressure (P) and bearing temperature (T) measurements are also often present. Overspeed (OS) is a must and shaft-relative vibration measurements may be augmented with seismic sensors to measure bearing absolute (A) vibration.

vibration to be monitored. These two measurements can be vectorially subtracted in the monitoring system to provide a shaft-absolute measurement (shaft vibration relative to free space) provided the proximity and seismic sensors are mounted in the same measurement axis. Shaft-absolute measurements are particularly important on highly compliant machines where there is appreciable casing motion compared to shaft motion.

Once steam turbines exceed approximately 30MW, an additional complement of measurements becomes necessary. These are known as TSI (Turbine Supervisory Instrumentation) measurements and are detailed extensively in our downloadable eBook on the topic. The first TSI measurement to come into play is usually rotor eccentricity and is a measure of shaft bow given the long unsupported rotor length between bearings. This measurement is usually required on all steam turbines above 30MW to ensure that the machine is not started if excessive shaft bow exists. To keep the shaft from bowing, it is never allowed to come to rest and is instead kept rotating at very slow speeds (usually 3 rpm or less) to ensure the rotor cannot sag by remaining stationary. Eccentricity is measured by means of a radial proximity probe, mounted at a shaft axial extremity where the bow will be most pronounced and thus easier to detect.

> "Vibro-meter has extensive experience monitoring steam turbines in all configurations and settings, whether combined-cycle, conventional thermal, geothermal, or nuclear. bro-meter has extensive experience monitoring steam turbines in all configurations and settings, whether combined-cycle, conventional thermal, geothermal, or nuclear."

The next TSI measurement is differential expansion and it is generally required on machines above approximately 50MW. Differential expansion occurs due to the differing thermal expansion rates of the rotor relative to the casing. As would be expected, the rotor with its smaller mass will heat (and thus grow) faster than the casing when a unit is started and steam is admitted. If the operator does not carefully control the admission of steam, the rotor will grow too fast and come into contact with the casing, severely damaging the machine and entailing outages measured in weeks or months rather than days. The same situation can happen in reverse where the rotor cools too rapidly relative to the casing, and thus shrinks faster than the casing and incurs an axial rub. This condition can arise during steady-state operation if abrupt changes in steam conditions occur. Either condition ("rotor long" or "rotor short") can be catastrophic and are measured by means of proximity sensors attached to the case that detect the relative position of rotor and casing to one another.

The last TSI measurement is so-called casing or shell expansion and is made on the high-pressure (HP) steam turbine casing. To ensure the HP casing does not warp or crack, one end is fixed and the other end floats, allowing it to expand as it heats. If the sliding end of the casing becomes stuck, damage will occur and the casing expansion is thus carefully monitored – via one or (ideally) two LVDTs – to ensure that the casing is growing at an expected rate until steady state conditions are reached and casing growth reaches equilibrium conditions. Case expansion measurements are usually required on units of 80MW or more.

Figure 4 shows the complement of TSI measurements that are used on large steam turbines, whether in mechanical drive service or power generation service.

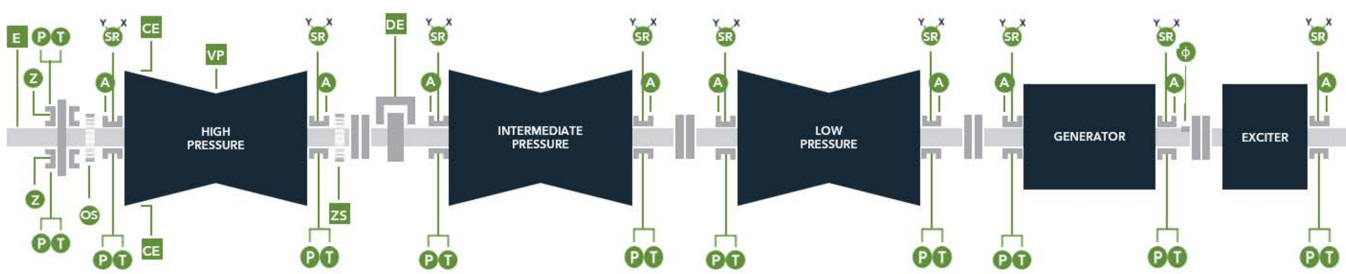


Figure 4: Once a steam turbine exceeds approximately 30MW, eccentricity (E), differential expansion (DE), and case expansion (CE) measurements come into play along with the measurements already mentioned in Figures 3 and 4. The zero speed (ZS) measurement occurs in conjunction with eccentricity and is used to detect when the shaft rotational speed has slowed to the point where a turning gear can be engaged and keep the rotor slowly turning (usually 2-3 rpm) to thus prevent a shaft bow. The valve position (VP) measurement is often done in the turbine control system rather than the TSI system but is shown here for completeness as it will occasionally be included in the TSI rather than turbine control platform.

Overspeed

Steam turbines are particularly vulnerable to overspeed and such events can be spectacularly catastrophic. By their nature, steam turbines are pressure vessels and are meant to contain high temperature, high pressure steam. During an overspeed event, blades will often become liberated from the shaft and may consequently puncture the casing. Not only does this represent danger to plant and personnel because the blades become projectiles, but the escaping steam can wreak havoc regardless of where the blading projectiles may exit the casing. A bystander would not be safe just because they are on the opposite side of the machine from where the blades exit.

While all steam turbines must be protected from overspeed events, smaller single-stage units can be particularly vulnerable. This becomes apparent when one considers the relatively small mass of the rotor and how quickly it can accelerate. Unlike larger turbines, the small rotor presents far less inertial opposition to a change in speed and can thus rapidly accelerate to speeds that will destroy the machine in less than a second.

You can learn more about the topic of overspeed in our Speedometer publication, a comprehensive 24-page guide that discusses overspeed, its consequences, industry standards, and vibro-meter's solution offerings including sensors and protection devices.

Combined Cycle Plants

While most power plants (nuclear, thermal, CSP, geothermal, or CHP) have a single steam turbine driving a load, and while most mechanical drive applications involve a single steam turbine coupled to its driven machine, combined-cycle plants deserve special consideration because the steam turbine may or may not be coupled to a gas turbine in some fashion.
As was mentioned in the introduction section of this article, a combined-cycle power plant uses the exhaust gas from one or more gas turbines to create steam which in turn is expanded through a steam turbine to make additional electricity. In a so-called 1:1 (one-on-one) arrangement, the exhaust heat from a single gas turbine is used to create steam for a single steam turbine. In some instances, the gas turbine and steam turbine will be connected to one another on a single shaft, driving a common generator. This is known as a single-shaft arrangement. In other instances, the steam and gas turbines will be on separate shafts and each will drive its own generator.

Another arrangement occurs when the exhaust gas from multiple gas turbines is used to create steam for a single steam turbine. For example, when two gas turbines create steam for a single gas turbine, this is known as a 2:1 (two-on-one) arrangement. Older combined cycle plants with numerous smaller gas turbines may have even higher ratios of gas turbines to steam turbines. For example, PGE's Beaver Plant in Oregon uses a 6:1 arrangement where six GE Frame 7 gas turbines create steam for a single 125MW steam turbine. This plant went into service in 1976 and is an example of older technology where a larger number of gas turbines "feed" a single steam turbine. The result is still that approximately 30% of the total electrical output comes from steam, but there is a higher proportion of gas turbines to steam turbines.

An example of a more modern combined-cycle plant is detailed in our case history for two plants owned and operated by AXPO in Italy. These plants use 1:1 configurations where a 260 MW gas turbine generates sufficient steam to power a 120 MW steam turbine, and thus 31.5% of the total electrical output. However, these are not so-called single shaft configurations as the gas and steam turbines each drive separate electrical generators.

You can access the case history here which details how the steam turbine monitoring systems were retrofit with vibro-meter's proximity probes and VM600 monitoring platform to eliminate the spurious (false) trips caused by the original system from another manufacturer.

Summary

Steam turbines use conventional radial vibration and thrust position measurements, but once the size exceeds about 30MW, an additional complement of measurements will be present. These measurements are known as TSI (Turbine Supervisory Instrumentation) and are detailed in a companion publication available here. Most combined cycle plants employ steam turbines larger than 30MW and will thus incorporate TSI measurements. Likewise, most conventional thermal power plants will use trains that range in size from 50MW to over 900MW and will also incorporate TSI measurements. Nuclear plants are designed with large reactors for economies of scale and the steam turbines in such plants are consequently very large, ranging in size from about 700MW to as large as 1800MW – enjoying the distinction of being the most powerful rotating machines in the world. In contrast, geothermal plants generally have smaller machines that rarely exceed 20MW and typically use only conventional measurements rather than TSI measurements. Concentrated solar plants (CSPs) are still relatively few in number, but typically have steam turbines ranging in size from 2MW up to about 200MW in size and may thus also have TSI measurements in addition to conventional measurements.

Vibro-meter has extensive experience monitoring steam turbines in all configurations and settings, whether combined-cycle, conventional thermal, geothermal, or nuclear. Our solutions are often supplied for new combined-cycle plants where we monitor both gas and steam turbines, but we are equally proficient in providing retro-

Figure 6: This 140MW steam turbine is used in a combined-cycle plant in Germany. Steam turbines in combined-cycle service have been specially enhanced over the last several decades to meet the demands of the steam conditions found in combined-cycle plants along with numerous other improvements[1].

fits to aging steam turbine monitoring systems. Indeed, many conventional thermal and nuclear plants were commissioned decades ago and their instrumentation systems are now reaching or have surpassed their intended design life. We are able to replace the protection systems and sensors[2], and augment these systems with condition monitoring if it is not already present.

In other situations, an outage may not be planned for some time and it is desirable to keep the underlying protection systems and sensors intact while either installing a condition monitoring system for the first time, or replacing an aging and/or unsupported condition monitoring system.

Lastly, because we have expertise on both gas and steam turbines, and because both machine types are often found in many plants, a single system and a single provider can be trusted to address all of your machinery along with the turnkey services scope to address any type of project, whether greenfield or brownfield.

