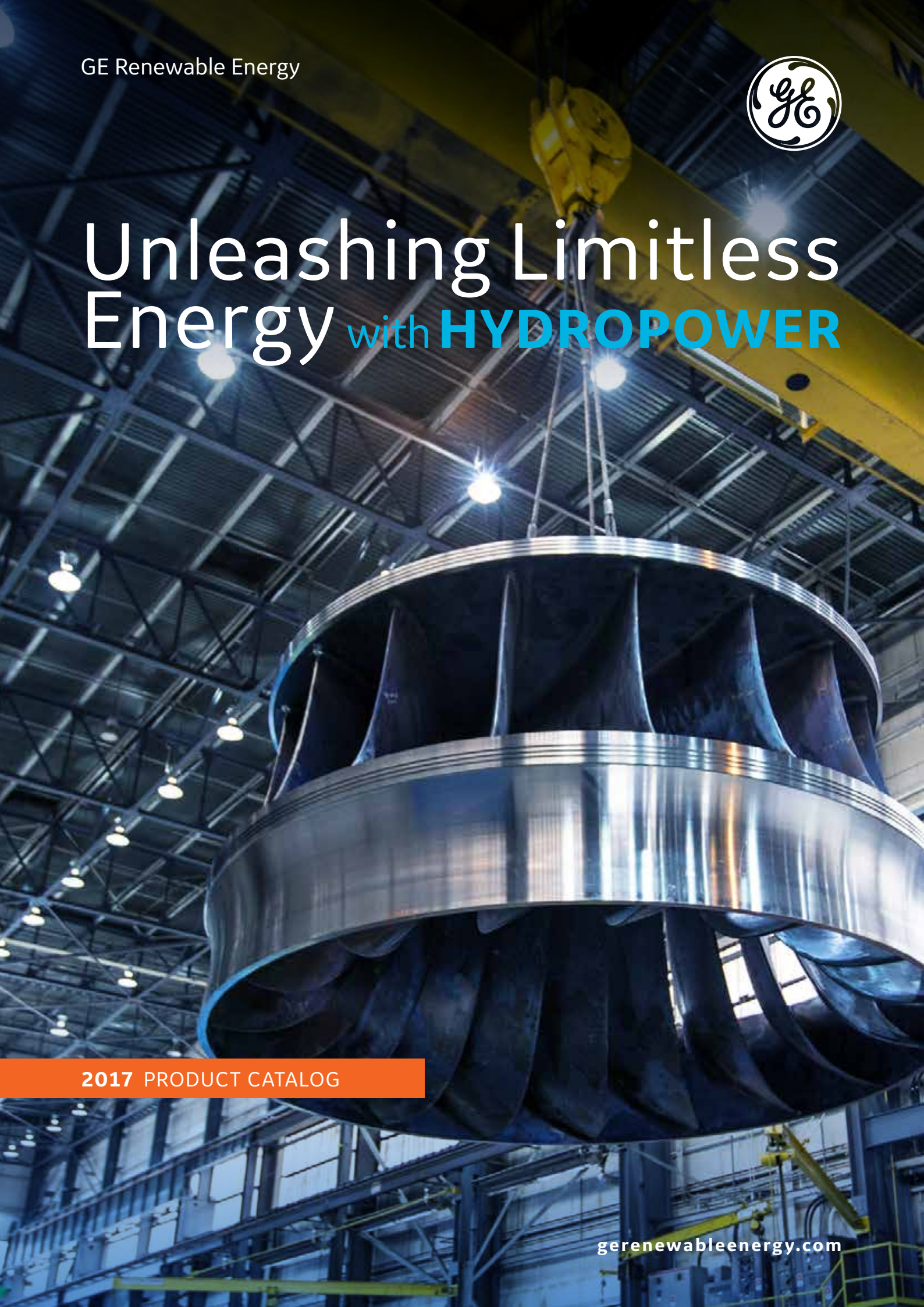
GE Renewable Energy

Unleashing Limitless Energy with HYDROPOWER



2017 PRODUCT CATALOG

gerenewableenergy.com

UNLEASHING LIMITLESS ENERGY



Hydropower is a leading source of renewable energy with over a 100-year track record. It is also one of the most flexible, being suitable for peak and base load production. Even more important, hydropower is a multi-purpose energy with many benefits such as sustaining agriculture, developing industry, securing health, bringing education and high quality jobs. At GE, we are proud to be a trustworthy long-term social partner creating value locally and supporting a sustainable and modern lifestyle, for everyone.

As a multi-industry company with a global footprint, we leverage all the resources we have in-house, such as the GE Store and GE's Global Research Centers, to accelerate differentiation and bring efficient solutions to our customers. We focus on the development of a competitive product portfolio aligned to our customers' needs and objectives in terms of cost, performance and time to market.

At GE we believe that digitizing the energy ecosystem from end to end is essential to meet growing demand. By combining the power of water and digital intelligence, by using GE's Digital impulse and knowledge of hydro machines, we can enhance the future of hydropower with an unmatched level of predictability, flexibility and efficiency.

We install Large hydro technology to provide a clean and sustainable base load energy to populations. We develop storage technology for hydropower to contribute to the integration of other renewable sources. We provide small hydro solutions to meet the needs of millions of people thanks to short lead times and less investments. We service and retrofit existing plants to take assets to a higher level of performance and availability.

We believe in Hydro as an answer to challenges our world is facing in reducing CO_2 emissions and delivering more affordable, more reliable and more sustainable power for everyone, everywhere.

With our people, our services, our technology and scale, GE is reinventing hydro!

Yves Rannou
CEO and President of GE's Hydro Solutions

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GE is **Reinventing** Hydro

Now is the time. The time when we have the means to provide electricity cleanly and sustainably to meet the seemingly insatiable appetite for more electricity. GE is a renewable energy powerhouse with 13,000 employees in 40 countries with a portfolio of solutions that includes onshore and offshore wind, concentrated solar power and hydro – the world's leading source of renewable energy by far.

Hydropower generates 17%[1] of all electricity yet only about 40%[2] of economically feasible capacity has been tapped globally. With a levelized cost of electricity ranging from $20/MWh to under $200/MWh[3] with select installations even lower, it is no wonder that hydro is expected to generate over 5,000 TWh of electricity by 2025 – an increase of about 25% over the amount generated in 2015.

Predictable, storable, flexible, reliable and rapidly dispatchable, one **large hydropower** plant can transform a country from an energy importer to an exporter, one **small hydropower** plant can be built quickly and generate electricity for remote villages or profits for independent power producers and one 120 MW pumped storage plant with sufficient reservoir capacity can store enough energy to supply the electricity needs of approximately 100,000 people for about 1 day – all while **supporting the grid** with critical power regulation capabilities.

Now is the era of the Industrial Internet – the blending of the physical and **digital** worlds where machines talk to machines and interact as part of systems, enabling them to perform, faster, smarter and more reliably.

Now, when about 30% of the global hydro **installed base** has been in service for over 40 years, is the opportunity to retrofit them, not only to make them as good as new but to make them better than ever, increasing efficiency and power output and incorporating the latest technology to increase reliability and decrease the environmental footprint.

Not only can we retrofit your hydropower plants, we provide a full range of plant support services offered on an as needed basis or via service agreements.

Not only are we a leader in hydro solutions, we can draw upon unrivalled depth of expertise, global reach and R&D via what we call the **GE Store**. No other company has the ability to transfer intellect and technology as we can through the GE Store.

Also part of the GE Store, **GE's Energy Financial Services** invests in long-lived and capital intensive projects and companies. Renewable energy is our fastest growing business segment and represents half of our business.

[1] International Energy Agency: World Energy Outlook 2016

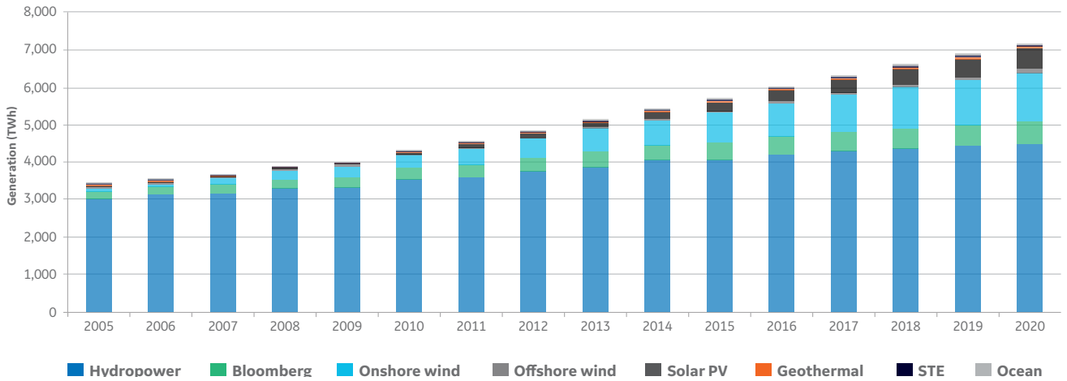
[2] The International Journal on Hydropower & Dams: World Map 2016

[3] International Energy Agency: Medium-Term Renewable Energy Market Report 2015 and World Energy Outlook 2016

We drive our Hydro Solutions business by supporting local economic and social development. Our mission does not end with the commissioning of hydropower plant equipment. It goes on with the training and qualification of local populations to enable them to operate and maintain their assets, lead their own development and manage their own destiny.

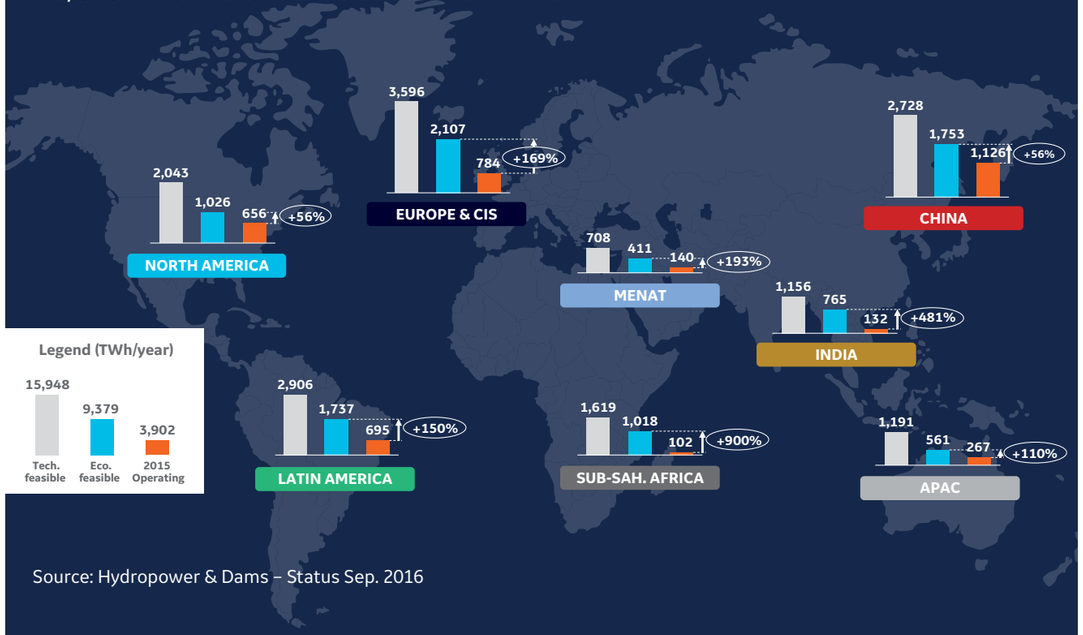
Oh, and by the way, we also invented the lightbulb.

