MITSUBISHI POWER

T-POINT 2 AND TOMONI™ TECHNOLOGY

A WINNING COMBINATION FOR CUSTOMERS

MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

T-POINT 2 AND TOMONI™ TECHNOLOGY: A WINNING COMBINATION FOR CUSTOMERS

Power companies are always striving to increase efficiency, improve reliability, reduce emissions, and decrease costs associated with operating power plants. **Mitsubishi Power** is doing significant work to help its customers achieve those objectives. Among the innovative, industry-leading approaches Mitsubishi Power has taken in developing advanced technology is utilizing demonstration plants built at its own facilities to validate the company's gas turbines and TOMONI™ digital solutions under real operating conditions. These units have been connected to the power grid, and the electricity generated by them has been used by the local power companies.

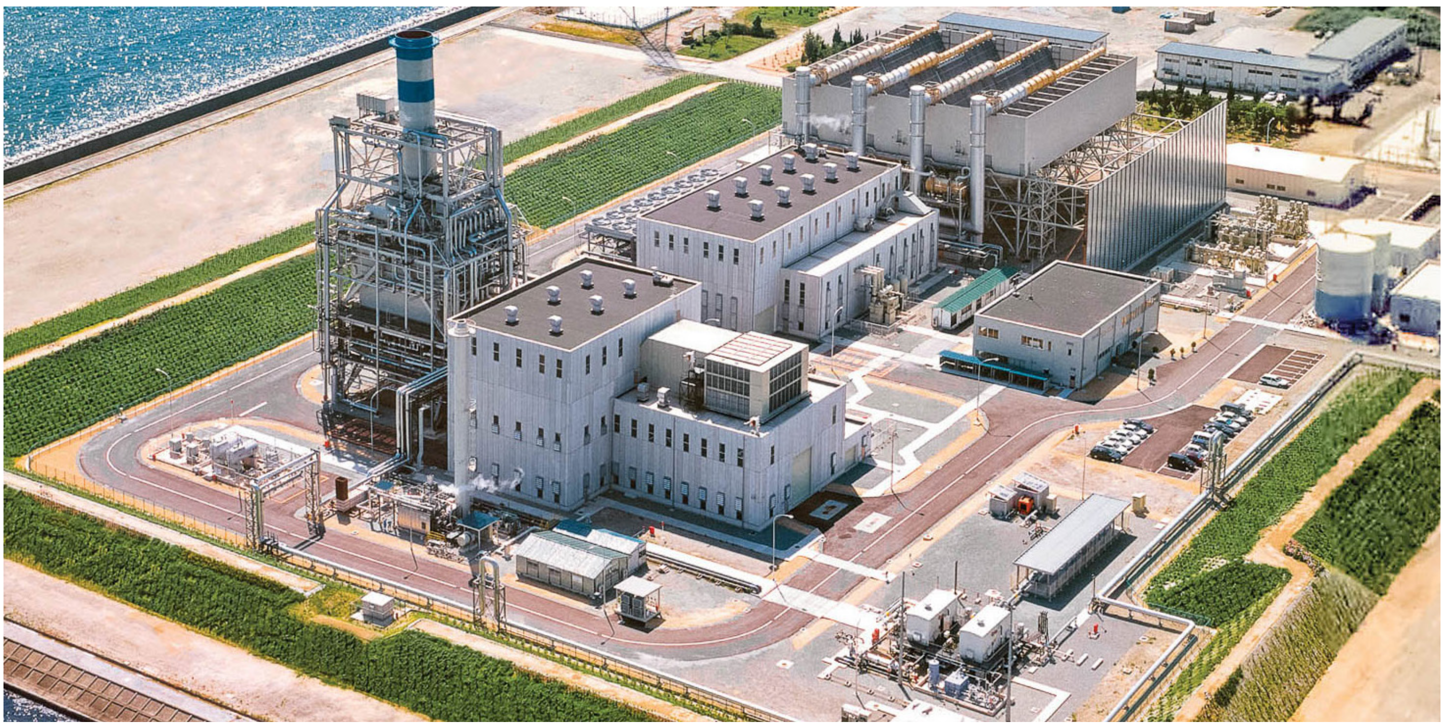
A HISTORY OF ACCOMPLISHMENTS

The first such demonstration plant was a 50-Hz unit known as K-Point. It entered service in 1992 at Mitsubishi Heavy Industries' facility in Kanazawa, Yokohama, Japan. The value was immediately recognized, leading the company to open a 60-Hz demonstration plant, called T-Point, at its Takasago Machinery Works facility in 1997.