Turnkey Solution Portfolio

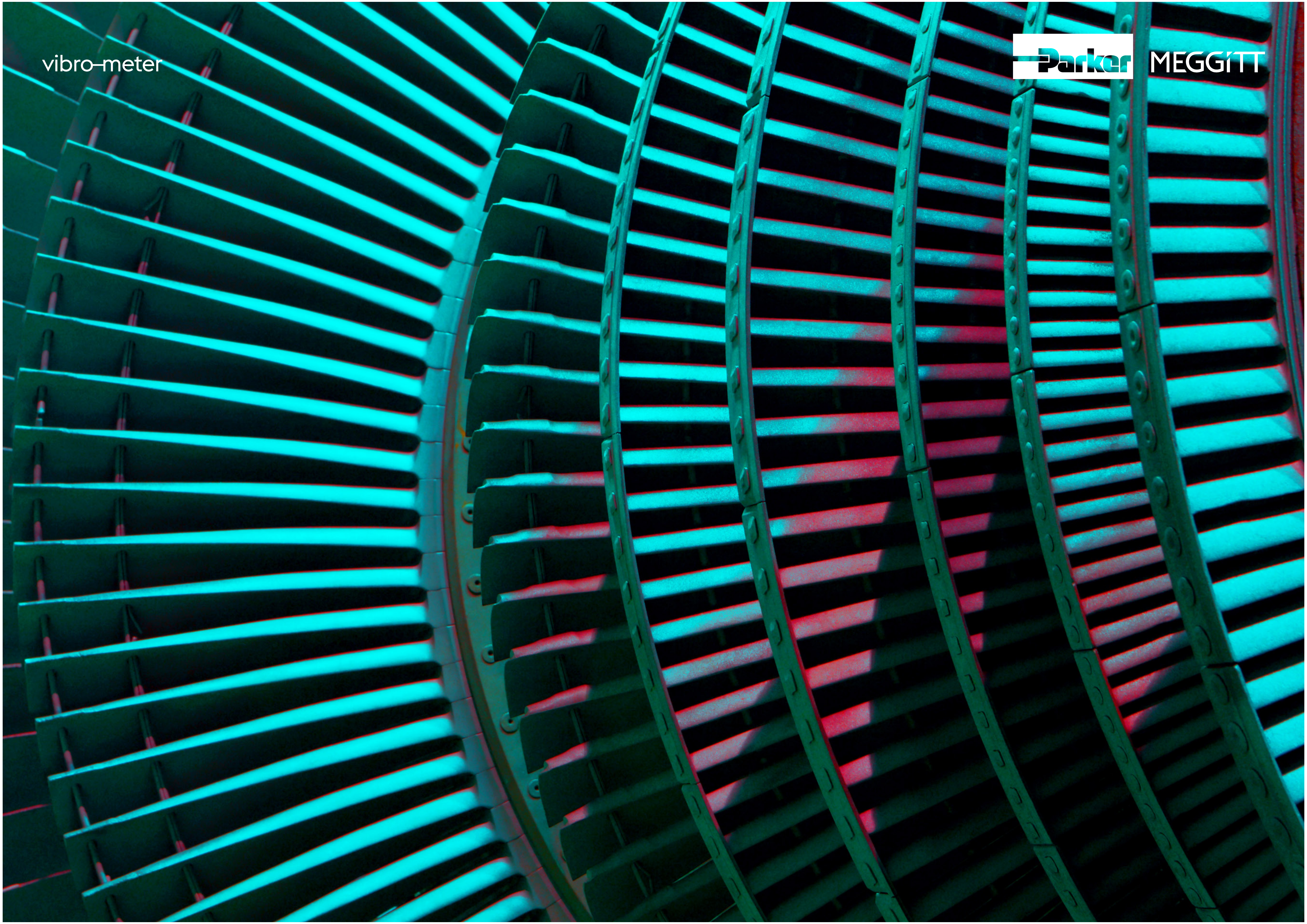
- ✔ Replaced protection system
- ✔ Replaced sensors
- ✔ Project Management
- ✔ Fully instrument "bare" machines
- ✔ Sensor Installation and Verification
- ✔ Turnkey Service
- ✔ Documentation
- ✔ Training

In addition to our products, vibro-meter has an extensive portfolio of turnkey services for projects involving steam turbines, gas turbines, and their driven machines.

Notes

1. "*Combined Cycle Power Plants*" IMIA Working Group Paper 91 (15); page 14, IMIA Annual Conference 2015, Merida (Yucatán), Mexico, 26-30 September 2015. Retrieved Sept 15, 2022.

2. Many older turbines are under-instrumented and can benefit from additional sensors – not just new sensors that retain the existing mounting locations and bracketry.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Turbine Supervisory Instrumentation – a forgotten art?

Whether you are a rotating machinery engineer, reliability specialist, maintenance practitioner, control room operator, or instrumentation professional, understanding what you are measuring and why is always important. As the world shifts away from steam turbines to gas turbines, it is reasonable to ask whether knowledge of steam turbine instrumentation is really even necessary or will eventually become just a largely extinct bit of knowledge – like hieroglyphics or the finer points of constructing feather quill pens – of little practical use and of interest to only a curious few.

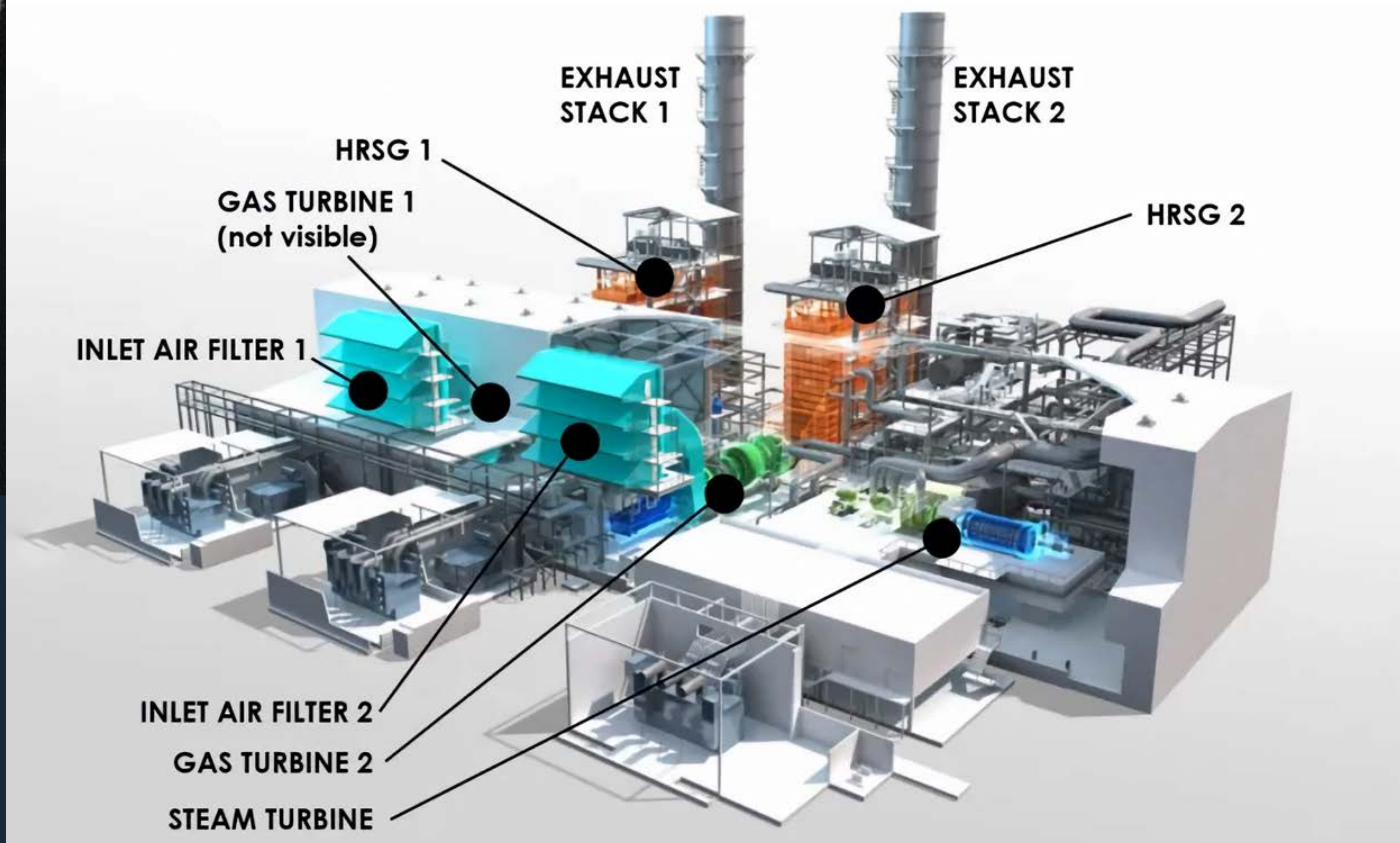
Turbine Supervisory Intrumentation

But the truth is that steam turbines will be with us for a long time to come. And therefore, measuring their conditions will remain important for a long time to come.

Even as the world relies more and more on electric motors where smaller, single-stage steam turbines were once used for mechanical drive applications, coupled with an increasing dependence on gas turbines and renewable sources for electricity generation, steam turbines – particularly large steam turbines – will remain a vital part of the mix for several reasons.

First, although the efficiency of simple-cycle gas turbine plants may outperform similar thermal plants using only steam turbine generators, they still waste considerable energy up the exhaust stack – energy that can be used to boil water and generate additional power through a steam turbine as part of combined-cycle operation. Compare the efficiency of today's best simple-cycle gas turbine plants at less than 45% with the 55 to 60% achievable in combined-cycle plants by simply adding a steam turbine and a Heat Recovery Steam Generator (HRSG). It really is like getting a free lunch: no additional fuel yet up to 50% more electricity production.

Second, combined-cycle plants are not the only place where steam turbines will continue to see application. Nuclear plants will continue to employ gargantuan steam turbine generators – some capable of producing the same power output in a single machine train as would require more than 640 average-sized wind turbines, all while consuming 500 times less real estate. And pure thermal plants using gas, coal, or oil will likewise continue to see



A modern combined-cycle power plant in a so-called "2 on 1" (2:1) configuration with two gas turbines and a single steam turbine. The Heat Recovery Steam Generators (HRSGs) capture the exhaust heat from the gas turbines that would otherwise go up the two stacks, using it to boil water for the steam turbine and thereby generate up to 50% more power than would be available from a simple-cycle gas turbine-only plant. Combined-cycle plants are typically referred to by the ratio of gas turbines to steam turbines. Other configurations include a single gas turbine and a single steam turbine (1:1) as well as larger ratios such as 4:1. Image courtesy of WSC, Inc.