WORLD RENEWABLE GENERATION AND FORECAST (TWh)



Source: Historical renewable electricity generation from IEA (2015a)

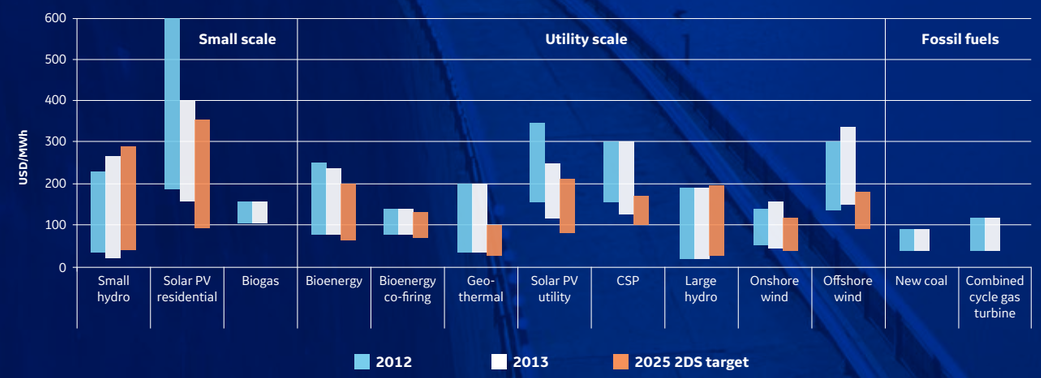
~2/3 OF TOTAL UNTAPPED POTENTIAL



Source: Hydropower & Dams – Status Sep. 2016

LCOE as low as **$20/MWh**

LEVELIZED COST OF ELECTRICITY



HYDRO VALUE PROPOSITION

GE **Store**



Driving competitive advantages across businesses

We drive enterprise advantages that benefit our customers through what we call the "GE Store." It means that every business in GE can share and access the same technology, markets, structure and intellect, making the totality of GE more competitive than the parts. No other company has the ability to transfer intellect and technology as we can through the GE Store.

The GE Store allows GE to innovate at scale, investing more than our peers and spreading the innovation across more businesses. Ten **Global Research Centers** (GRCs) in key locations around the world with about 3,000 PhDs, engineers and scientists are driving fundamental and applied research for GE. In 2015 alone over 3,000 new patents were filed. In the GRCs, we're applying expertise in fields from electronics to chemistry, biosciences to computing, metallurgy to fluid mechanics, materials to imaging—and many more—against the world's toughest challenges.

The GE Store brings to bear enormous computing power—millions of processor cores—to solve the most complex physics-based challenges that GE's Hydro Solutions R&D teams face in developing solutions for customers.

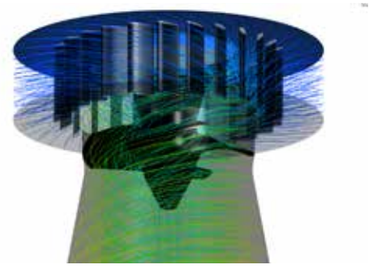
The GE Store allows one GE business to go beyond its own product range to offer complete end-to-end solutions. As an illustration, GE's Power Conversion business applies the science and systems of power conversion to help drive the electric transformation of the world's energy infrastructure. GE's Hydro Solutions takes full advantage of this knowledge and experience – most notably in the Power Electronics segment, enabling efficient and flexible conversion and conditioning of electrical energy. All of GE's variable speed pumped storage projects have used power electronics from the GE Store.

The GE Store is more than technology and products, it is also about GE technical and business experts providing our customers with consulting on solving the electric power industry's most pressing challenges—driving the evolution of electric power systems with greater affordability, reliability, and efficiency. **GE's Energy Consulting** team provides innovative solutions across the entire spectrum of power generation, delivery, and utilization. With our cross-company resources, GE's Energy Consulting business is able to serve a diverse global client base with a strong local presence.

Consulting and collaboration converge at the **GE Digital Foundries** which bring together different talents, experiences and perspectives to incubate and elevate the Digital Industrial Transformation. We invite customers, partners and startups to learn and collaborate with us on creating new Industrial Internet applications.

Engineering **Excellence**

345 GW installed



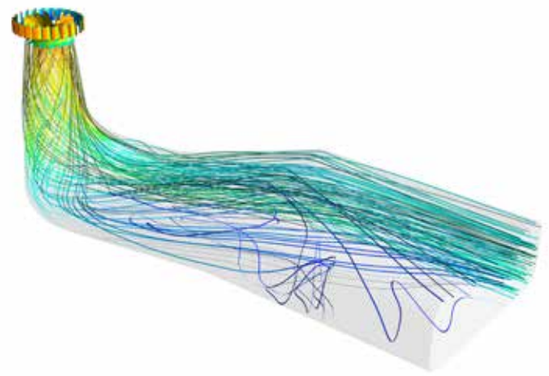
With 345 GW installed and references in 120+ countries over 100 years, GE has supported projects pretty much anywhere there is water. Reliability and robustness are the hallmarks of our engineering and they are key to our customers' loyalty.

GE follows the full lifecycle of a hydropower project, working with customers, consulting engineers, lenders and EPCs to define the best suited and most efficient and affordable technology for the project during the conception stage. We then design, test, manufacture and install the equipment onsite as the project comes to life. Once the hydropower plant is operational, we use our engineering know-how to provide plant support services through assistance agreements or on demand requests, as well as operating and maintaining them for customers. Finally, we retrofit plants to lower the cost of electricity and increase flexibility.

Located around the world in close proximity to our customers, we have dedicated centers of excellence with over 700 engineers that focus on specific technologies for the benefit of our customers worldwide.

Our engineering excellence is built upon the foundation of GE's Global Research which has served as the cornerstone of GE innovation for more than a century. Currently, more than 3,000 of the world's brightest scientists, engineers and researchers are working together to deliver technical breakthroughs for GE customers.

Complementing GE's Global Research Centers and collaborating with them are dedicated hydro technology centers which ensure that the most innovative solutions are available across the whole range of GE's hydro products to address evolving market needs. The proof of success of the GE's Hydro Solutions technology program is its rich patent portfolio.



All of the hydro technology centers are standardized on the latest CFD (Computational Fluid Dynamics) and FEA (Finite Element Analysis) software. Leading industry software is complemented by sophisticated GE-designed applications. CFD and FEA simulations are validated by scale model tests in one of GE's hydraulic test laboratories in Brazil, China, France or India. GE's lab in Grenoble, France, the largest hydraulic test lab in the world, has the industry's only reversible bulb test rig which means that GE is the only company that can fully test tidal bulb turbines. Hydraulic test labs simulate the conditions found in a hydro power plant, enabling GE's engineers to test and refine designs and guarantee performance prior to manufacture and installation.

FLEXIBLE HYDROPOWER

Adapting to the intermittent nature of renewable generation

The sun isn't always shining and the wind isn't always blowing. And, it isn't always sunny or windy when we need electricity. Furthermore, the flow of rivers feeding hydropower assets, a subject area known as hydrology, varies according to the season and subsequent rainfall. As a result, we have had to adapt the way we generate electricity to the intermittency of wind and solar power.

Hydro is one of the few power generation sources that can have its power output widely "adjusted" or that can be turned off and on rapidly and repeatedly—something known as flexibility or dispatchability in the industry.

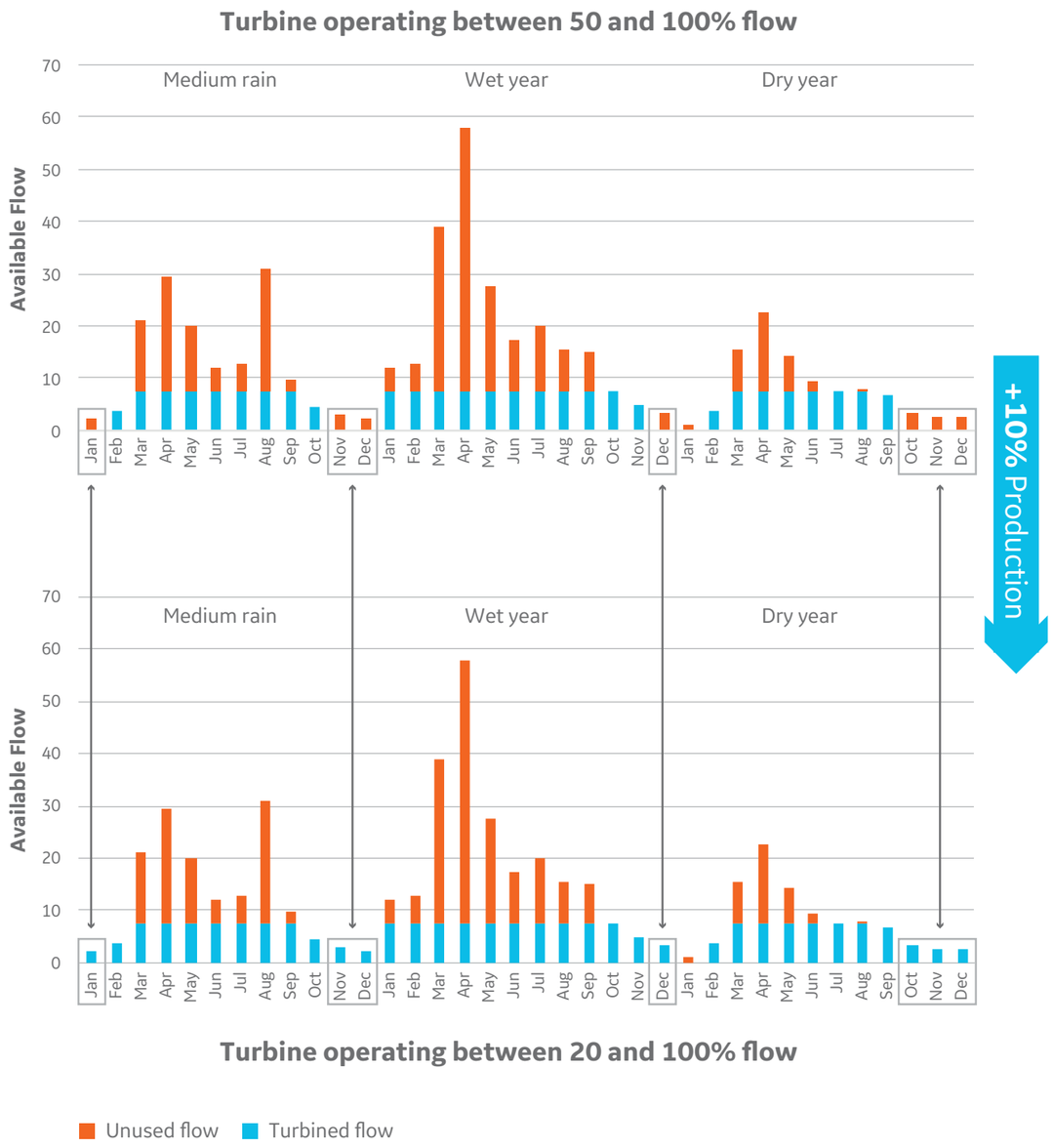
In the past, hydro turbines were designed for specific set points of operation and much deviation beyond these points created hydraulic and mechanical phenomena such as cavitation and vibration which could potentially damage hydropower plant equipment. Traditionally, adjusting power to match river flow was achieved by turning off or on turbine and generator units. This method did not provide grid power regulation capabilities.