"Prior to opening T-Point, Mitsubishi Power launched full-load shop testing (limited only to 100 hours of operation) of the 60-Hz M501F, as well as partial-load operation (but also with limited time) of the 50-Hz M701F at K-Point in Yokohama," said Junichiro Masada, Senior Vice President, co-Chief Technology Officer, and Deputy Head — Turbomachinery Headquarters with Mitsubishi Power. "These short testing times were not optimal and we experienced multiple fleet issues with the F-class."

Recognizing that short-term testing does not reveal all technology issues, Mitsubishi Power decided to launch long-term verification of the 60-Hz M501G at T-Point. Once the 60-Hz machine was verified, the company did a mechanical run on the 50-Hz M701G, which is a scaled version of the 60-Hz machine, achieving 100% reliability.

"Afterwards, we started verifying the J-class machines through a similar process at T-Point. We were able to demonstrate sound reliability for both M501J and M701J," said Masada.



Grid-connected validation plant, T-Point. Hyogo Prefecture, Japan

Now, after more than two decades of successful validation of technological advancements at T-Point, Mitsubishi Power has commissioned T-Point 2 — its largest and most ambitious demonstration plant yet. Today, the company is validating its latest advanced gas turbine, the M501JAC. Initial verification for the M501JAC was successfully completed and long-term verification is ongoing at T-Point 2.

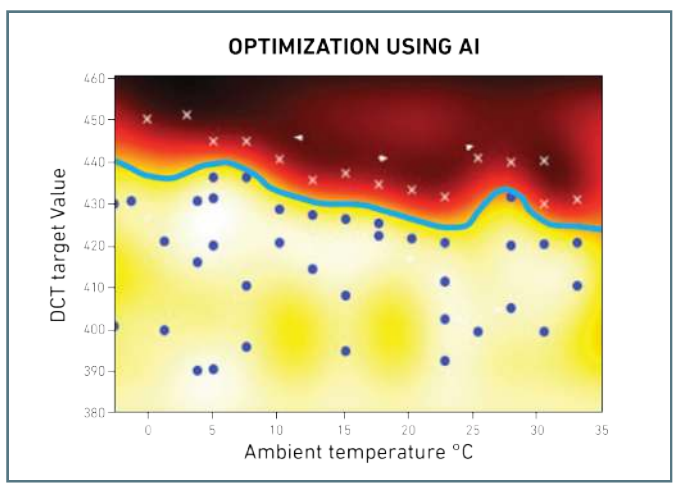
Constructed on a site next to the original T-Point at Mitsubishi Power Takasago Works in Hyogo Prefecture, Japan, T-Point 2 has already received accolades from the reputable industry journal *POWER* magazine, winning the publication's Plant of the Year Award in 2020. "Our editorial staff felt the facility stood out for multiple reasons and deserved recognition," said Aaron Larson, Executive Editor of *POWER*. "For one, it is operating what Mitsubishi Power calls the 'most efficient heavy-duty gas turbine in the market.' Additionally, its integration of TOMONI technology — a suite of digital power plant solutions with cutting-edge analytics — has prepared T-Point 2 to become the world's first autonomous combined cycle power plant," he said.

TECHNOLOGY IS AT THE HEART OF T-POINT 2

TOMONI™ digital solutions is a customizable suite of user-driven, digital power plant solutions developed based on Mitsubishi Power's vast experience. It turns operational data into actionable insights to improve plant availability and reduce original equipment manufacturer (OEM) costs. At T-Point 2, the journey to become the world's first autonomous combined cycle power plant includes the validation and demonstration of many of the building blocks of that autonomous power plant. These building blocks will be at the heart of future power plants and many are retrofittable to existing plants to improve their dispatchability.

"As we move into a digital era, it is important to leverage emerging technologies as much as possible to optimize operations while maximizing economic benefit," Masada said. "Mitsubishi Power has been implementing digital solutions in T-Point 1 since the early 2000s, starting with the remote monitoring system and other advanced data visualization and analytics. Since then, our TOMONI™ digital solutions and the latest DIASYS Netmation® control systems have advanced to the point where we can operate remotely with some functions automated. In fact, many of the functions at T-Point 2 are already automated."