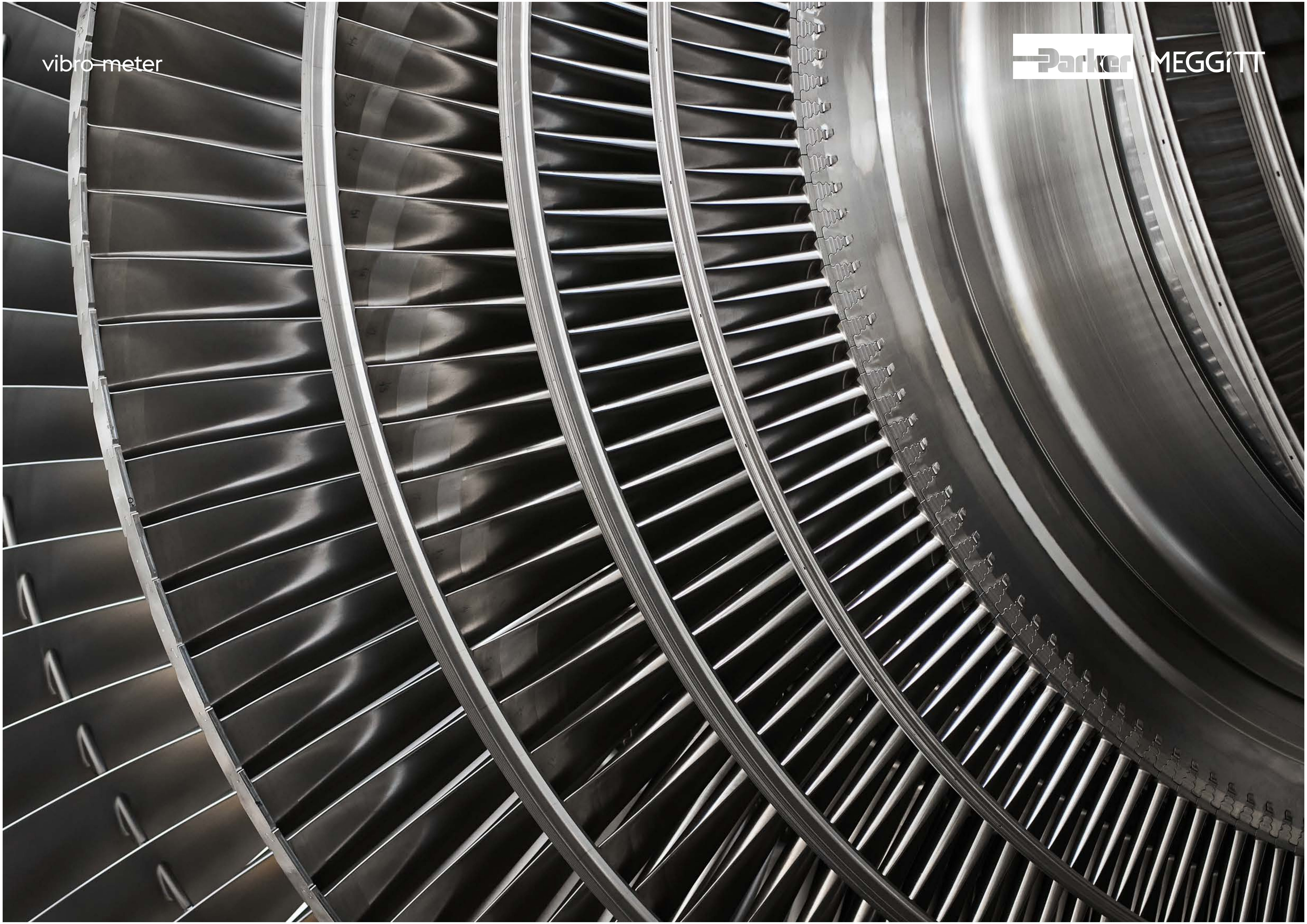
A typical steam turbine generator train in a thermal power plant. These machines range in size from less than 100MW to as much as 1200MW. The steam turbine cases in this photo are blue, the piping that routes the steam from the HP/IP turbine sections to the LP turbine section is silver, and the generator/exciter is yellow. Originally designed for a continuous baseload operation, many thermal plants today are used to supplement baseload during periods of peak demand, placing additional wear and tear on machines that were not intended to run up and down so frequently. Comprehensive monitoring has thus become more critical – not less – on such machines.

use to help meet peak demand even as renewables such as hydro, wind, and geothermal form a larger percentage of capacity and cleaner sources of generation from gas turbines become the go-to sources for meeting baseload demand. In fact, as thermal plants become more and more relied upon for peak demand rather than base demand, the mechanical stresses on machines that were originally intended for continuous, baseload operation but are now running up and down multiple times per week becomes acute. The instrumentation on these large steam turbine generator trains becomes more important than ever because cyclic mechanical and thermal stresses are being incurred for which the machines were never originally intended.

A typical steam turbine generator train in a thermal power plant. These machines range in size from less than 100MW to as much as 1200MW. The steam turbine cases in this photo are blue, the piping that routes the steam from the HP/IP turbine sections to the LP turbine section is silver, and the generator/exciter is yellow. Originally designed for a continuous baseload operation, many thermal plants today are used to supplement baseload during periods of peak demand, placing additional wear and tear on machines that were not intended to run up and down so frequently. Comprehensive monitoring has thus become more critical – not less – on such machines.

Because these steam turbines are so large, their casings and rotors expand thermally at different rates, entailing special measurements to ensure rotor-to-casing rubs do not occur. In addition, the massive rotors can sag due to gravity if allowed to come to a complete standstill during times when the turbines are not operating. This entails another set of important measurements. And, because both the casings and the rotors of these machines can undergo substantial vibration, the normal assumptions that only shaft-relative vibration measurements are required may not apply. Can you name all of these measurements, the variations in how they are made, and why they are made? You'll find the answers in our comprehensive TSI - Practical Guide via our website.

The steam turbines in a nuclear plant are exceptionally large, ranging in size from 800MW to over 1700MW. The largest steam turbines in the world are in nuclear plants and capable of delivering the same power in a single machine train as would require 640 typical wind turbines. Pictured here are the 1000MW units at the Kursk Nuclear Power Plant in Russia.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CASE STUDY*

Replacement of an unreliable Machinery Protection System to address spurious trips

When faced with a history of spurious trips due to unreliable machinery protection systems on the steam turbines at the Sparanise and Rizziconi combined cycle power plants, Axpo enlisted vibro-meter's expertise and technology to resolve the problems – once and for all. In this case study, we explore both the problem and the solution along with the economic implications of unchecked spurious trips.
The Sparanise and Rizziconi combined cycle plants use identical 1:1 combined cycle configurations consisting of a V94.3 gas turbine (260MW) and a 120 MW steam turbine, both manufactured by Italy's Ansaldo Energia.

Axpo Case Study

Each plant has two of these 1:1 configurations resulting in a total plant output of 760MW. Major auxiliary equipment at each plant includes four feedwater pumps (two per train) manufactured by Sulzer.

When originally built, the gas turbines were equipped with vibro-meter VM600 machinery protection systems providing integrated vibration and combustion dynamics monitoring. Indeed, vibro-meter is the standard and preferred supplier of sensors, machinery protection, and condition monitoring systems for Ansaldo. However, the steam turbines were instrumented with competing products from a regional Italian manufacturer. The solution included both the monitoring systems and the transducers. The feedwater pumps were unmonitored.

Particularly during the last few years, the plants began to experience spurious trips from the systems monitoring the steam turbines. While the economic implications vary somewhat due to the particular contractual obligations for electricity supply from each plant on any given day, a general rule of thumb is that each hour of interrupted supply incurs approximately €50K in losses, and that the minimum interruption imposed by a single spurious trip is at least one hour. Due to the aging of the installed systems monitoring the steam turbines, and the need to improve the reliability of those monitoring systems, Axpo thus began exploring new solutions.

> "When faced with a history of spurious trips due to unreliable machinery protection systems on the steam turbines at the Sparanise and Rizziconi combined cycle power plants, Axpo enlisted vibro-meter's expertise and technology to resolve the problems – once and for all."

Figure 1: The plants at Rizziconi (shown here) and Sparanise are essentially twins and utilize two 1:1 combined cycle configuration consisting of a 260MW Ansaldo V94.3 gas turbine, a Heat Recover Steam Generator (HRSG), and a 120MW steam turbine. The cooling towers are within the blue structures, the turbines within the green structures, and the HRSGs are the tall structures adjacent to each exhaust stack.