GE scientists and engineers at its state-of-the-art hydraulic test lab in Grenoble, France and in collaboration with a leading engineering university, has been working to make hydro turbines operate over a very wide range without the negative hydraulic & mechanical phenomena. Another benefit of a wider operating range is that the number of turbine and generator units can be reduced and still cope with river flow variations while also providing ancillary services to the grid.

Wider operating ranges are only one part of the dispatchability equation. More frequent starts and stops – known as cycling – is the other part. Hydro comes online faster than any source of energy and it can also withstand frequent starts and stops. However, cycling is a cause of generator fatigue. GE is at the forefront of developing computation methods and robust products that mitigate generator fatigue. Generator oblique elements are one example of a GE development that diminishes generator fatigue.

Hydro is storable at a grid scale and this energy storage capability is another way in which hydro is flexible. As we know solar and wind generation is often not aligned with demand so hydro's storage capabilities, specifically pumped storage can help to match solar and wind generation with demand.

For even more flexibility, pumped storage plants can be equipped with variable speed technology which enables the plant to provide power regulation capabilities in generation and pumping modes. Traditional fixed speed pumped storage can only provide power regulation in generation mode. GE is a world leader in pumped storage plant equipment and is the only supplier with in-house capabilities not only for turbines and generators but also the full electrical balance of plant including power converters.



Digital Hydro Plant

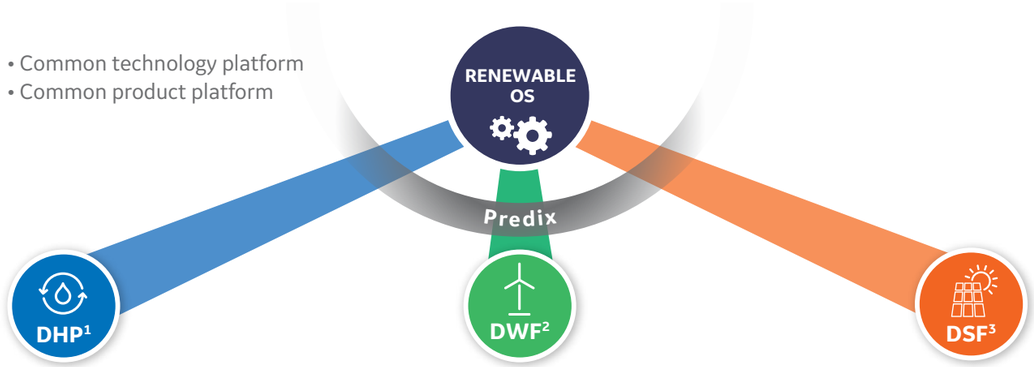


Bridging the intelligence gap between people and machines

Based on Predix*, GE's Digital Hydro Plant can reduce maintenance costs by up to 10%, increase plant availability by up to 1% and increase revenue by up to 3%. Predix is a cloud-based application platform with unlimited storage and an easy-to-use interface. Accessible anytime and anywhere, Predix manages and analyses massive volumes of industrial data.

WINNING WITH THE RENEWABLES ECOSYSTEM

- Common technology platform
- Common product platform



Business Optimization	Market Intelligence and Forecasting	Portfolio Optimization	
Operations Optimization	Fleet Excellence	PowerUp Services	Work and Outage Optimization
Asset Performance Management	Machine and Equipment Health	Reliability Management	Maintenance Optimization

[1] DHP: Digital Hydro Plant

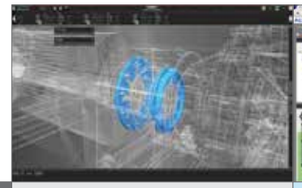
[2] DWF: Digital Wind Farm

[3] DSF: Digital Solar Farm

GE's Hydro Edge Analytics is an essential and highly differentiating part of GE's Hydro Asset Performance Management (APM) solution. Based on GE expertise in machine behavior, it processes raw signals from any asset in real-time on variables such as temperature, vibration, pressure, sound and particle concentration to build smart indicators contextualized with an instantaneous operating environment. With this real-time information, GE's APM can identify potential failures before they happen preventing expensive outages. Edge Analytics is complemented with cloud-based analytics that enable the creation of highly interactive dashboards that calculate and display plant/fleet health and performance KPIs so that the best maintenance strategy can be dynamically adjusted as asset and business conditions change over the life time of the plant.

Using real time data, **GE's Digital Twin** builds a digital clone of your machine, accurately reflecting the condition of the asset in real time so that you can predict failures, test new operating patterns and optimize your asset to its full potential. For example, we have developed a turbine lifetime prediction model that continuously estimates remaining useful life by calculating in real time the cumulative damage incurred from partial load, transients and repeated starts and stops.

DEMONSTRATING APM CAPABILITIES AT CUSTOMER SITES

	Asset Visibility	Case Management	Asset Strategy[1]
			
Asset Performance Management	Machine and Equipment Health	Reliability Management	Maintenance Optimization
Pilots	**Pont Baldy HPP**	**Bourg Les Valence HPP**	**Dagachhu HPP**

[1] Powered by Meridium

True **cybersecurity** means no breaches. For that GE provides end-to-end cybersecurity solutions and services for digital hydro plants from inside the plant to the cloud. The Predix cloud based platform is built with the most advanced security protocols and is based on a 'gated community' model to ensure that tenants of the cloud belong to the industrial ecosystem. It is compliant with the latest security guidance and standards including CSA, IEC27017/18 and SSAE/SOC. At the plant level, GE controllers are Achilles certified making them one of the most secure in the market. Our control architectures embed several layers of defense including the MS Active Directory Domain Services, the intrusion detection system (IDS), rugged switches, security certificates and code integrity checker native in GE controllers. In addition, control networks can be hardened with a SIEM system (security information and event management) that continuously monitors traffic. For installed legacy and non-legacy OT (operations technology) systems, GE offers security field services in partnership with Wurldtech, a GE company, that includes site assessment, NERC-CIP certification, training and industrial control networks hardening using the OpShield product

GE is developing applications for **operations and business optimization** of hydropower plants:

- **Operating Range Extension** will enable safely extending machine operating limits.
- **Sequence Booster** is a water to wire plant modeling tool that will calculate the best control loops to have the shortest transition times between operating modes.
- **Load Control Optimization** will calculate how to best balance power demand across multiple units and multiple plants given machine efficiencies and conditions, operating zones and start and stop limitations.
- **Energy Forecast** will calculate hydropower plant production considering hydrological models and weather forecasts. It can be connected to trading markets so that revenues simulations can be done in real time.

CUSTOMER SUCCESS

***Pont Baldy**, a hydropower plant operated in the southeast of France is using GE Hydro Edge Analytics. Since December 2015, Hydro Edge Analytics has collected and analyzed almost two Terabytes of raw data per month and has also digested three years' worth of temperature, maintenance and downtime data previously collected by the utility. As a result, GE is able to generate diagnostic assessments of the remaining lifetime of turbine components, compute a health index for the plant and make operations and maintenance recommendations. For example, the plant had a bearing with elevated temperatures. Hydro Edge Analytics determined that the elevated temperature was benign and no action was needed, saving the time, expense and outage time of an unnecessary repair.*

Energy **Financial** Services

Over $1B annual renewable energy investment

Working as a builder, not just a banker

Financing is often one of the biggest challenges we see to implementing hydropower projects, particularly in emerging markets. Hydropower has low operating costs, but it is highly capital intensive and return on investment takes time. GE has financial products and works with third parties to fund clean energy projects.

GE Energy Financial Services (EFS) has a long track record of investing in renewable energy with a cumulative total of $12 billion in renewable energy commitments. GE, through EFS, invests more than $1 billion annually in renewable energy projects, primarily making equity investments and assisting partners in raising project debt. EFS support can be especially significant for smaller developers and/or projects with a more complicated risk profile.

EFS has primarily cash equity but also structured equity, tax equity investment (as well as debt investment) commitments with over 300 customers in 17 countries.

In addition to GE's in-house financial services, we have a global team with extensive experience working with Export-Import Banks and Export Credit agencies that finance and insure the purchase of goods and services internationally.

TAILORED FINANCING SOLUTIONS: ADDRESSING SPECIFIC NEEDS AND GAP:

Co-Development
- Enable customers to win across regions using GE relationships and expertise
- Technology optimization + development equity

Tax Equity
- Extensive experience with hedge, merchant, corporate and utility offtake
- Extensive experience in structures

Equity/Debt
- Enabling strategic project in Montenegro
- Flexible structure to meet project specific need

Third Party/ECA
- Private equity raise
- Optimal debt from ECA and commercial banks

Enabling Co-Development opportunities through financing

Lower financing costs by optimizing tax equity

Developing solutions to meet commercial goals

Optimizing external financing opportunitis

Financial Partners

Equity				Debt			
Private	**Developers**	**Niche**	**Alternative**	**ECAs**	**DFIs**	**Int'l Banks**	**Reg'l Banks**
Gulf Capital, Global Infrastructure Partners, Impax, Maquarie, Denham Capital	GDF Suez, Foster Wheeler, Group Five, Vinci	InfraCo, Conduit, Actis, Fengate	Allianz, Cerberus, Teachers' Pension Plan	Export/ Import Bank of the United States, Sinosur, BNDES, EDC, Euler Hermes, SACE, Coface	European Investment Bank, IDB, KFW, ADIB, ADB, JBIC, The World Bank	CITI, Standard Chartered, ICICI Bank, Standard Bank, Deutsche Bank	Banco do Brasil, HSBC, BNP Paribas, Santander, ICBC, DBS, Al Baraka, Suburbane, ANZ

Product **Differentiators**

Excellent insulation condition **after 50 years**

Increasing reliability and decreasing environmental footprint

Understanding our customers' ever present need to make their hydropower plants more reliable and environmentally friendly, we have developed or implemented a number of innovations that do just that.

INNOVATIONS THAT INCREASE RELIABILITY INCLUDE:

Maintenance-free generator oblique elements allow free thermal expansion of the stator frame, rotor and brackets, relieving stress on the foundation and they do so without maintenance-requiring moving parts. They increase for example stator reliability by ensuring a consistent and perfectly round shape at all operating temperatures, preserving the air-gap.



Maintenance-free stator core clamping system prevents loosening of core sheets and doesn't require periodic tightening, and decreasing maintenance.

High quality insulation systems for stator bars and windings use MICADUR® Vacuum Pressure Impregnation (VPI) or DURITENAX® Resin Rich for stator bars and Round Packing System for stator windings that securely hold the bars in place yet allow them to be removed when necessary. GE has produced bars with MICADUR® VPI insulation that are still in excellent condition after over 50 years of operation.