One example of a building block that supports autonomous operation at T-Point 2 is the unit's AI-CPFM (artificial intelligence-combustion pressure fluctuation monitoring) system, which minimizes combustion fluctuations by making quick adjustments



AI Flow Modulation

to combustor settings when changes in ambient temperature, fuel composition, or frequency occur. Another is the Gas Turbine Cooling Air AI-Optimization solution that actively controls disc cavity cooling air flow.

Other TOMONI™ digital solutions building blocks can optimize maintenance plans through component life projections. Life consumption and possible component failures can be predicted in advance. These analytics create automated notifications to alert operators — whether on-site or remote — of anomalies and pending failures, and provide proper instructions to prevent forced outages.

Collaboration is the foundation of TOMONI™ digital solutions.

TOMONI™, which means "together with" in Japanese, expresses the philosophy that intelligent digital solutions that utilize AI and other advanced analytics work through collaboration between OEMs and plant owners and operators. "Each of the TOMONI™ digital solutions building blocks is meant to integrate with the customer's existing systems and processes at their plants. This means that our control system — Netmation®— and our TOMONI™ Intelligent Solutions co-exist with other digital platforms at the customer's facility," explained Marco Sanchez, Vice President of Intelligent Solutions with Mitsubishi Power.

"What sets it apart is that we are pioneering the application of AI, machine learning, and advanced technologies, such as augmented reality and simulation in power generation, and collaborating with engineering, procurement, and construction contractors, operations and maintenance providers, and industry partners to develop smart systems to address issues that are impacting availability, flexibility, and performance at plants," Sanchez said.

IMPROVING THE CONSTRUCTION PROCESS

The Japanese are well recognized around the world for their very high construction standards. In the case of T-Point 2, construction of the facility coincided with significant work being done in Japan in preparation for the Tokyo Olympic games. Nonetheless, Mitsubishi Power used its skills as an engineering, procurement, and construction (EPC) contractor to assemble a high-quality workforce for T-Point 2, and the project logged about 20,000 man-days per month during the peak of construction.

"We conducted intensive training to maintain safety and health of the workers and improve quality of work. Some of the key induction trainings include construction safety, road safety, disaster prevention, and health and safety training. The training was provided to improve the skills of the workers before they started working on the project, and the results have been very positive," said Junichiro Masada, Senior Vice President, co-Chief Technology Officer, and Deputy Head — Turbomachinery Headquarters with Mitsubishi Power.

The training and sound oversight paid dividends. The lost-time incident rate for the project was an amazing 0.00, and the total recordable incident rate was a very respectable 0.26. "We are proud to have achieved such great safety results even as we worked under tight timelines," said Masada.

T-Point 2 during construction, October 2019.

In addition to training, Mitsubishi Power also provided several countermeasures to maintain safety and improve productivity. For example, during the hot summer season, "air-conditioned suits" were utilized by workers to stay cool and prevent heatstroke. Other advanced technologies that contributed to a safer and more productive working environment included mixed reality technology and a block insulation system, which brings new technology to overcome the limitations of traditional approaches to casing and piping insulation.

Mixed reality was used during the construction phase to simulate assembly procedures using virtual reality. The process included superposition of the actual plant over the 3D model. Using the tool, the team was able to simulate the carry-in and carry-out of large equipment, and assemble the main unit virtually. The technology enabled workers to significantly improve productivity and quality control.

The proprietary block insulation system was a new method to install insulation in the gas turbine casing, which remarkably improved productivity. With this technique, the team was able to complete the same work with only 20% of the man-hours that had been previously required.

"The mixed reality and block insulation system solutions were very effective," Masada remarked. "We anticipate using these technologies in future projects."

AN EVER-EVOLVING PLATFORM

TOMONI™ digital solutions has its roots extending well back in time to the transition from analog to digital control systems in the 1970s. Mitsubishi Power developed several iterations of new information and communications technology (ICT) from the 1980s to today. In 1999, Mitsubishi Power opened its first remote monitoring center (RMC) in Takasago to monitor thermal power facilities in Japan and overseas. Two years later, it opened an RMC in Orlando, Florida, focused mainly on North American gas turbine combined cycle plants. Since then, RMCs have been added in Alabang (Muntinlupa, Philippines) and in Nagasaki on the island of Kyushu in Japan.