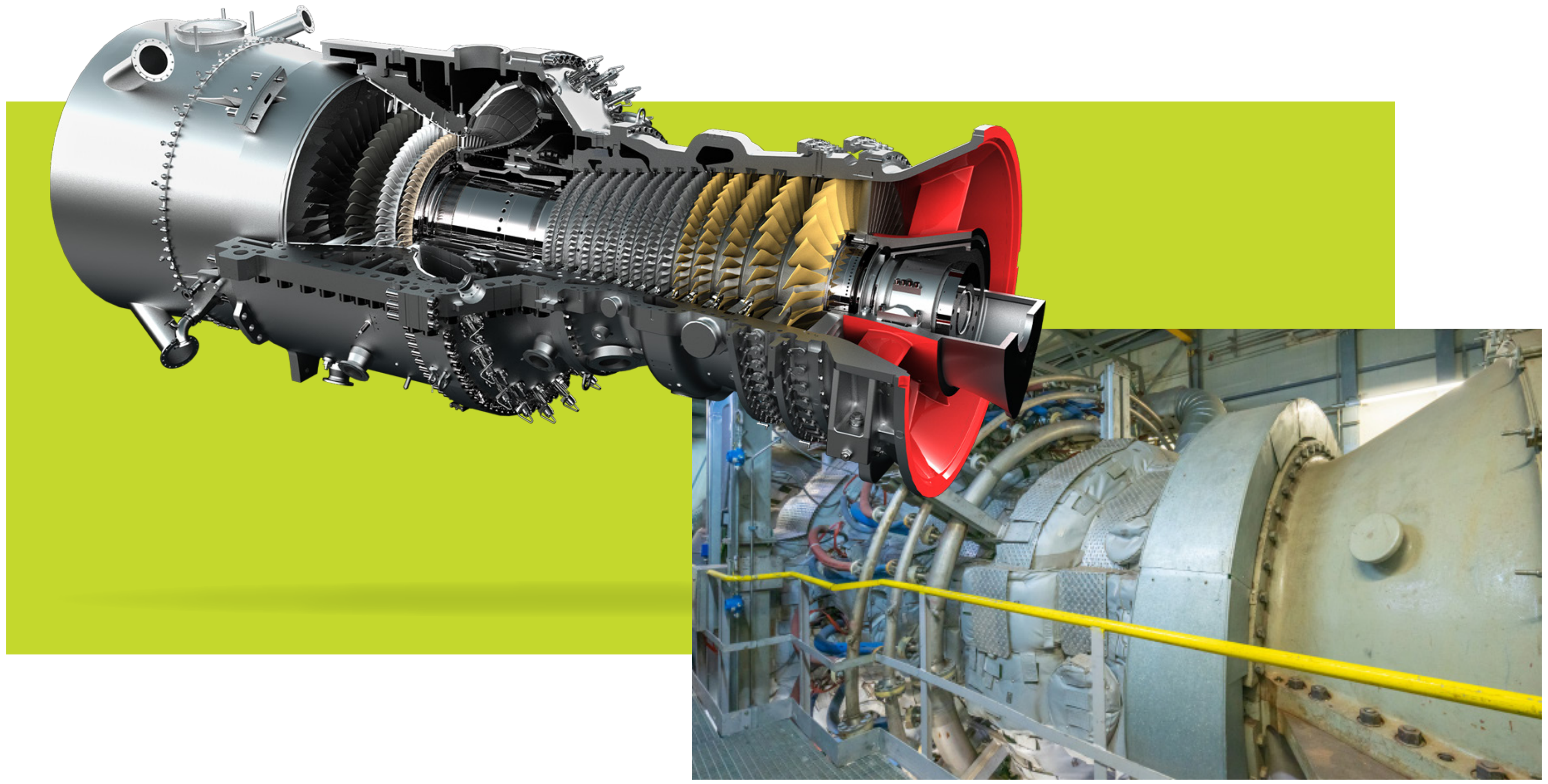


Figure 2: Twin Ansaldo V94.3 gas turbines are at the heart of each combined cycle plant, protected by vibro-meter transducers and VM600 monitoring systems.

Figure 3: Each of the plants' two 120MW steam turbines were originally fitted with a regional Italian competitor's products that emerged as a source of constant problems with spurious trips – and the ensuing costs therefrom

vibro-meter Solution

Due to Axpo's trouble-free experience with the systems monitoring the gas turbines, and the strong relationship between Ansaldo and vibro-meter, we were the obvious candidate to resolve their spurious trip issues by replacing the steam turbine systems with our VM600 platform.

The decision was also made to replace the steam turbine sensors because it was believed that they may well be the ultimate source of the problems through a high susceptibility to electromagnetic interference. To reduce project costs, vibro-meter field service personnel re-used existing transducer housings and simply retrofit our own products given the universal nature of most mounting accessories such as external probe holders and stems. The steam turbine measurements are shown in Figure 4 and comprise conventional vibration measurements as well as turbine supervisory instrumentation (TSI) measurements.

Lastly, Axpo chose to retrofit monitoring on the four un-instrumented feedwater pumps at each plant as part of the steam turbine instrument upgrade project. The pumps are motor-driven and reflect a mix of rolling element (motor) and fluid-film (pump) bearing types. Although the OEM supplied the machine trains with provisions for mounting transducers on each bearing cap (surfaces spot faced; holes drilled and tapped), transducers had not been installed when the machines entered service in 2008. Consequently, one accelerometer was mounted on each bearing cap as shown in Figure 5. For monitoring, the VibroSmart system (Figure 6) was selected due to its distributed architecture and corresponding ability to reduce wiring costs by keeping the individual sensor cabling runs short while mounting the modules near each machine.

In contrast, because wiring had already been run for the incumbent steam turbine monitoring system, the centralized architecture of the VM600 was a better fit. This illus-

> "Axpo chose to retrofit monitoring on the four un-instrumented feedwater pumps at each plant as part of the steam turbine instrument upgrade project."

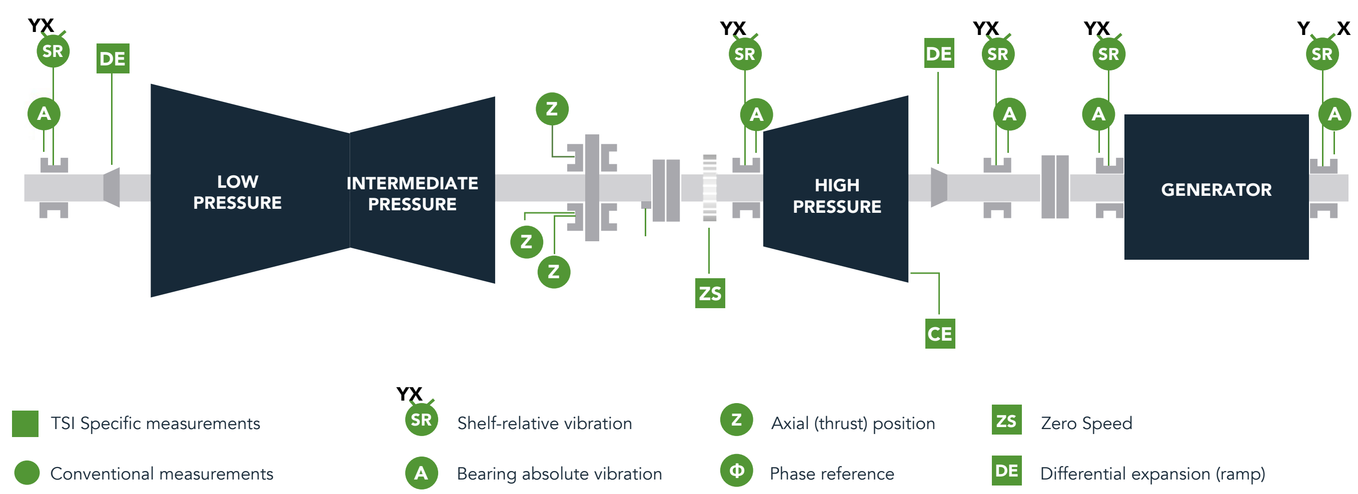


Figure 4: Machine train diagram for steam turbine generator showing arrangement of conventional and TSI measurements.w

trates how the complementary VM600 and VibroSmart solutions work hand-in-hand to address customer needs by offering solutions with either a distributed or centralized architecture, but similar functionality and capabilities.

In addition to machinery protection, the feedwater pumps received condition monitoring capabilities. Like the VM600, VibroSmart monitors have integrated condition monitoring capabilities and were thus connected to our companion VibroSight condition monitoring software, providing a comprehensive solution for both protection and condition monitoring. In contrast, on the gas turbines and steam turbines, Ansaldo is used as a service provider for condition monitoring. However, the basis of Ansaldo's condition monitoring solution relies of vibro-meter software and at a future date, all of the condition monitoring in the plant will likely be tied together within VibroSight with capabilities for local access by plant personnel, remote access by Axpo personnel in Genoa, remote access by Ansaldo personnel (also in Genoa), and even remote access by and even remote access by vibro-meter (Fribourg, CH) and its partner in Italy, AESSE (Milan) when support may be needed.

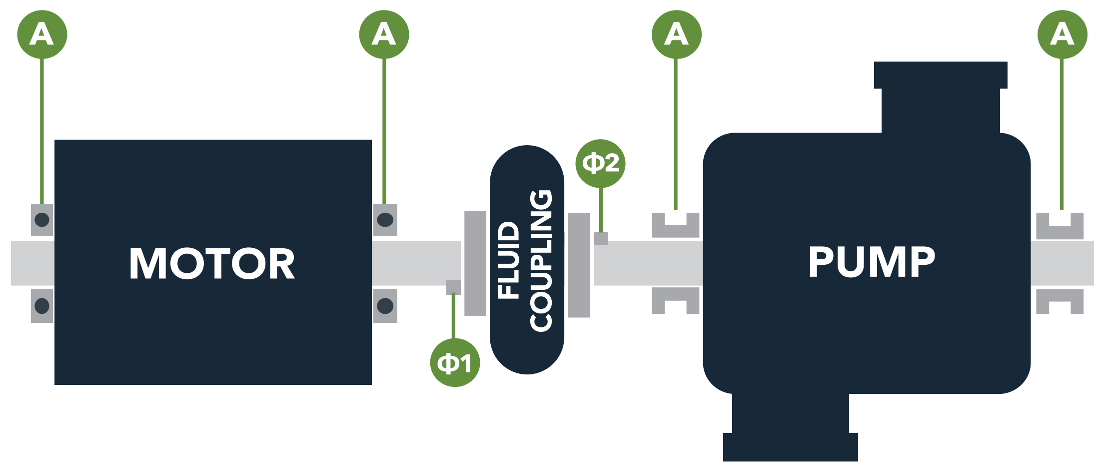


Figure 5: The feedwater pumps have four radial bearings. Those on the motor are of rolling element design and those on the pump of fluid-film design. All are monitored via seismic sensors on each bearing cap. Because a fluid coupling allows the motor and pump to turn at different speeds, two phase reference sensors are installed.

Complementary Capabilities

vibro-meter works with numerous partners globally to provide sales and service support. In Italy, that partner is AESSE Misure Srl, based in Milan.

As one of vibro-meter's longest lasting partnerships (20+ years), AESSE possesses deep knowledge of our products and have forged a very strong relationship with Ansaldo, allowing them to deliver excellent local sales and service support for this major vibro- meter account. Thus, while vibro-meter products were selected for this project, AESSE provided all installation design services, commissioning, and project management, working closely with vibro-meter's factory-direct personnel based in Switzerland. AESSE also provided engineered enclosures – both cabinets and field junction boxes – used for the instrumentation.