Long-lasting Polypad™ composite thrust bearing pads last longer and support more weight than babbit metal thrust bearing pads. Their increased durability enables them to withstand more starts and stops, including hot starts, which are increasingly part of the rugged operating regime of today's hydropower plants. In retrofit applications, supporting more weight means that they can accept upgraded higher power generators, which are typically heavier, without having to replace the original thrust bearing and make expensive civil works modifications.

Ring gates decrease civil works costs by up to 15% for an underground cavern (as much as 30% in cases with poor surrounding rock quality). They also protect the wicket gates from silt, reduce leakage and the resulting head losses (versus a butterfly valve) and provide additional powerhouse safety when no other main inlet valve is used. GE has the largest fleet of ring gates and we provide the choice of mechanical or hydraulic synchronization. GE has patented the precise fail-safe synchronization using hydraulic cylinders.





INNOVATIONS THAT DECREASE ENVIRONMENTAL FOOTPRINT:

Efficiency-increasing hydrostatic water guide bearings use water instead of oil to lubricate and cool the bearings and support the radial load while centering the shaft line. In addition to their environmental benefit, hydrostatic water guide bearings increase efficiency by up to 0.5% and replace the maintenance-requiring shaft seal.

Oil-free hubs do not use petroleum-based lubricants, eliminating the possibility of oil leaking from the hub into the aquatic ecosystem. GE installed this technology in the bulb turbines at the Paldang hydropower plant in South Korea.

SELECTED PRODUCT DIFFERENTIATORS

	Technical differentiators/ Type of machine	Bulb	Kaplan	Francis	Pelton	PSP	NEW	INSTALLED BASE
RELIABILITY	**Oblique elements**	✔	✔	✔	✔	✔ (mainly low head)	✔	□
	Stator core clamping	✔	✔	✔	✔	✔	✔	✔
	Insulation system	✔	✔	✔	✔	✔	✔	✔
	Polypad™	□	✔	✔	✔	✔	✔	✔
	Ring gate			✔		✔ (mainly low & medium)	✔	
ENVIRONMENT	**Hydrostatic Water Bearing**			✔	□	✔	✔	✔
	Oil free hubs	✔	✔				✔	✔

✔ Ideally suited
□ Suited

PRODUCT PORTFOLIO

Large **Hydro** Generation

GE equipped **6 of 9** most powerful power plants

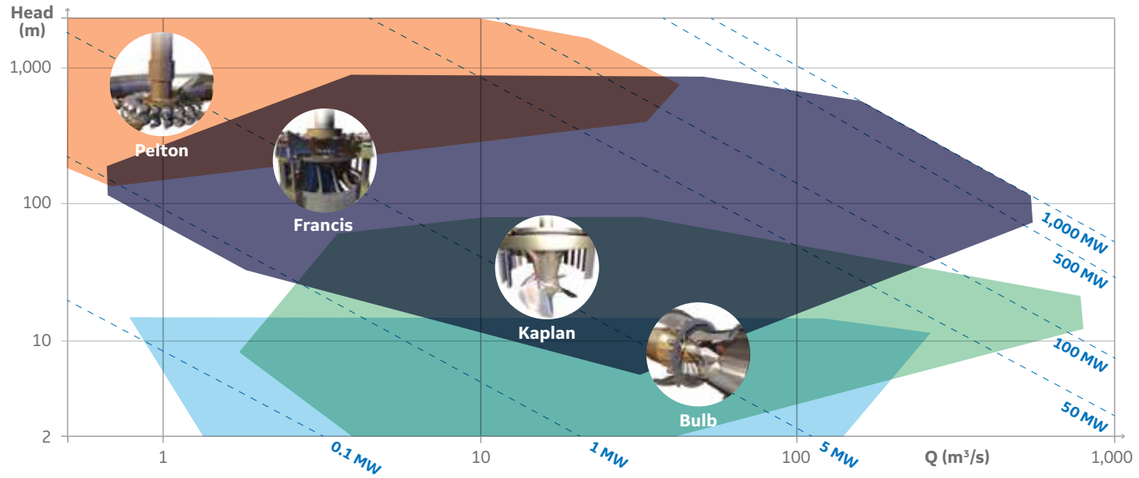
Transformational hydropower

Hydropower is one of the very few power generation technologies where one plant can completely transform a country's energy supply so it is no surprise that the nine highest installed capacity power plants of any kind in operation are hydropower and of these nine, GE equipped six[1]. One large hydropower plant can change a country from an energy importer to an energy exporter overnight. Bujagali (5 x 50 MW) hydropower plant in Uganda is a perfect example. This one plant almost doubled the installed base of the country and is now providing 49% of Uganda's electricity generation.

GE provides full electro-mechanical and hydro-mechanical equipment for low, medium and high head hydropower installations as turnkey plants or individual components for run-of-river, tidal barrage or conventional reservoir applications. We've equipped bulb, Kaplan, Francis and Pelton-driven projects all around the world.

[1] Three Gorges (22.5 GW), Itaipu (14 GW), Guri (10.2 GW), Tucurui (8,4GW), XiangJiaBa (6.4GW) and Longtan (6.4 GW)

HEAD IN FUNCTION OF FLOW PER TYPE OF MACHINE



BULB-DRIVEN HYDROPOWER PLANTS

Unrivaled power capacity ratio for low head applications

With references for the most powerful bulb units in operation and under construction, GE is a clear leader in bulb plants overall and especially plants with large turbines that are over 6 m in diameter.

Bulb turbines can support a wide range of head and discharge which is important when they are used in run-of-river situations where the flow varies with the season and reservoir volume is limited. Bulb turbines are double regulated which means that the flow of water into the turbine can be adjusted by the wicket gates and the angle of the blades can be adjusted to adapt to the discharge. They are one of the most efficient solution for very low nominal heads – up to 20 or 25 m. Bulb turbines have a straight water passage through the draft tube which improves the unit's overall performance and results in low submergence which in turn reduces size and cost of civil works.

In addition to their most frequently used run-of-river application, bulbs can also be used in tidal barrage applications like La Rance in France which GE equipped.

THE GE DIFFERENCE

GE patented V-shaped elements increase low speed horizontal generator reliability and longevity by ensuring a concentric stator core, maintaining the air gap and avoiding a potential outage-causing rotor-stator contact. V-shaped elements provide the necessary stiffness required by extreme loads yet have enough flexibility to protect against stator core buckling and do so with less height than other design concepts, allowing overall dimensions to be optimized.

Site measurements at Jirau and Santo Antônio by GE enabled us to further optimize Generator ventilation and cooling system design, reduce losses and increase overall plant efficiency. Calculation and onsite measurement campaigns allow GE to continuously improve generator ventilation and cooling system.

GE'S EXPERIENCE

- 210 unit/7.2 GW bulb installed base (≥ 20 MW per unit)
- Designed, manufactured and installed the most powerful bulb units in operation: 10 x 75 MW/83 MVA for Jirau in Brazil
- Designing the bulb units that will be the most powerful when they enter service: 3 x 82 MW/91 MVA for Chicoasen II in Mexico
- Designed, manufactured and installed the largest diameter bulb turbine runner (7.8 m) in China
- Equipped 23 projects with turbine runners over 6 m in diameter
- Designed and manufactured the world's largest downstream gates: 190 square meters for Santo Antônio in Brazil
- Equipped the world's first tidal barrage hydro power plant for La Rance in France



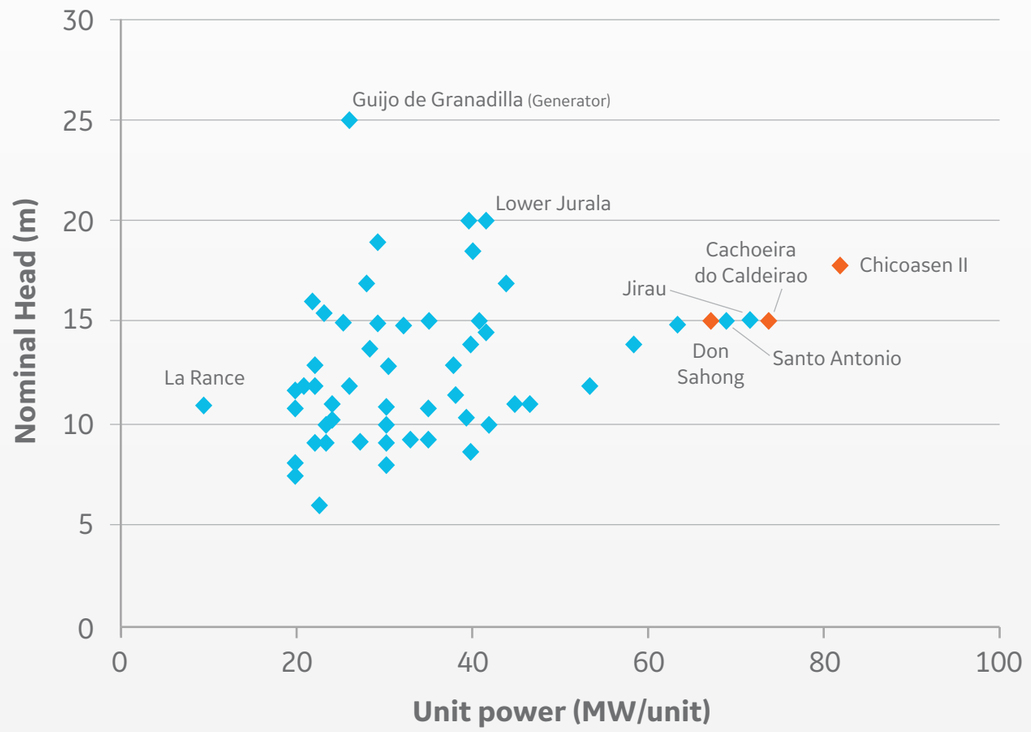
CUSTOMER SUCCESS

Jirau and Santo Antônio *on the Rio Madeira in Brazil are equipped with the most powerful bulb turbine and generator units in operation. GE designed, manufactured and installed 10 x 75 MW bulb turbines and 17 x 83 MVA low speed horizontal generators for Jirau and 21 x 71 MW bulb turbines and 26 x 80 MVA low speed horizontal generators for Santo Antônio. Santo Antônio also includes the world's biggest downstream gates. GE even built a workshop nearby to speed delivery of these gates and other hydro-mechanical equipment.*



The **world's most powerful** bulb units are GE

GE BULB-DRIVEN UNIT EXPERIENCE



◆ **Under Construction**

BULB RANGE

Maximum Head	Unit Power	Runner Diameter	Speed
m	MW	m	Rpm
≥ 5 and ≤ 30	≤ 92	≥ 4.5 and ≤ 8	≥ 50 and ≤ 300

KAPLAN AND PROPELLER-DRIVEN HYDROPOWER PLANTS

Wide head range and high unit output

Kaplan turbines are double-regulated (wicket gates and blade angle), making them an efficient solution over a wide range of head and discharge – an important feature given that they are often used in run-of-river configurations where the flow varies significantly with the season.

Unlike Kaplan turbines, propellers have fixed blades, making them a good solution for rivers with stable flows. Propellers have other advantages as well, such as smaller hubs which increase performance; and welded blades eliminate adjustment mechanisms, decreasing maintenance requirements.