TOMONI™ digital solutions has evolved from its early applications that were focused on gas turbine monitoring and operational flexibility to today's advanced total plant solutions that form the basis of the Mitsubishi Power strategy to steadily create the building blocks of the smart, autonomous power plant of the future. A good example of this evolution is the advanced analytics being applied at T-Point 2 to enable true data-driven condition-based maintenance (CBM). Too often in the past, CBM was simply a reasoned judgment of a subject matter expert based on risk tolerance because the data was not available to accurately calculate component remaining lifetime. Today's monitoring and diagnostics capabilities make true CBM possible.

A Gas Turbine Combined Cycle (GTCC) Performance Diagnosis tool is also being validated and trained currently at T-Point 2. It is a thermal cycle model-based diagnostic package that compares actual GTCC thermal cycle performance with as-designed and as-last-maintained conditions to identify deviations and automatically deliver engineering insights to suggest troubleshooting and corrective actions to maximize cycle efficiency.

"Our near-term product roadmap has additional new product deployments scheduled after the successful commissioning of T-Point 2," said Sanchez, adding that even more features are planned once T-Point 2 reaches 8,000 actual operating hours (AOH). "With the rapid advancements in digital technologies in all aspects of our lives and society, the journey to the smart, autonomous power plant of the future will be a continuous one, as new capabilities and technologies emerge regularly, and are steadily evaluated and validated," he said.

T-POINT 2 DELIVERS INSURABILITY BENEFITS

But T-Point 2 was built for more than just showcasing Mitsubishi Power's technology and capabilities, it also serves as a living laboratory, testing and validating the latest and greatest improvements being developed by engineers and scientists at the company. No other OEM in the power industry is validating gas turbines the way Mitsubishi Power does, and it shows.

Donald Schubert, Principal of SHL Consulting and retired Senior Vice President for Marsh, a global insurance brokering and risk management advisory firm, said, "Without question, Mitsubishi Power's validation and its testing philosophy are far and away better than the rest of the OEMs' because they address the long-term distress, corrosion, erosion and other long-term related issues."

"If you look at the history of testing and validation, until the 1970s, no OEM was testing or validating industrial gas turbines. The first client was the guinea pig," said Carlos Koeneke, Chief Technology Officer—New Generation Systems with Mitsubishi Power Americas. "This was terrible for the first site, and the insurance companies ended up paying fortunes for design issues, not to mention that the first project was commonly delayed."

In the 1980s, all the OEMs started doing shop tests with water brakes or other energy dissipation devices. This improved outcomes, but the extremely high cost of fuel involved in running large frame gas turbines at high loads made it economically prohibitive to sustain tests longer than 100 hours. It was also a waste of energy and required significant resources to move large frame gas turbines weighing several hundreds of tons into test facilities and to connect all the sensors, piping, manifolds, and more — all for a 100-hour test.

Furthermore, the vast majority of failures in rotating equipment, especially under high-temperature oscillations, involve mechanisms that cannot be detected immediately, but rather take time, or a large number of starts and stops, or both. For example, low-cycle fatigue, creep, erosion, and corrosion failures generally do not occur until units have operated for thousands of hours.

While most OEMs are unwilling to invest several hundreds of millions of dollars to build a power station to validate their gas turbines, Mitsubishi Power sees the value. It believes having a reputation for high reliability and high durability is worth the cost. Schubert agrees. He said history shows Mitsubishi Power's validation process works. The company's gas turbines have had fewer and less-costly insurance claims on a per turbine basis than all other OEMs.

"If you were to spend time with insurance companies, you'll find that without question every one of them would argue the Mitsubishi Power approach to testing and validation is pretty much the cream of the crop," he said.

Transporting the M501JAC to T-Point 2.

RELIABLE STEAM-COOLED GAS TURBINES

Some power industry observers have developed an unfavorable view of steam cooling applied to gas turbines, but not all steam-cooled designs have low reliability. Mitsubishi Power mastered steam-cooling technology by testing and validating equipment at its K-Point and T-Point facilities. The company began studying steam cooling in the mid-1990s at K-Point, where steam-cooled components were retrofitted for evaluation downstream of the unit's combustor basket. This led to the validation of the first commercial application of steam cooling at T-Point in 1997.