The installation occurred during a series of four separate mobilizations to site during May 2021 and September 2021 – one mobilization for each of the four steam turbines and its corresponding feedwater pumps.

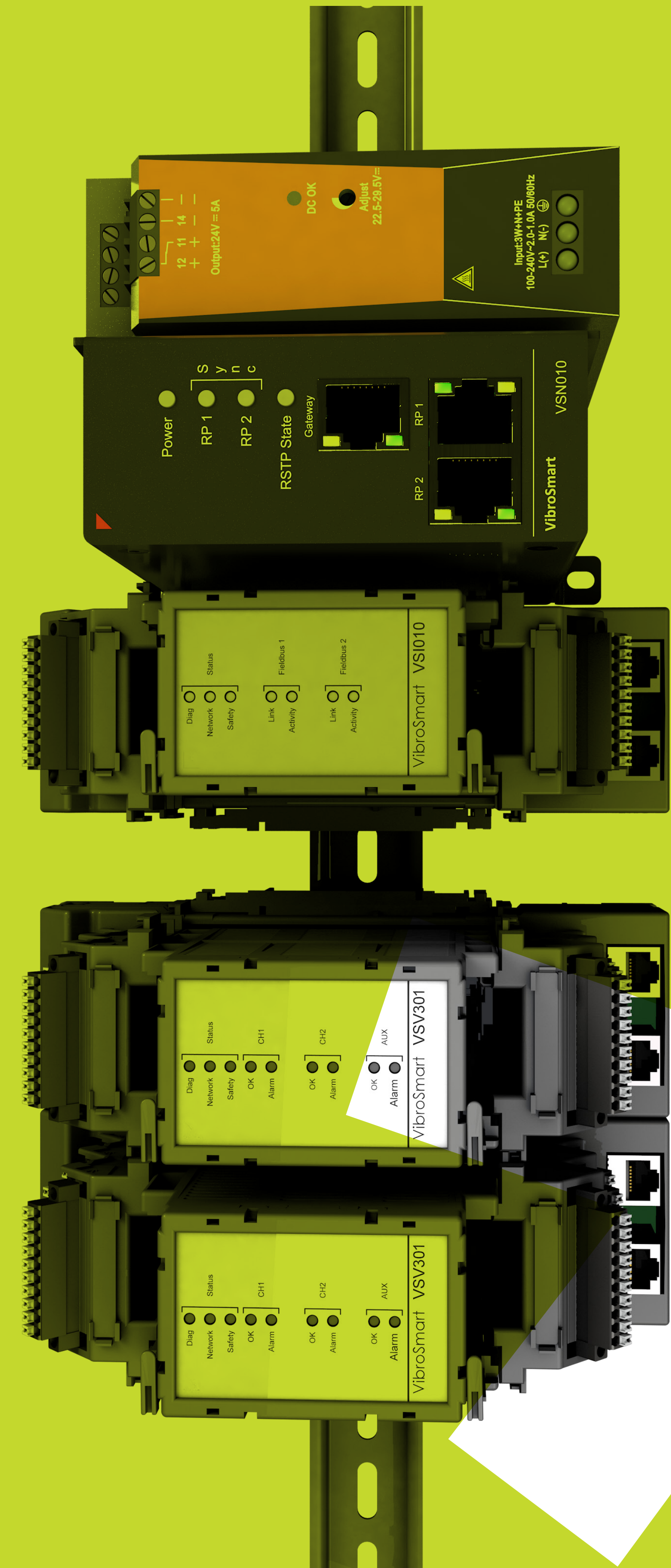


Figure 6: The VibroSmart distributed monitoring system was used to address the feedwater pumps.

Spurious Trips

Although missed trips can lead to catastrophic machine failure and corresponding costs, spurious – or false – trips can also be very costly. While the operator eventually isolated the problem to the steam turbine instrumentation, machinery trips are always disruptive and spurious trips generate a mistrust of critical measurements such as from the TSI system in this story.

Consider the time it takes to rule out a legitimate machinery problem instead of an instrument problem, and consider the implications of restarting a machine like a large steam turbine where differential expansion, rotor bow, and case expansion measurements must all be observed while admitting steam, accelerating the machine, and then synchronizing. With each spurious trip causing at least an hour of lost generation at a cost of at least €50k per hour, the plants were highly motivated to eliminate the instrumentation problems and their attendant costs.

The spurious trips caused by the plants' incumbent TSI systems have now been fully resolved as a result of replacement with vibro-meter VM600 systems and turnkey project execution by vibro-meter's partner in Italy, AESSE Misure, Srl.

Results

The TSI systems have been operational now for more than a year without any spurious trips. Several modifications were made to the prior arrangement which had the signal conditioners for the proximity probes mounted on the machine, rather than several meters away in a junction box as is customary.

Results

Although the machine-mounted signal conditioners had been suspected as the cause of the spurious trips, the operator had never been able to conclusively isolate this. Nevertheless, the project team placed the signal conditioners off the machine in junction boxes where they could be more easily accessed and serviced, while also providing a vibration-free environment that would not contribute to loose wiring connections and corresponding intermittent problems. Also, because vibro-meter transducer systems provide an option for a current-modulated signal output instead of voltage-modulated, a signal that is less susceptible to electromagnetic interference – such as from hand-held radios – was used for applicable transducers. The field wiring from sensors to monitoring systems could all be reused and this made the centralized architecture of the VM600 rack-mounted system the right choice. It also meant that the integrated condition monitoring capabilities of the VM600 can be enabled in the future when the plants begin migrating to VibroSight software as part of Ansaldo's service offering strategy for condition monitoring.Lastly, Axpo chose to retrofit monitoring on the four un-instrumented feedwater pumps at each plant as part of the steam turbine instrument upgrade project. The pumps are motor-driven and reflect a mix of rolling element (motor) and fluid-film (pump) bearing types.

Although the OEM supplied the machine trains with provisions for mounting transducers on each bearing cap (surfaces spot faced; holes drilled and tapped), transducers had not been installed when the machines entered service in 2008. Consequently, one accelerometer was mounted on each bearing cap as shown in Figure 5. For monitoring, the VibroSmart system (Figure 6) was selected due to its distributed architecture and corresponding ability to reduce wiring costs by keeping the individual sensor cabling runs short while mounting the modules near each machine.

In contrast, because wiring had already been run for the incumbent

Conclusion

In addition, the feedwater pumps are now protected and fitted with online condition monitoring – a logical progression given the critical role these machines play in ensuring full plant output.
The work performed by vibro-meter and its partner, AESSE Misure, allowed the plant to maintain its outage schedules and come back up as planned. Replacement of protective instrumentation on critical machinery is an area of particular expertise and the ability to treat this scope in a turnkey fashion was highly desirable for the operator. They could focus on conducting their outage to address other rotating and non-rotating equipment, while vibro-meter and AESSE could

"Both the Rizziconi and Sparanise facilities now enjoy trouble-free machinery protection on their steam turbines, joining the reliable protection and combustion dynamics monitoring that vibro-meter has provided on the plants' gas turbines since the very first MW was generated back in 2008. "

Figure 7: An operator at Rizziconi Energia keeps watch over the two 380MW combined cycle processes from a control room vantage point overlooking the plant.

completely manage the machinery instrumentation issues.
vibro-meter and its partners around the globe are highly skilled at such retrofit projects, whether to replace the underlying protection system and its transducers, to replace the protection system while reusing the existing transducers, to install transducers on partially or fully un-instrumented machines, or to add (or replace) condition monitoring without disturbing the underlying protection system – regardless of make or model.

You can learn more about these capabilities in our informative webinar, available on-demand when you register on our website. We address the most common scenarios faced by customers and outline our ability to deliver world-class solutions that can be adapted to your specific needs and ranging from complete turnkey scope to mixed scope where customers and vibro-meter personnel work side-by-side.

Turnkey Solution Portfolio

- [x] Replaced protection system
- [x] Replaced sensors
- [ ] Replaced condition monitoring system
- [ ] Upgraded condition monitoring system
- [ ] Upgraded protection system
- [x] Project Management
- [x] Fully instrument "bare" machines
- [x] Sensor Installation and Verification
- [x] Turnkey Service
- [ ] Custom Products
- [x] Documentation
- [x] Training
- [ ] Remote Machinery Diagnostic Support
- [ ] Rule Box expert knowledge embedded in Rule Box software

- [x] Services provided for this project


vibro-meter
Parker
MEGGITT

CASE STUDY*

A vibro-meter case history featuring India's largest power utility.

Upgrading condition monitoring

When faced with an aging and unsupported condition monitoring system, vibro-meter was selected by India's leading state-owned power utility for a state-of-the-art solution that allowed them to leave their incumbent turbine supervisory protection systems and transducers undisturbed while reusing existing cabinet space and without requiring a special outage.

The project covered replacement of condition monitoring instrumentation on three identical 500MW steam turbine generator (STG) trains at a Super Thermal Power Plant (STPP) in India[1].

STPP Case Study

Each STG has seven bearings and consists of HP, IP, and LP cases, a generator, and an exciter (Figure 1). The units are of German design and were supplied originally by a major Indian OEM complete with Japanese Turbine Supervisory Instrumentation (TSI) systems and companion condition monitoring. Each of the three units uses two TSI racks to address its 39 measurement points.

The existing TSI system is an aging platform, introduced in the early 1990s and was thus 15-year old technology by the time it was installed on the 3 STGs in the 2008-2010 timeframe. It was accompanied by a companion condition monitoring system from the same manufacturer, consisting of separate data acquisition hardware and corresponding software. Figure 2 shows the cabinet containing the two TSI racks on the left and the cabinet with the condition monitoring racks on the right. Figure 3 shows the right-most cabinet with the door open.

> "The project covered replacement of condition monitoring instrumentation on three identical 500MW steam turbine generator (STG) trains at a Super Thermal Power Plant (STPP) in India[1]. "

While manufacturers generally introduce new protection systems every 15-20 years, and typically design them with a service life of 20+ years, the same is not often true of condition monitoring systems where software technology and operating systems typically last only half that long before they become obsolete. Of particular concern are evolving operating systems that also demand change of computer hardware and accompanying cybersecurity issues that require frequent patches and attention.