Kaplan and propeller turbines support nominal heads from 15 to 45 m with outputs up to 250 MW. Their vertical configurations allow larger runner diameters (over 10 m), enabling higher unit power. GE's Kaplan and propeller turbines are available in 4-blade configurations for lower heads and 5- or 6-blades for higher head applications.

GE has lengthy experience in large low-speed vertical generators, coupled with strong in-house calculation tools.

THE GE DIFFERENCE

Optimized intakes and draft tubes reduce unit volume which in turn can reduce civil works costs by up to 25% because of the straight flow of water through the draft tube and shorter intake length.

Short and stiff generator shafts enable a reduction in powerhouse height and, as a result, the cost to build the powerhouse is also reduced. The optimised shaft lines are stiffer, reducing losses and improving mechanical behavior.

GE'S EXPERIENCE

- 517 unit/16.7 GW vertical Kaplan installed base (≥ 20 MW per unit)
- 64 unit/ 3.4 GW Propeller installed base (≥ 20 MW per unit; GE machines since 1950)
- Designing and manufacturing the world's second largest diameter Kaplan turbine runner: 10.7m 143 MW/159 MVA for the Jinsha hydro project in China
- Designed, manufactured and installed 35 runners over 6 m in diameter

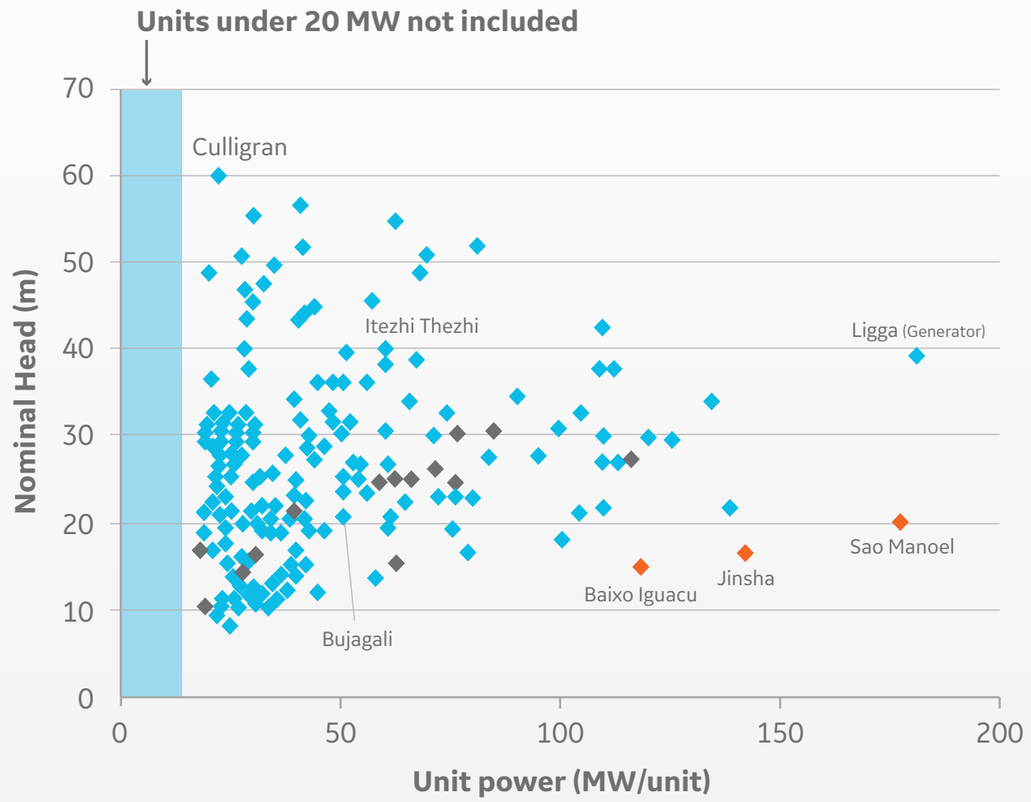


CUSTOMER SUCCESS

*Minimizing capital expense by reducing the civil works for the **Baixo Iguaçu** (3 x 119 MW) and **São Manoel** (4 x 177 MW) Kaplan hydropower plants in Brazil was key. GE optimized the design to reduce the size of the inlet, outlet and dimensions of the powerhouse leading to an overall capital expense reduction.*



GE KAPLAN- AND PROPELLER-DRIVEN UNIT EXPERIENCE



KAPLAN RANGE

Maximum Head	Unit Power	Runner Diameter	Speed
m	MW	m	Rpm
≥ 5 and ≤ 60	≤ 240	≥ 3.5 and ≤ 11	≥ 50 and ≤ 150

FRANCIS-DRIVEN HYDROPOWER PLANTS

The most efficient hydro turbine

Efficiency up to 96%, suitability for a nominal head range from under 40 m to over 500 m and power outputs over 800 MW have made Francis turbines, by far, the most widely used hydro turbine in the world. They also power all of the world's highest rated hydropower plants.

THE GE DIFFERENCE

- Double Layer thrust bearings are used on very large machines. These bearings maximise plant efficiency by operating at a higher specific pressure. This allows them to be more compact, minimizing friction losses.
- Support Membrane for thrust bearings acts as a self-regulating mechanism to support the bearing pads and guarantees equal oil pressure under each membrane with a very thin layer of lubricating oil. The membrane technology increases reliability because the possibility of overheating is greatly reduced and reduces commissioning and maintenance time because of the self-adjusting capability.
- Water-cooled rotating vat shell bearings for turbine guide bearing applications. The water cooling eliminates the need for oil cooling auxiliaries such as pumping systems, piping and heat exchangers that require maintenance. Their design also facilitates access to the shaft seal for ease of maintenance and they do not require a dynamic seal.

GE'S EXPERIENCE

- 1372 unit / 142 GW Francis installed base (≥ 30 MW per unit)
- Designed, manufactured and installed the world's most powerful Francis turbine and generator units in operation: 812 MW/889MVA at Xiangjiaba in China
- Designed, manufactured and installed the world's largest generator: 19.3 m stator core diameter for Xiangjiaba in China
- Measured 98.7% efficiency on 778 MVA low speed vertical generator at Three Gorges in China with higher efficiencies recorded since
- The only non-domestic supplier to equip all of the Three Gorges powerhouses with the world's largest Francis turbine runner: 10 m diameter and 450 tons
- Designed, manufactured and installed the most powerful Francis turbine and generator units in Southeast Asia: 6 x 400 MW at Son La in Vietnam. GE provided a wide scope of supply for this plant which provides about 10% of Vietnam's entire generating capacity. This project has been recognized with three industry awards and the customer's satisfaction with GE led to another project – Lai Chau

- Equipped 4 of the world's 5 highest installed capacity hydropower plants with Francis-driven units
- Designed the Francis turbine and generator units for what will be the highest installed capacity hydropower plant in Africa once it enters service: 6,000 MW at Grand Renaissance in Ethiopia
- Designed, manufactured and installed the most powerful Francis turbine and generator units in operation in Africa: 3 x 415 MW at Cahora Bassa in Mozambique
- Designed, manufactured and installed the largest Francis turbine runners in Brazil, Chile, China, India and Vietnam
- Designed, manufactured and installed low head Francis machines at Foz do Chapecco (50 m) and Teles Pires (52 m) both in Brazil
- Designed, manufactured and installed the tallest and heaviest ring gate at Ahai in China. This hydropower plant includes GE's patented precise fail-safe synchronization using hydraulic cylinders

CUSTOMER SUCCESS

Xiangjiaba *is one of the most important hydropower plants to come on line recently. Its turbine and generator units are the highest output hydro units ever produced (812 MW and 889 MVA respectively). Its generators are also the highest capacity generators ever built and the first with 23 kV air-cooled stator windings. The units were commissioned in record time for such large machines – at an average of one unit every two months.*

It is China's third highest capacity hydroelectric plant, the world's seventh highest capacity hydro plant and the world's ninth highest capacity plant of any fuel type. The 6,400 MW capacity Xiangjiaba hydro is a key part in China's West to East Electricity Transfer Program which supplies electricity for the growing needs of the eastern provinces.

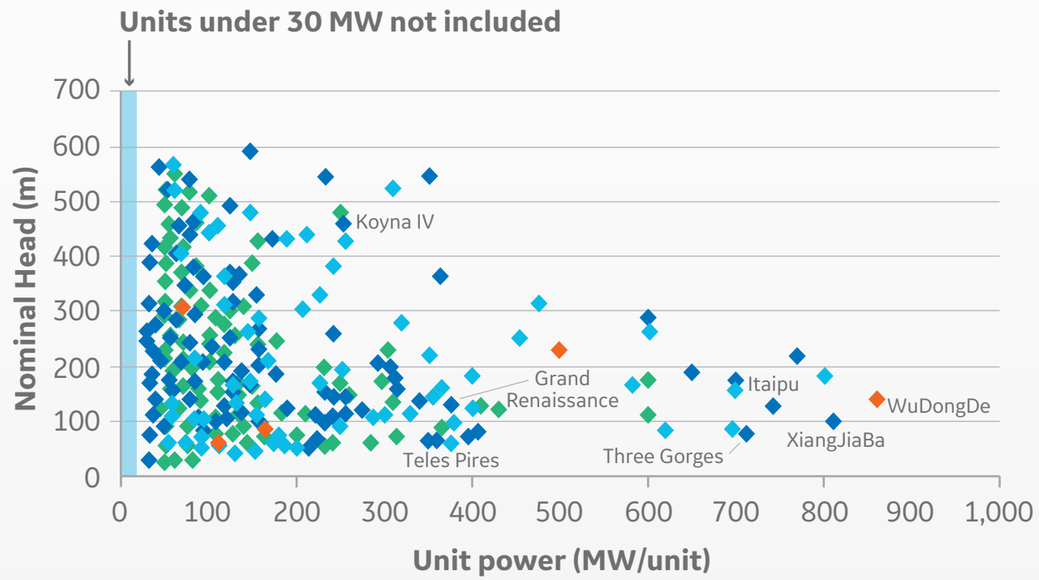
GE received an excellent supplier award from China Three Gorges Corporation for its work on Xiangjiaba and the plant received the "Project of the Year – Best Hydro Project" in 2013 from Power Engineering and Renewable Energy World Magazines.





The **world's most powerful**
hydro generators are GE

GE FRANCIS-DRIVEN UNIT EXPERIENCE



FRANCIS RANGE

Maximum Head	Unit Power	Runner Diameter	Speed
m	MW	m	Rpm
≥ 40 and ≤ 500	≤ 1000	≥ 1.5 and ≤ 10	≥ 50 and ≤ 750

PELTON-DRIVEN HYDROPOWER PLANTS

Proven solution for low investment per MW

Pelton hydropower plants are best suited for high head, low flow sites, typically from 200 to 1,900 m and outputs up to 500 MW. Such sites have high energy density and require a relatively low investment per MW. Pelton turbines are impulse turbines meaning the velocity of water jets directed at buckets on the runner by injectors turns the turbine. GE provides Pelton turbines with one to six injectors. Pelton hydropower plants use high speed vertical and horizontal generators.