"The reliability of Mitsubishi Power's steam-cooled fleet is simply outstanding," Koeneke said. "The high reliability is, among others, the result of improvements of the original design, and more important, the subsequent validation of the modified unit." Koeneke's claim is backed up by a third-party evaluation. Strategic Power Systems Inc. (SPS) conducted thorough analysis of multiple steam-cooled units, substantiating the claim.

SPS began collecting data on M501G units in 2009. The company's Operational Reliability Analysis Program collects operational, capacity, age, and outage data from a variety of operating plants with the intention of monitoring and measuring the availability and reliability performance. In a paper co-authored by SPS and presented at POWERGEN International (PGI) in 2013, one of the conclusions was that Mitsubishi Power's G-Series "has grown to be the largest and most reliable steam-cooled gas turbine fleet in the market." More recent analysis confirms the finding.

In the PGI presentation, SPS also noted that the M501G's reliability of 98.73% achieved over the five-year period analyzed was better than the air-cooled F-class peer group value of 97.77% over the same timeframe. Furthermore, only 18% of downtime for the Mitsubishi Power units was unplanned, compared to 35% of downtime being unplanned for the F-class peer group, suggesting Mitsubishi Power M501G units had a higher probability of achieving planned fiscal performance.

This trend has continued over the years, and the gap has widened. The latest SPS report shows the reliability of the M501G increased to 99.12%, while the F-class group declined to 97.43%.

"Based on the analysis, it is logical to conclude that the poor reputation often attributed to steam-cooled gas turbines stems mainly from the meager performance of non-Mitsubishi Power steam-cooled designs. We have the largest and most-reliable steam-cooled fleet, and that is another testament to the effectiveness of T-Point," Koeneke said.

SPS DATA FIRST

Period	Oct 2015 - Sep 2020		
Category	"F" Class	Advanced Technology	M501J***
Number of Units	717	36	12
Reliability*	97.43%	98.08%	99.58%
Availability*	90.16%	90.14%	92.63%
Forced Outage Factor**	0.97%	1.06%	0.20%
Unscheduled Maintenance Outage Factor**	0.73%	0.70%	0.79%
MTBF** (hours)	2,853	3,386	9,581
MTTR** (hours)	25.41	26.90	9.24
Frame	GT24/26, 6F/FA, 7F/FA, 9F/FA, 7FB/9FB W501F, V84.3, V64.3A, V84.3A, V94.3A M501F/M701F	7H/9H W501G M501G/M701G	M501J

* - Values based on "Simple Cycle Plant" = GT + Gen. + Controls + Direct Ancillaries + Station Equip.
** - Values based on "Gas Turbine only"
*** - The M501J Units started reporting in August 2018

ORAP

January 2021

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SPS gas turbine reliability analysis report, January 2021

CONTINUOUS IMPROVEMENTS ARE PART OF THE PROCESS

T-Point 2 was constructed using a single-shaft configuration. In such an arrangement, the gas turbine and steam turbine are on one shaft, connected by a synchronous self-shifting (SSS) clutch. The two turbines drive a single, common generator, whereas, in multi-shaft designs the gas turbine and steam turbine are on different shafts, each driving an independent generator.

M501JAC rotor installation.

"Because of the single-shaft configuration, the generator at T-Point 2 is sized for gas turbine + steam turbine output. This will allow us to test larger gas turbines in the future because we can either reduce the steam turbine output or decouple it (through the SSS clutch) and run larger gas turbines at full load," explained Koeneke.

Another important improvement is associated with the use of state-of-the-art sensors and electronics. Since the original T-Point unit was 22 years old, it did not have all of the advanced technology that is incorporated into T-Point 2. The new plant will help facilitate further development of control systems and TOMONI™ digital solutions technology. The latest version of the Netmation® control system – DIASYS Netmation 4S® control system – is already being validated for large advanced class GTCC applications.