After experiencing difficulties obtaining support for their existing condition monitoring system (CMS), and after developing a strong appetite for advanced features such as intelligent machinery condition advisories suitable for operators, the end-user began exploring options. However, simply running without any condition monitoring system on the STGs was quickly dismissed as a viable solution because the customer is particularly noted within India for highly efficient operations and

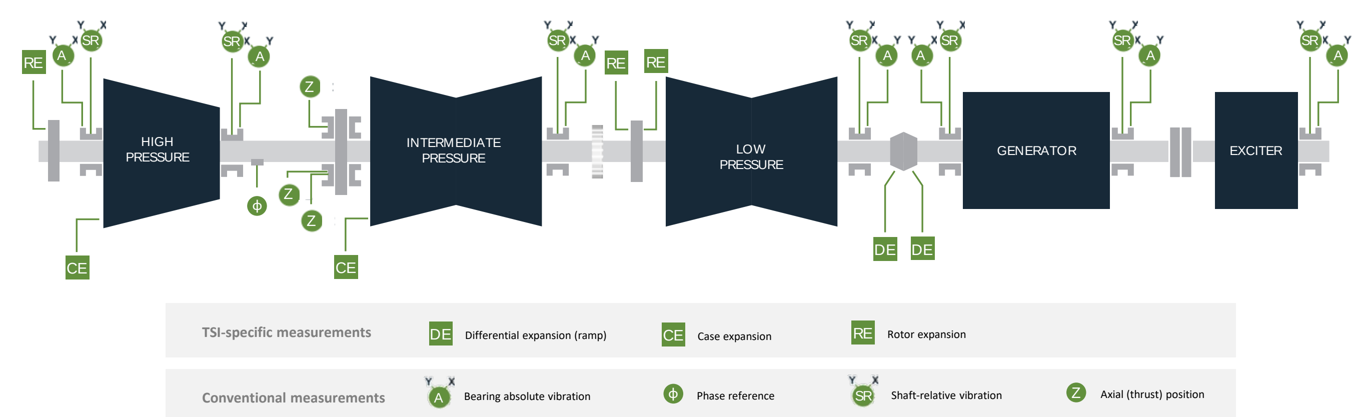


Figure 1: The plants at Rizziconi (shown here) and Sparanise are essentially twins and utilize two 1:1 combined cycle configuration consisting of a 260MW Ansaldo V94.3 gas turbine, a Heat Recover Steam Generator (HRSG), and a 120MW steam turbine. The cooling towers are within the blue structures, the turbines within the green structures, and the HRSGs are the tall structures adjacent to each exhaust stack.

Figure 2: Two TSI racks are used to provide machinery protection for each unit and are visible in the left-most cabinet. These racks have been in service since the units were commissioned in the 2008-2010 timeframe. The adjacent cabinet to the right holds the condition monitoring hardware.

Figure 3: Cabinet from figure 2 but with door open showing vacated panel cutouts from old condition monitoring hardware. The incumbent CMS required six (6) large data acquisition units for each train, as noted by the six panel cutouts. Note that the new vibro-meter data acquisition hardware occupies only two-thirds of a single panel cutout (fourth opening from top) and thus consumes nine times less space. Fitting the new CMS into existing panel space was an important project requirement as there was no room for any additional cabinets.

timely machinery condition information is necessary to enable this.

Upgrading the system was thus pursued but a simple upgrade path did not exist without so-called "ripping and replacing" the existing CMS solution.
Since this was the case, there was no particular advantage to remain with the incumbent provider and after considering their options, vibro-meter was selected to work with the project imperatives shown in Table 1:

Table 1

Project Imperatives

1. The project needed to be accomplished **without requiring an outage** of the affected three units.

2. The project would need to **leave the existing protection systems and transducers undisturbed** until the plant eventually decides to replace them during a scheduled plant outage.

3. The project would need to **re-use the existing cabinet space** where the condition monitoring hardware was mounted.

4. The project would need to **deliver advanced capabilities** where knowledge could be **embedded in the software** and thus **allow intelligent advisories for operators** rather than merely conventional over/under alarms

5. The project would require the vendor to not only remove the old system and **provide turnkey installation and commissioning of the new CM system, but also training.**

Instilling Confidence

Because the customer was moving away from a system that could no longer deliver the necessary functionality, it was important for them to satisfy themselves that the new system would meet their needs prior to permanently deploying it.

Results

This was particularly easy for vibro-meter to demonstrate because the same hardware and software we use for permanent installation can also be deployed portably. To this end, a portable system was brought to site and connected to the buffered outputs of one of the TSI racks. Figure 4 shows one of the plots obtained during that time: an orbit/timebase from the shaft-relative probes on the unit's #2 bearing.

Figure 4: VibroSight Vision software showing actual plots from the pre-installation portable deployment. The ease with which this portable deployment was accomplished and the quality of condition monitoring data it collected helped the customer reassure themselves that the new CMS hardware and software would deliver the necessary functionality.

Delivering Value

Cost is of concern to all our customers but so is quality.

In scoping the project, we carefully examined the measurements that needed to come into the CMS for each of the three units and divided them into two categories: so-called quasi-static measurements like pressures, positions, loads, and speeds (Table 2) and so-called dynamic measurements such as bearing vibration and phase reference (Table 3). We then selected optimal data acquisition hardware that represented an ideal balance of capabilities and cost for addressing each of these two categories.

For the dynamic measurements, vibro-meter's XMV16 modules (Figure 5) were the perfect solution, each providing 16 dynamic input channels and 4 tachometer / phase reference channels for a total of 20 possible inputs per module. Two such modules were thus required for each STG to encompass the 28 vibration inputs and associated phase reference signal. These signals were brought into the XMV16 modules from the buffered outputs of the existing TSI racks[2].

Figure 5: The VM600 XMV16 condition monitoring module consists of the signal processing and computation module (left) and the companion I/O module (right). It accepts a total of 16 dynamic signals from vibration and other sensors, and 4 tachometer signals used for speed or phase reference measurements. Gigabit Ethernet ports are provided on both the processing module and the I/O module; either one can be used to connect the processed data from the XMV16 to VibroSight condition monitoring software. The XMV16 can accept dynamic vibration signals from elsewhere in the VM600 rack via the system backplane, or (as in this project) via externally wired connections to the I/O module.

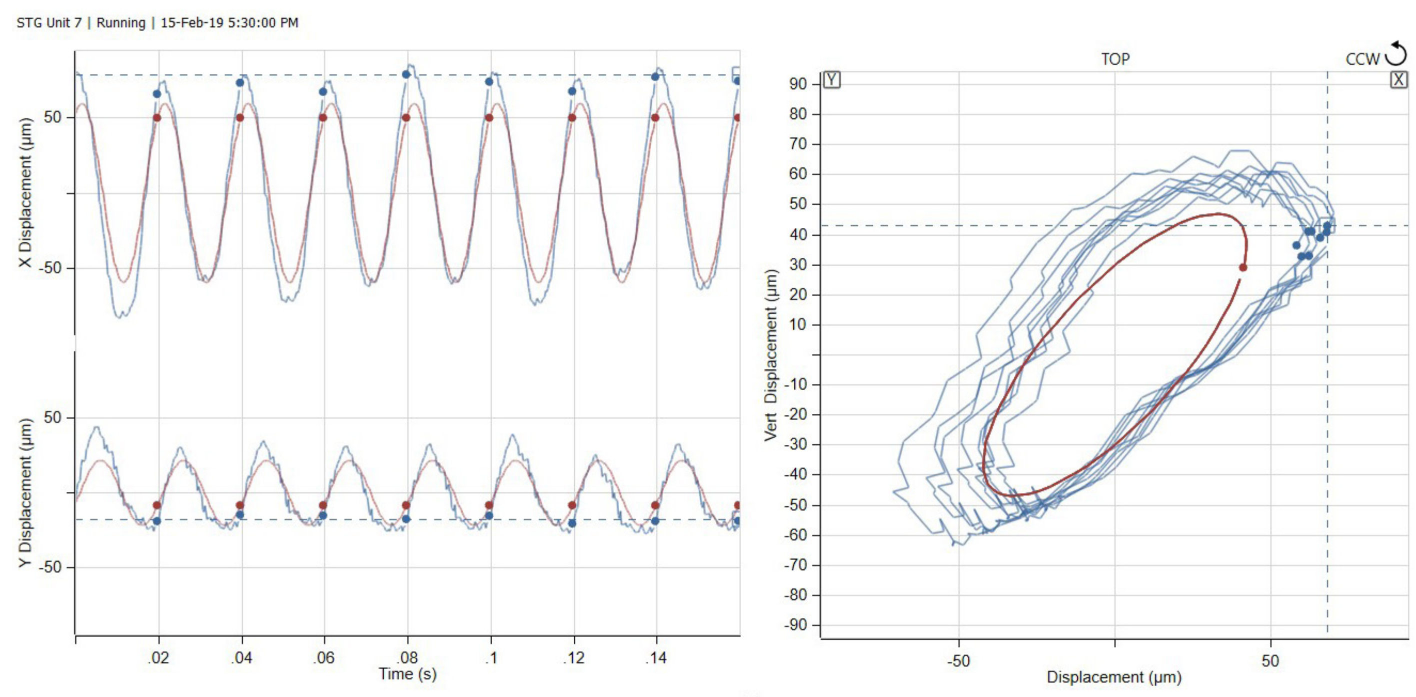


Figure 4

Table 2
Position/Expansion and Process Measurements

Case	Measurement
HP	• Rotor Expansion • Casing Expansion • Differential Expansion • Main Steam (MS) Pressure • Cold Reheat (CRH) Pressure
IP	• Rotor Expansion • Casing Expansion • Differential Expansion • Hot Reheat (HRH) Pressure
LP	• Differential Expansion
N/A	• Thrust Poition (x3 probes) • Load • Speed

Table 3
Dynamic Measurements

Phase Reference	BRG 4, Shaft Rel Y
BRG 1, Shaft Rel X	BRG 4, Casing Vib Y
BRG 1, Casing Vib X	BRG 5, Shaft Rel X
BRG 1, Shaft Rel Y	BRG 5, Casing Vib X
BRG 1, Casing Vib Y	BRG 5, Shaft Rel Y
BRG 2, Shaft Rel X	BRG 5, Casing Vib Y
BRG 2, Casing Vib X	BRG 6, Shaft Rel X
BRG 2, Shaft Rel Y	BRG 6, Casing Vib X
BRG 2, Casing Vib Y	BRG 6, Shaft Rel Y
BRG 3, Shaft Rel X	BRG 6, Casing Vib Y
BRG 3, Casing Vib X	BRG 7, Shaft Rel X
BRG 3, Shaft Rel Y	BRG 7, Casing Vib X
BRG 3, Shaft Rel Y	BRG 7, Shaft Rel Y
BRG 4, Shaft Rel X	BRG 7, Casing Vib Y
BRG 4, Casing Vib X	

Slimline Rack

Part of vibro-meter's VM600Mk2 (as well as legacy VM600) architecture is a special chassis designed to hold only a single card while providing necessary power. This is known as a "slimline" rack (Figure 6) and is just 1U tall by 19" wide, designed for 19" EIA rail mounting or mounting in a 19" panel cutout. Because the outgoing CMS hardware used 19" cutouts, the two required slimline racks for each STG could be easily mounted in the existing cutouts without modification as shown in Figure 3.