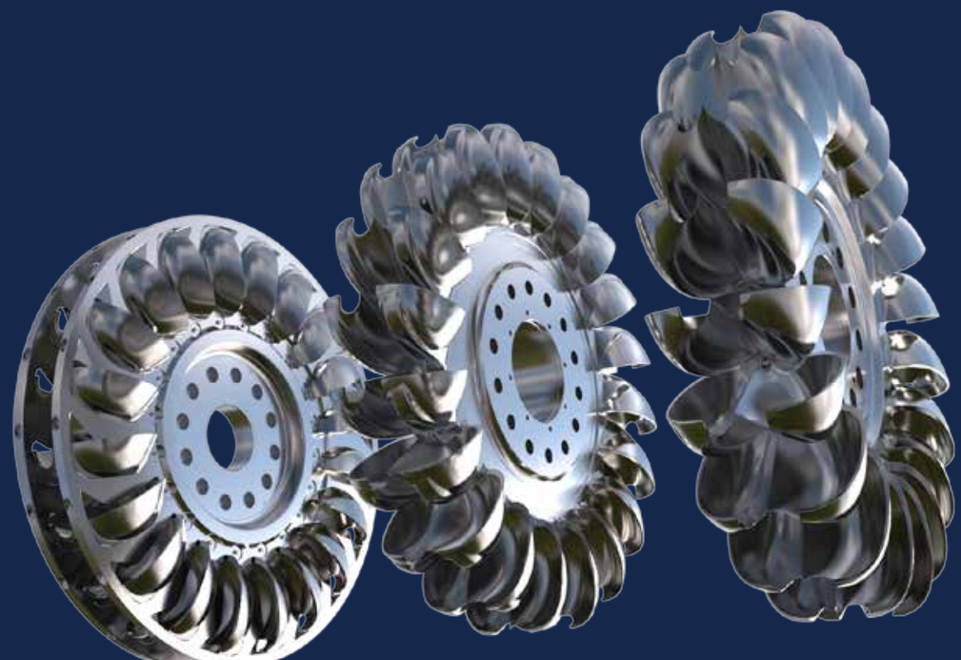
THE GE DIFFERENCE

Patented GE Hooped Pelton runners withstand mechanical stress better than forged or cast runners and reduce vibration by up to 90%. Less stress and less vibration mean outage-requiring runner inspections are divided by 2 or 3. Individual buckets can be replaced as needed instead of replacing the entire runner all at once. Hooped Pelton runners also eliminate the risk of flying buckets – a situation where the bucket breaks free from the hub as a result of too much mechanical stress over time. GE has Hooped Pelton references from 40 MW to 170 MW.

Hard coating: GE provides hard coating that protects turbine runners from silt damage the latter can dramatically alter the hydraulic profile of the turbine, lead to a noticeable loss of efficiency and even destroy the runner. Silt damage is common in the Himalayas, the Andes and the Alps where river water becomes laden with sediment during the monsoon season or during the spring snow and ice melt. GE has a test rig in Vadodara, India dedicated to testing coatings to protect against silt damage.

GE'S EXPERIENCE

- 466 unit/17.3 GW Pelton installed base (≥ 20 MW per unit)
- The leader in high speed vertical generators with 110 plants equipped.
- Proven high speed horizontal and vertical generator technology: 2159 units/72.7 GW (including Pelton, PSP, Medium/High head Francis)
- A leader in high head, high power (above 600 m and 100 MW)
- One of the industry's highest power density per pole: 33.2 MVA per pole for the 465 MVA, 429 rpm, 21 kV fully water cooled high speed vertical generator at Bieudron in Switzerland



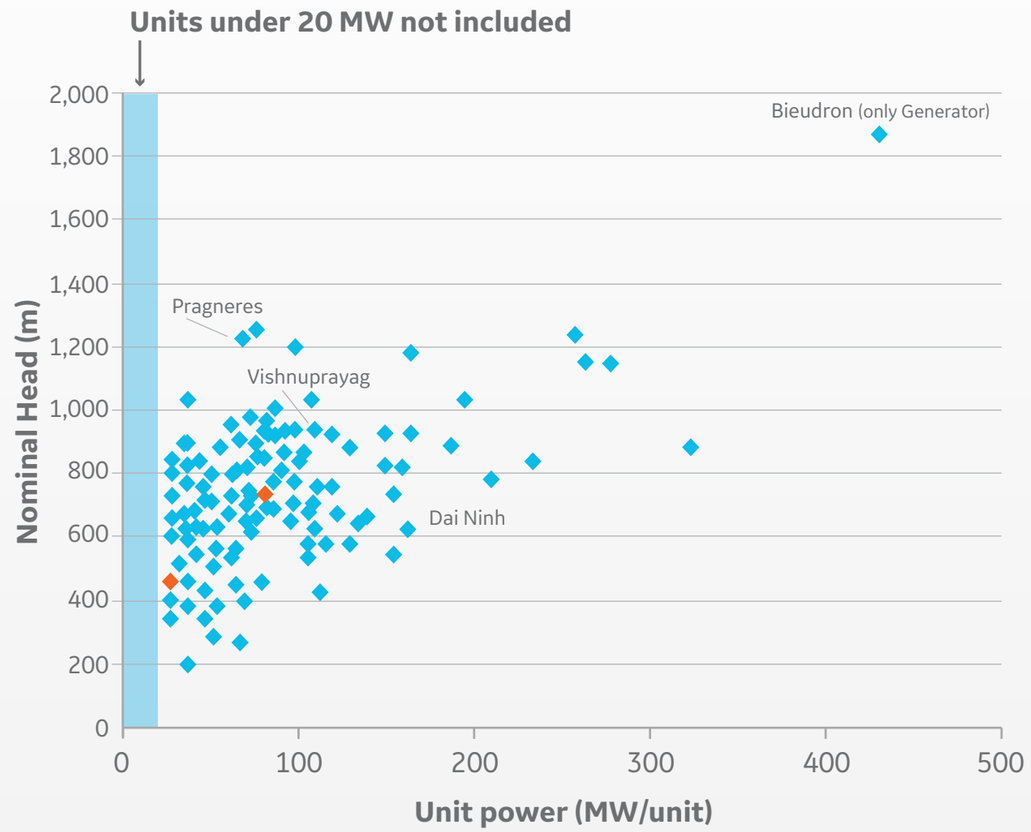
CUSTOMER SUCCESS

*GE provided the 4 x 103 MW turbine and generator units, as well as service contracts for runner maintenance for **Vishnuprayag** in India.*



GE is the leader in
high speed vertical generators

GE PELTON-DRIVEN UNIT EXPERIENCE



PELTON RANGE

Maximum Head	Unit Power	Runner Diameter	Speed
m	MW	m	Rpm
≥ 200 and ≤ 1,000	≤ 240	≥ 1.5 and ≤ 4.5	≥ 240 and ≤ 1,800

HYDROPOWER PLANT INTEGRATION

The broadest product and services scope of any supplier

Not only do we have water to wire capabilities but we provide the wire as well. Simply put, we offer turbines, generators, control systems, hydro-mechanical equipment, balance of plant and services offered as turnkey plants or individual components, as well as advanced electrical grid solutions to transmit power from the hydro power plant to the neighborhood sub-station. No other company can do all of this for customers.

As a turnkey supplier, GE has the experience, competence, complete product portfolio and full range of services to be the single point of contact for all hydropower plant operators' and owners' equipment and services needs.

GE provides a complete range of hydro-mechanical equipment including gates (radial, bulkhead, fixed wheel, sliding, mitre and bottom outlet), penstocks, trash racks and overhead and gantry cranes for all hydro applications needs. Hydro-mechanical equipment are critical elements to ensure the safety of the plant.

THE GE DIFFERENCE

Downstream gates reduce material and civil works costs compared to upstream safety gates. They also protect against runaway conditions and provide downstream isolation during unit de-watering. For units without control devices (fixed distributor), the downstream gate also initiates unit start-up, coupling, progressive loading and shutdown.

For balance of plant, GE provides energy evacuation equipment – key components linking the generator to the high voltage transmission line – as well as electrical and mechanical auxiliaries necessary for the efficient operation of hydropower plants.

Main Inlet Valves: GE has extensive experience with Main Inlet Valves, especially large valves. GE's valve experience includes Butterfly valves, most frequently used with Francis units and Spherical valves, most often used with Pelton and pumped storage units. GE's notable references include:

- **Tarbela hydropower plant in Pakistan**: 7.5 m Butterfly valve which is one of the largest diameter valves of this kind ever built.
- **Tehri variable speed pumped storage plant in India**: 4.3 m diameter Spherical valve.
- **Bissorte pumped storage plant in France and the Linthal variable speed pumped storage plant in Switzerland** have Spherical valves with some of the highest maximum pressures ever at 161 bars and 105 bars, respectively.

GE'S EXPERIENCE

- Key turnkey hydropower plant references include:
  - Bakun (4 x 300 MW) in Malaysia,
  - Son La (6 x 400 MW) in Vietnam
  - Foz do Chapeco (4 x 271 MW) in Brazil
  - Gilboa (2 x 150 MW pumped storage plant) in Israel is currently under construction and includes an 18-year operation and maintenance contract as well.
  - Tehri (4 x 250 MW pumped storage plant) in India is currently under construction
- Provided over 4,800 gates and more than 42,000 tons of penstocks
- Designed and manufactured the world's largest downstream gates: 190 square meters for Santo Antônio in Brazil
- Provided 20,000 tons of hydro-mechanical equipment and 20 radial gates for Santo Antônio
- Provided 6,000 tons of hydro-mechanical equipment for Devoll Möglice & Banja in Albania.



CUSTOMER SUCCESS

*GE provided full turnkey scope of supply to **Bujagali** (5 x 50 MW) in Uganda. This plant not only ended Uganda's chronic power shortage but it enabled it to sell electricity to neighboring Kenya and provides virtually half of the country's electricity generating capacity. GE designed, manufactured and installed the five Kaplan turbines and low speed vertical generators, control systems and balance of plant. GE supplied 2,800 tons of Hydro-mechanical equipment including two bottom radial outlet gates, on flap gate, 10 fixed wheel gates, stoplogs, trashracks, trashrack cleaning machines and cranes. The balance of plant included a 132 kV substation.*