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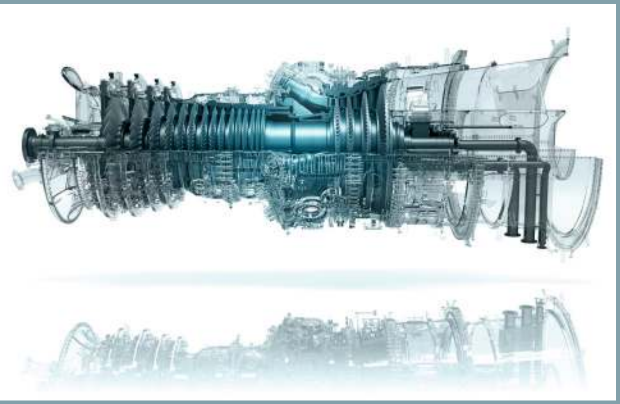
FUTURE-PROOFING WITH HYDROGEN CAPABILITY



Many experts have pointed to hydrogen as a potential gamechanger for the power industry. The concept revolves around utilizing electricity generated by renewables when supply is high and demand is low. This could be around mid-day when solar power production is peaking but the need for power is relatively light. Rather than curtailing output, the excess power could be used to produce hydrogen through electrolysis, with the hydrogen stored for later use. Then, when demand increases and renewable supplies decrease around sunset, the hydrogen could be used to fuel a gas turbine, thus supplying renewable energy.

Mitsubishi Power has been leading the industry forward with its hydrogen projects. The company announced in May 2019 that it was partnering with Magnum Development, the owner of a large and geographically rare underground salt dome in Utah, on a project that could store renewable hydrogen year-round in caverns within the salt dome and provide it to power markets in the western United States when they need it.

To use hydrogen to its fullest extent, gas turbines must be able to operate with 100% hydrogen. That is why Mitsubishi Power is also working on a Carbon-Free Gas Power project in the Netherlands. The project will convert one of three units at the 1.32-GW Magnum combined cycle power plant to run on 100% hydrogen by 2025.

But it is not as easy as it sounds. A gas turbine has three main sections: compressor, combustor, and turbine. The compressor and turbine sections require no significant changes to run on 100% hydrogen. What needs changes is the combustion section — where the fuel drives the gas turbine process.

"We need a different combustion technology to utilize hydrogen in a dry low-NOx kind of way," Paul Browning, CEO of Mitsubishi Power Americas, explained. "We are in the process of developing that now. Our existing technology can utilize natural gas with 30% hydrogen. The new technology is going to be able to run with 100% hydrogen."

The development could be vitally important for customers as the power landscape evolves in the future. By having the capability of 100% hydrogen fueling, gas turbines are essentially future-proofed, making them assets that can be relied upon in the long term, even as — and because — more renewable resources are being added to the grid.

"DIASYS Netmation 4S® control system uses the latest controls hardware and software technology to increase system reliability and usability," Sanchez said. "Another key feature of this new version is that it comes with Netmation Secure Gateway, which has already been proven in deployments to existing, earlier Netmation® control system installations. It prevents unauthorized access to the control system from outside and offers a one-way data diode to channel the massive amount of on-site data for centralized analytics and remote subject matter expert evaluation."

The J-Series steam-cooled gas turbines were thoroughly validated at the original T-Point plant, followed by validation of the air-cooled version, the M501JAC. Now T-Point 2 features the M501JAC with an enhanced air-cooling concept that allows increasing the turbine inlet temperature (TIT) from 1,600C to 1,650C without changing hot gas path materials. The M501JAC also allows clearances to be adjusted during operation, thereby achieving record-setting efficiency under load by minimizing clearances.

"We are also applying a slightly thicker thermal barrier coating to deal with the higher TIT," said Koeneke, noting that this technology had been validated for several years in the previous plant as well.

Mitsubishi Power's technology is sound and well proven, not only at the K-Point, T-Point, and now, T-Point 2 validation facilities, but also in customers' power plants all around the world. The company is constantly striving to push efficiency to new heights, which is good for the environment and even better for generators' bottom lines. Mitsubishi Power is leading the gas turbine industry forward with technology designed to increase TIT, provide autonomous plant operation, and utilize new fuels that provide carbon-free energy. Technology advancements and the company's proven demonstration methods provide a winning combination for customers.

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Mitsubishi Power Americas, Inc.
www.amer.power.mhi.com
407-688-6100