Figure 6: The VM600 "slimline" rack is just 1U tall and designed for mounting in a 19" cutout or on 19" EIA rails. It provides all necessary power and holds a single VM600 module such as the XMV16 shown here to provide a 20-channel condition monitoring solution (16 dynamic channels + 4 tachometer channels). The slimline chassis can also be used with other VM600 modules such as the MP-C4Mk2 to provide a compact, 4-channel machinery protection solution.

Project Execution

The project scope included not just installation of the new system, but complete documentation, procurement of necessary accessory items for networking such as switches and hubs, commissioning, and then site training for personnel on use of the new system. Figure 7 shows the system arrangement along with the distances between various components.

Because vibro-meter has a strong presence not only globally but also in India, factory-direct field service personnel from our Bangalore facility were able to execute this project. The project was completed on-time and on-budget in January 2021 when the customer signed off on the project completion letter.

Indeed, the customer was so pleased with vibro-meter's products and project execution that a nearly identical project was done on two units at a sister plant. In 2023, the plant showcased in this case history is planning to install condition monitoring on the two boiler feedwater pumps (BFPs) on each of the three STGs using an approach identical to that described here: retaining the existing protection systems and adding condition monitoring. In fact, the CMS hardware will be mounted in the same cabinet as shown in Figure 3 given the generous amount of space still left for additional equipment. When complete, each cabinet will house the condition monitoring hardware for the STG and its two associated BFPs

"The project scope included complete documentation, procurement of necessary accessory items for networking such as switches and hubs, commissioning, and then site training."

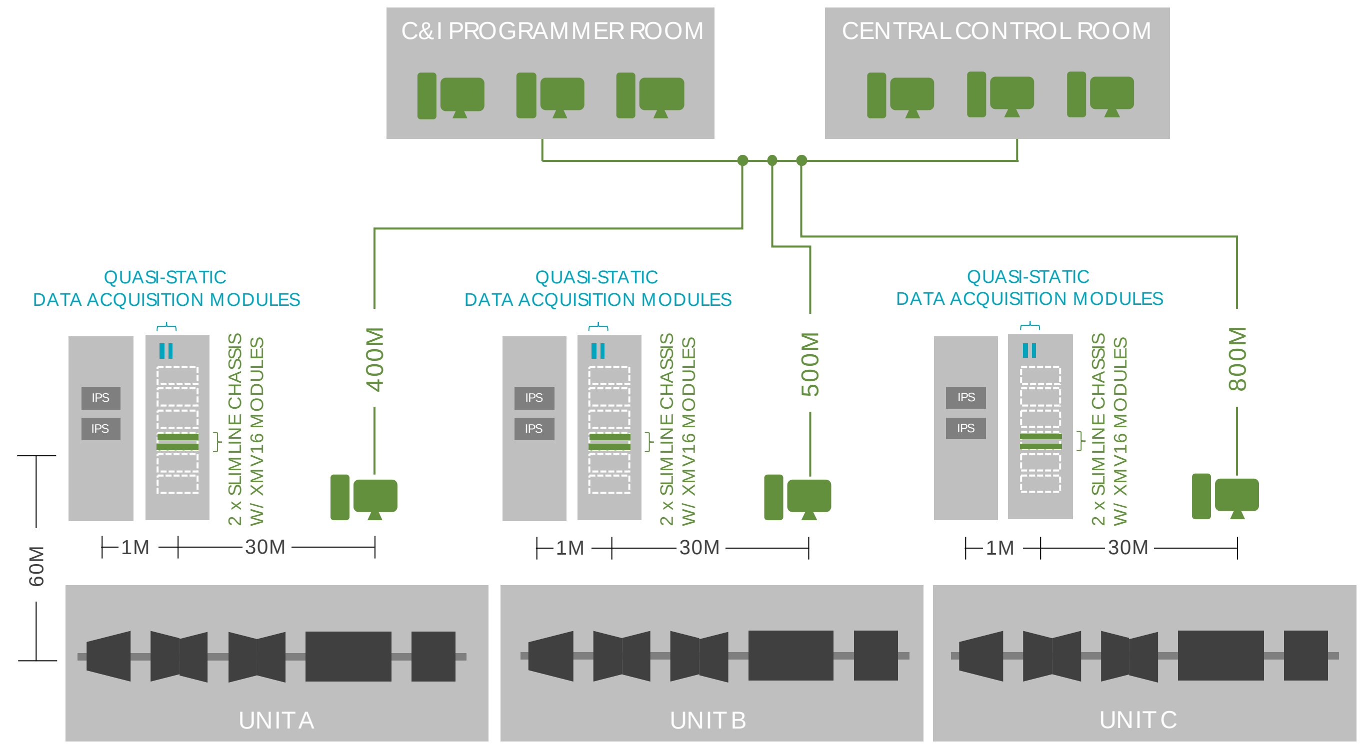


Figure 7: System arrangement showing relevant distances between machines, incumbent protection systems (IPS), new condition monitoring hardware, servers, and remote workstations

Universally Extensible Approach

The approach used for this project is instructive in showing how vibro-meter's condition monitoring solution is designed to be non-disruptive, simple, and cost-effective, allowing customers to retain their existing third-party protection systems and sensors while easily adding condition monitoring or replacing an aging, inadequate, or obsolete condition monitoring system (Figure 8).

Because most incumbent monitoring systems installed around the world have the raw transducer signals available through buffered output connections, the signals needed for input to vibro-meter's XMV16 modules are readily available.

Although it is possible to bring quasi-static signals into XMV16 modules, there are also additional possibilities for introducing such data into the VibroSight condition monitoring software. This allows data to originate as 4-20mA signals, proportional quasi-static voltages, or digitally if the signals are already in the DCS and can be exporting via Modbus, OPC, or other suitable format. For this reason, VibroSight has been designed with the ability to ingest data via these digital protocols in addition to ingesting the dynamic data from XMV16 modules[3].