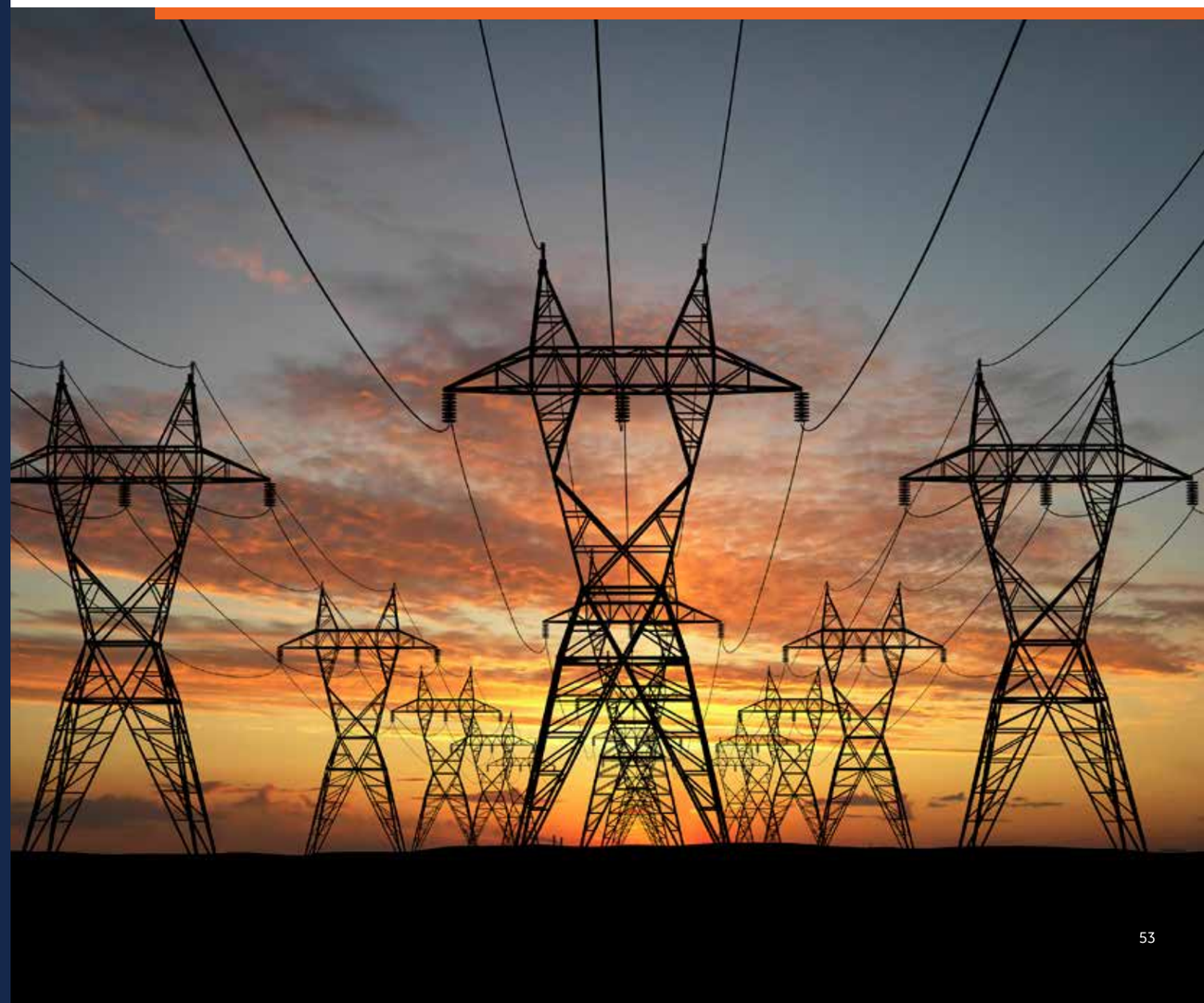
Grid **Support**

Ensuring reliable and stable electrical grids

Grid stability is affected by fluctuating power generation resulting from increasing intermittent renewable energies and more demand for management services for cross-border interconnections in deregulated markets (market coupling).

Pumped storage can deliver ancillary services to improve grid stability by providing grid frequency support in both directions, reactive power compensation, voltage support, black start capability and large-scale energy storage. The high inertia of rotating machines can also stabilize the grid in case of disturbances, which influences grid frequency.

Synchronous condensers generate reactive power, as well as voltage control for the grid, enabling low-inertia renewable energies, such as wind and solar to enter the grid and allowing their power to be transmitted over great distances.



PUMPED STORAGE PLANTS

The only mature, cost-effective GWh-scale energy storage

Intermittent renewable sources of energy such as wind and solar are driving the need for energy storage because, unfortunately, the wind isn't always blowing and the sun isn't always shining.

Essentially the world's largest batteries, pumped storage plants store energy using a system of two interconnected reservoirs with one at a higher elevation than the other. Water is pumped to the upper reservoir in times of surplus energy and, in times of excess demand, water from the upper reservoir is released, generating electricity as the water passes through reversible Francis turbines on its way to the lower reservoir. The process is then repeated with an overall cycle efficiency of 80%.

Pumped storage is the only mature, cost-effective GWh-scale energy storage system available today. For comparison one GWh of storage would require almost 42,000 lithium ion batteries of the type found in most electric cars[1].

In addition to their storage capabilities, pumped storage plants provide critical power regulation for the grid. With conventional fixed speed plants, power regulation is only possible while the plant is generating electricity but with the newer state-of-the-art variable speed technology, power regulation in specific ranges is possible while generating and while pumping, providing an extra level of flexibility for the grid.

Pumped storage plants have very fast black start capabilities – until 5 minutes, approximately 5 times faster than gas turbine – and they can re-establish the grid power after a blackout without an external energy supply.

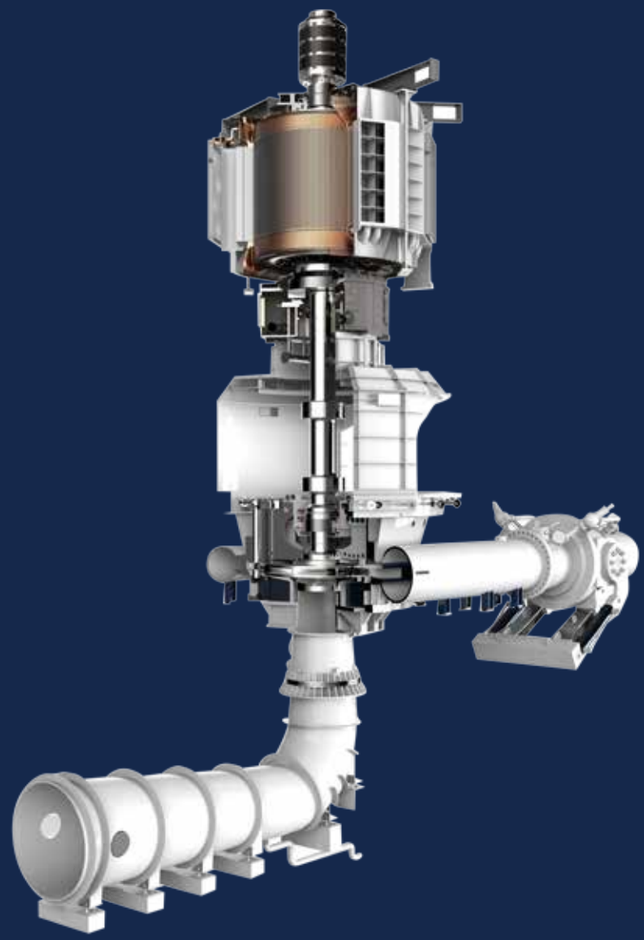
GE offers integrated solutions for fixed and variable speed pumped storage power plants. Its reversible Francis pump turbines provide high efficiency in both pump and turbine mode with no cavitation erosion over the entire operating range. Stable operation behavior and low vibration in pumping and generation modes also characterize GE's pump turbines.

GE also offers very efficient synchronous motor generators for fixed and variable speed plants and asynchronous motor generators for variable speed plants, as well as Medium Voltage converters and electrical BoP, including transformers, High Voltage switchgears and generator circuit breakers.

GE'S EXPERIENCE

- 314 unit/30 GW pumped storage installed base
- 260 motor generators supplied worldwide with efficiency levels measured as high as 98.5% with bearing losses and 99% without bearing losses
- Rated voltage up to 23 kV
- Electrical insulation system in service for over 50 years
- The largest number of asynchronous motor generators installed or under construction
- The only regulated double-stage reference in the industry: Yang Yang in South Korea

[1] eStorage Project



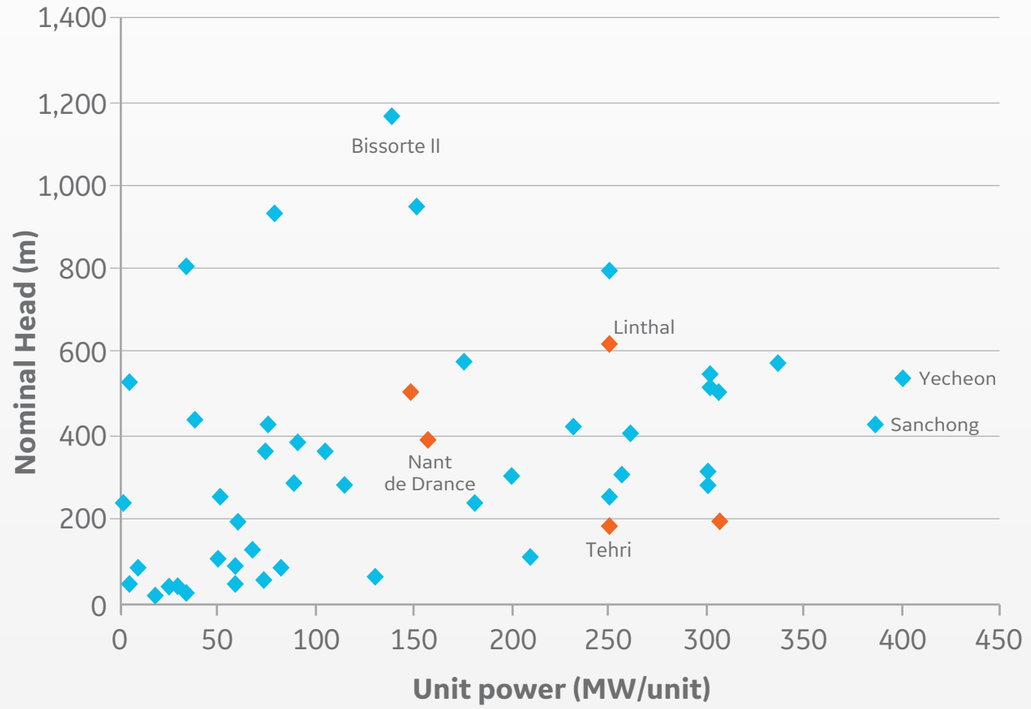
99% motor generator efficiency

CUSTOMER SUCCESS

Arguably the world's most technologically sophisticated pumped storage plant of any kind, ***Linthal*** *(4 x 250 MW) variable speed pumped storage plant in Switzerland began commissioning in 2015. One of the newest pumped storage plants, Linthal has the highest head single stage pump turbine, from 590 to 709 m and the highest speed variation, from 461 to 530 rpm of any pumped storage plant in the world.*



PUMPED STORAGE EXPERIENCE



◆ **Under Construction**

PSP RANGE

Maximum Head	Unit Power	Runner Diameter	Speed
m	MW	m	Rpm
≥ 50 and ≤ 750	–	≤ 6	≥ 100 and ≤ 750

SYNCHRONOUS CONDENSERS

Efficient operation and fast reactive power compensation to support the grid

Reactive power is needed to support and to control grid voltage. Rotating machines like synchronous condensers, but also generators and motor-generators, play an important role in providing reactive power and inertia to stabilize electrical grids and HVDC transmission lines.

The increasing penetration of renewable sources of energy in the grid is a driver for synchronous condensers because wind and solar photovoltaic energy decrease system inertia and hydro, wind and solar energy are often generated far from the demand center and are transported by HVDC systems which consume reactive power.

Power network inertia helps limit frequency fluctuations during power imbalances. Furthermore, synchronous condensers increase the short-circuit power in weak grids, which is very important in island grids.