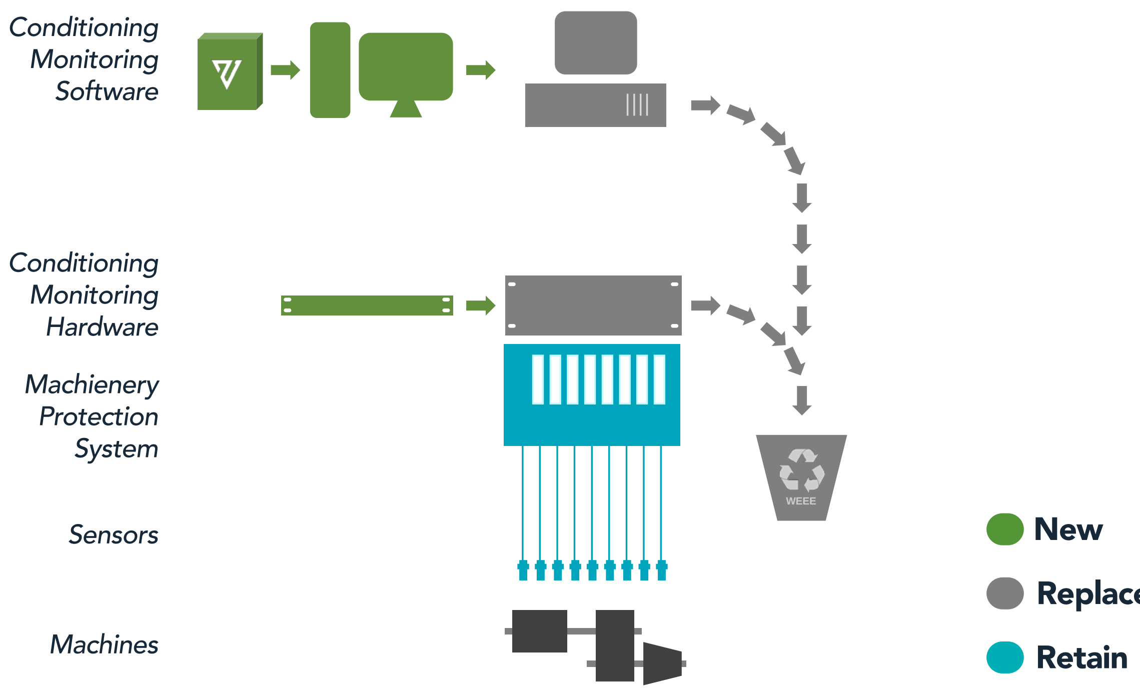


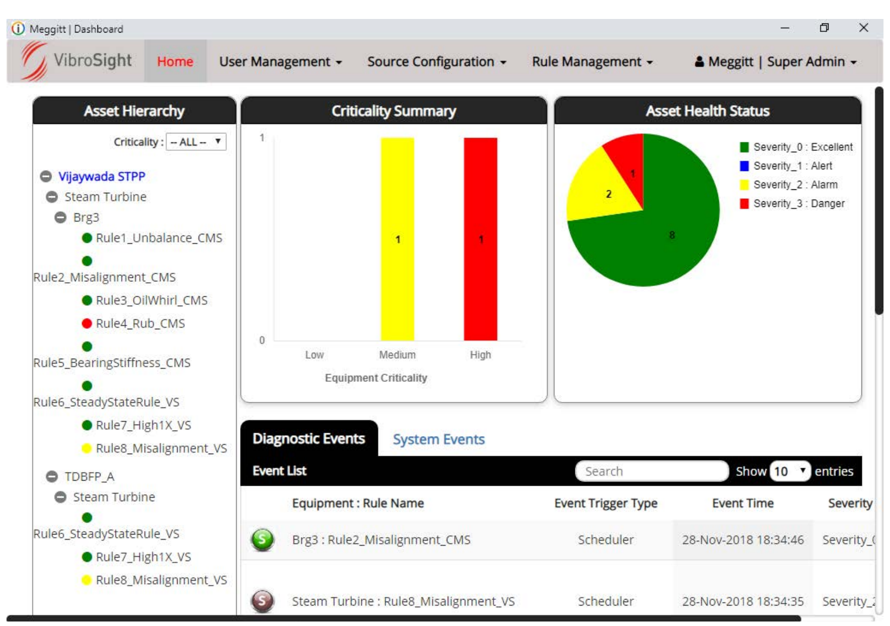
Figure 8: Retaining an existing machinery protection system and sensors while replacing an outdated condition monitoring system is non-disruptive, simple, and cost-effective using vibro-meter's XMV16 modules and VibroSight software. In most cases – such as in this project – a single XMV16 module can replace two or more chassis of outdated condition monitoring hardware.

Intelligent Advisories

While most condition monitoring software has powerful capabilities for visualizing data, the plot types are quite specialized (such as in Figure 4) and not easily interpreted by operators and others without extensive training and experience in vibration data analysis. A key aspect of the customer's desire for a new CMS was the ability to automatically analyze this data and present it in the form of intelligent advisories that could readily be understood and acted upon by plant operators.

Our VibroSight software suite can deliver such capabilities via the Diagnostic Rule Box application and was indeed part of the scope of this project. It can be configured to detect dozens of different malfunctions and is limited only by the types of data available. In addition to the automatic diagnostic capabilities of Rule Box software, it also has operator "dashboard" capabilities as shown in Figure 9.

Figure 9: Many customers prefer the user interface of VibroSight's Rule Box software as the primary window into their condition monitoring system because it provides a high-level dashboard summarizing anything an operator needs to act on. Instead of complicated and specialized plots, it uses simple status indicators and narrative descriptions of problems detected, their severity, and what actions to take. This dashboard is taken from an actual vibro-meter installation at an STPP in India.



Results

As this case study has shown, vibro-meter has an engineered solution that is non-disruptive, simple, and cost-effective.

The ability to add or replace condition monitoring hardware and associated software without disturbing the underlying protection system is a frequently encountered scenario. It can arise for a variety of reasons, including:

- The protection system still has remaining useful service life while the condition monitoring software is often designed with a shorter lifespan and thus becomes obsolete more quickly.

- The protection system has also reached the end of its useful life but the plant's next scheduled outage may not occur for several years and replacement of machinery protection is generally scheduled during an outage since it is unwise to run critical machines without protection. In the meantime, however, the plant may need better condition monitoring to ensure the unit can indeed continue to run until its scheduled outage. This is particularly true if the unit is exhibiting anomalies but the severity and cause is unknown.

- A plant may have a variety of machinery protection systems and wants to unify them all under a common, integrated condition monitoring environment. The cost to replace all of the protection systems before installing condition monitoring might represent unacceptable delays and entail numerous outages.

- A plant may have no condition monitoring and because its units are now undergoing more aggressive operation such as frequent starts and stops rather than baseload, steady-state conditions for many months or even years at a time, insight into real-time machinery health is more important and required continuously.

As this case study has shown, vibro-meter has an engineered solution that is non-disruptive, simple, and cost-effective. It also consumes very little cabinet real estate which can be especially important when no condition monitoring system was initially present and large amounts of spare panel space are unavailable. Even when large amounts of cabinet space are available, as was the case in this project, the spare cabinet space could be used for networking appliances and peripherals, and

Turnkey Solution Portfolio

- [ ] Replaced protection system
- [ ] Replaced sensors
- [x] Replaced condition monitoring system
- [ ] Upgraded condition monitoring system
- [ ] Upgraded protection system
- [x] Project Management
- [ ] Fully instrument "bare" machines
- [ ] Sensor Installation and Verification
- [x] Turnkey Service
- [x] Custom Products
- [x] Documentation
- [x] Training
- [ ] Remote Machinery Diagnostic Support
- [x] Expert knowledge embedded in Rule Box software

✓ Services provided for this project

no issues with air circulation, cooling, or other aspects needed to be addressed as is often the case with bulkier solutions.

Finally, this case study has shown that vibro-meter has not just the technology to make a retrofit or replacement very straightforward, it has the experienced field service engineers to manage the entire project in turnkey fashion and to provide training for personnel.

While this project involved replacement of only the condition monitoring environment, vibro-meter is also able to replace the underlying sensors and machinery protection systems when necessary – in which case the condition monitoring hardware discussed in this article can be replaced with hardware that provides integrated protection and condition monitoring without requiring any additional cabinet real estate at all.

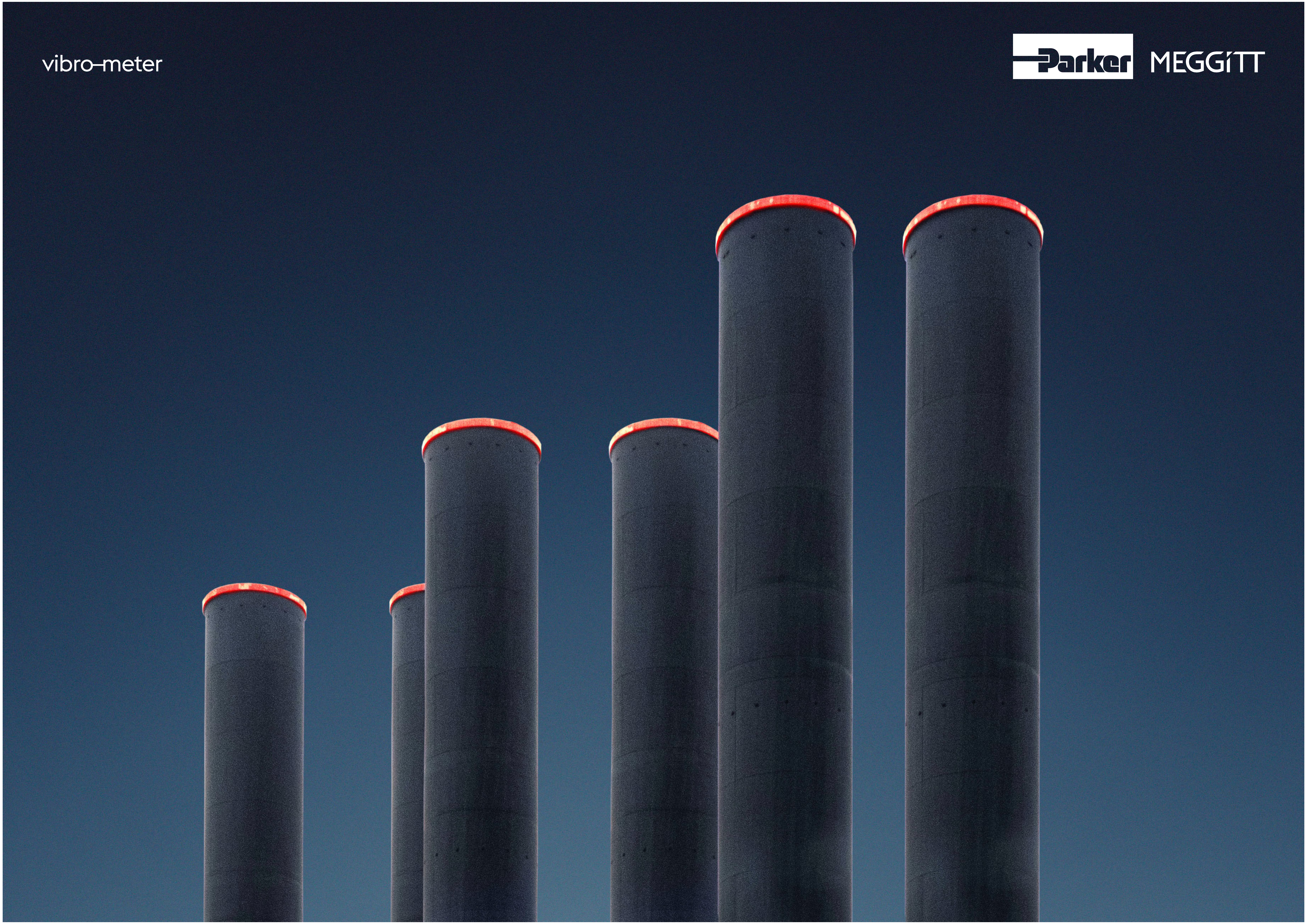
You can learn more in an informative webinar that discusses retrofits and replacements in more detail. You can also contact your nearest vibro-meter sales professional through our extensive network of factory-direct personnel and representative partners.

Notes

1. A STPP is defined as a thermal power plant exceeding 1000 MW in output. There are more than 65 such plants in India. India also defines an even larger category called Ultra Mega Power Plant (UMPP) that is 4000 MW or larger. There are several UMPPs in India and plans exist to build more. For comparison, the ten largest thermal plants in the world are in China, Taiwan, and South Korea, all with 5000 MW or more.

2. As is the case with many systems, buffered outputs were available on the TSI racks from BNC connectors at the front and permanent wiring terminals at the rear. Because the BNC connectors on the front of racks are intended only for temporary connections to portable instruments, the wiring terminals at the rear are preferred for permanent installations whenever available as they afford more robust, trouble-free connections

3. When the installation involves monitoring of gas turbines and combustion dynamics sensors are used, a variant of the XMV16 is also available for these specialized dynamic pressure signals: the XMC16.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