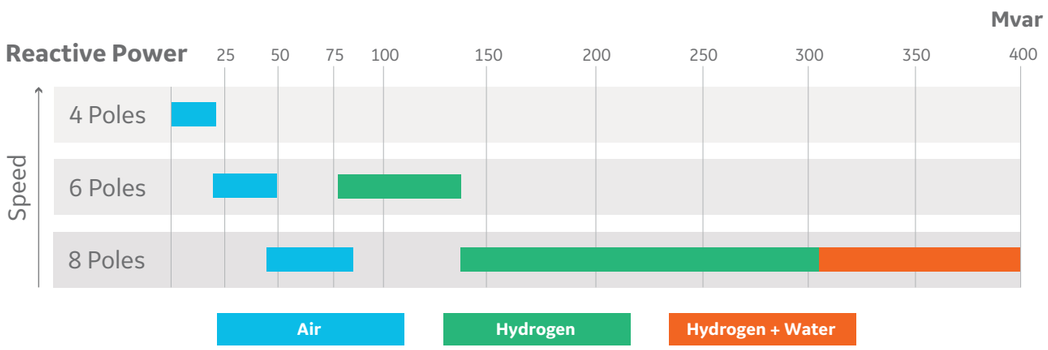
GE provides fully integrated synchronous condenser solutions based on salient pole generator designs. These synchronous condensers can be designed either as air or hydrogen cooled machines, with low losses from 1.0 to 1.5% depending on the cooling system.

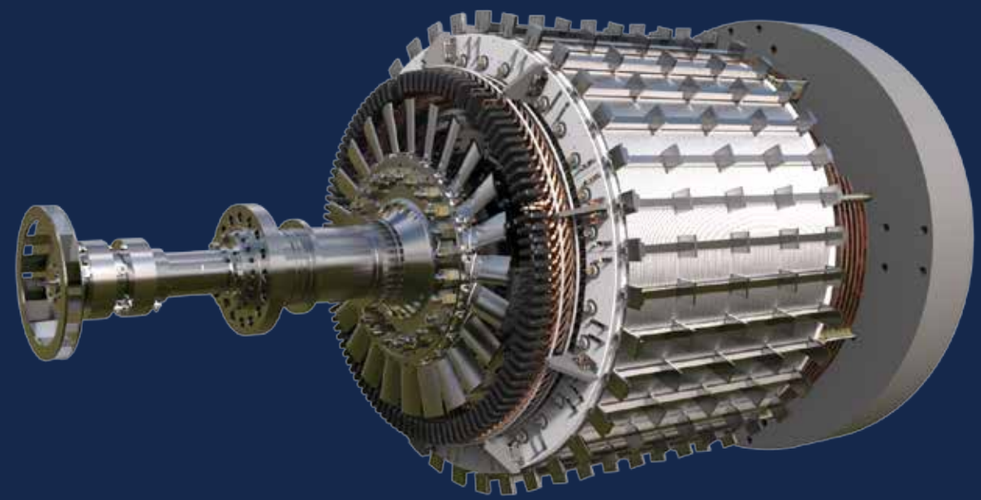
GE'S EXPERIENCE

- 40 synchronous condensers installed globally
- Rated voltage up to 21 kV, 50 and 60Hz
- References up to 326 Mvar and inertia up to 8 MWs/MVA
- Inertia increase with flywheels

Cooling Systems

Application range of 4, 6, 8 pole designs





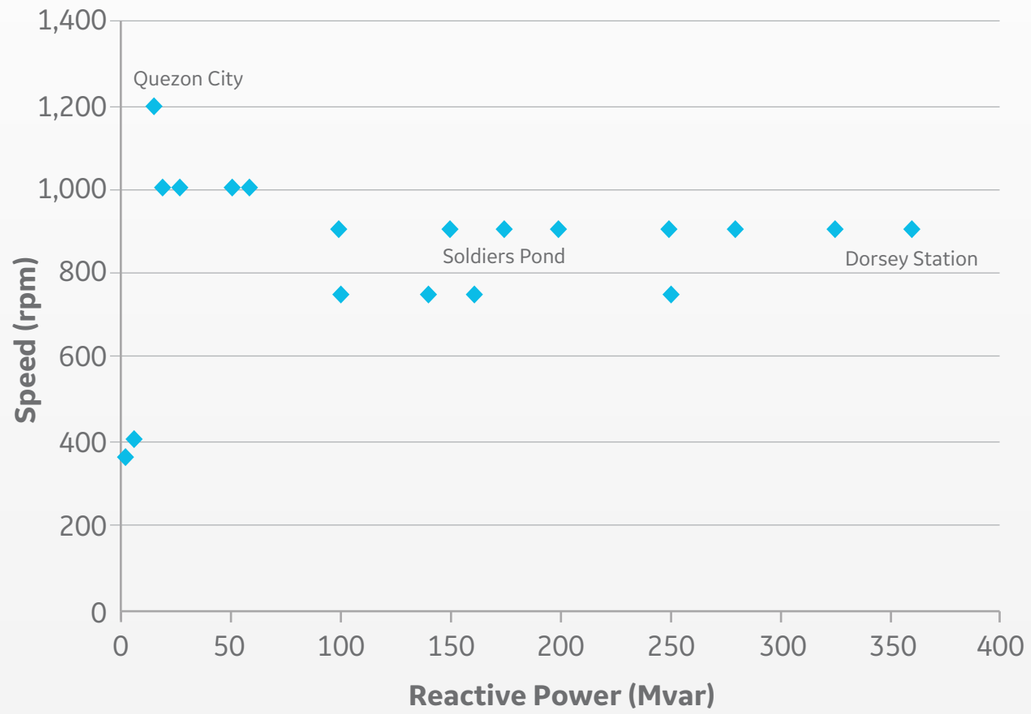
Only **1%** losses

CUSTOMER SUCCESS

***Soldiers Pond** in Canada (3 x 175 Mvar). These synchronous condensers provide reactive power for the HVDC transmission line from the Muskrat Falls hydropower plant in Labrador to the converter station at Soldiers Pond in Newfoundland – a distance of 1,100 km*



GE SYNCHRONOUS CONDENSERS EXPERIENCE



SYNCHRONOUS CONDENSERS

Unit Power	Speed
MW	rpm
≤ 375 Mvar	≤ 1,800

Small Hydro Generation

Cost-effective reliability

Hydro is likely the most scalable of any power generation technology with one hydro turbine and generator unit capable of producing less than one MW to more than 800 MW. GE's small hydro range covers plants equipped with units ranging from 5 to 30 MW (60 MW for Francis). For these customers, we have developed a **standardized range of products** to deliver the highest level of reliability/availability in the shortest lead time so they can start generating electricity and revenue quickly. Our solution optimizes global investment with savings in civil works, as well as in operation and maintenance. GE's equipment has standardized interfaces with civil works, helping to ensure the project development timeline stays on track.

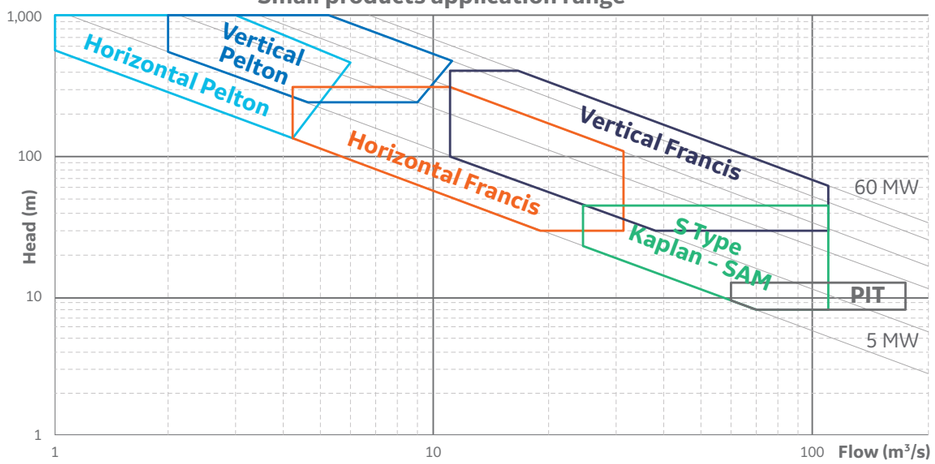
One significant difference from a large hydro project is that the engineering team will use an existing hydraulic design from our vast catalogue of hydraulic profiles. Our unparalleled experience with some of the world's most famous large hydro projects has given us a very extensive portfolio of profiles to leverage. This **minimizes project lead time and cost** while providing the highest level of performance for customers.

GE provides **turnkey solutions** (including turbine, generator, electrical and mechanical balance of plant, control system and hydro-mechanical equipment) for low and medium head hydropower plants with specific products such as PIT, SAM, horizontal Francis or vertical Francis turbine and generator units.

No matter where in the world our customers' small hydropower plants are located, they can benefit from **GE's expert after sales service** thanks to the geographical coverage of our service teams. For even greater peace of mind, GE offers assistance agreements or operation and maintenance contracts specifically adapted to the needs of small hydro customers.

GE's digital hydro plant offers small hydro customers big data analytics with cloud data storage based on Predix, as well as a remote connections solution for control and monitoring of assets. Cybersecurity is fully embedded in all our control and digital solutions.

Small products application range



KAPLAN PIT

Cost-effective installation and maintenance

Pit is the adaptation of bulb turbines for small hydropower applications for heads up to 20 m and outputs up to 25 MW. Being a Kaplan type turbine, Pit units are double regulated, making them suitable for a wide range of discharge.

GE has developed Pit units with a direct coupling between the turbine and generators so a gearbox isn't needed. This development reduces the size of the generator and noise in the plant while maximizing reliability. It also provides for an open pit above the turbine for faster installation and easier access for maintenance.

GE EXPERIENCE:

• 21 unit/176 MW Pit small hydro installed base

KAPLAN S-ELBOW UPSTREAM 'SAM'

Minimizing capital expense and lead time for low head applications

GE developed the S-type turbines SAM as a horizontal small hydro solution for heads up to 40 m and a power output as high as 40 MW. GE is the only vendor offering a horizontal solution for outputs as high as 40 MW for this type of turbine. As the configuration offers significant benefits in terms of investment cost and maintenance & operation, this solution has rapidly become a market standard.

SAM is GE's S-type Kaplan with upstream elbow is the latest evolution of S-type small hydropower solutions featuring a horizontal axis, straight draft tube and double regulated turbine directly coupled to the generator.

The key benefits of using a SAM solution over a vertical solution are the reduced lead time (up to 6 months on commissioning date), reduced civil works costs due to reduced excavation requirements, standardized interfaces defined early in the project and optimized operation and maintenance because of easier access to the machine.

THE GE DIFFERENCE

• Faster assembly so customers can begin selling electricity earlier

• Easier access to the machine for facilitated maintainability

• Smaller box-type civil works reduce excavation and reduce civil works costs

GE'S EXPERIENCE

• 53 unit/438 MW SAM installed base

The world's **most powerful SAM units** are GE



Kaplan S-Elbow Upstream 'SAM'

CUSTOMER SUCCESS

*For **Tepekisla** (2 x 35 MW) SAM small hydropower plant in Turkey, GE proposed SAM instead of a vertical Kaplan machine which enabled the customer to begin commercial operation six months earlier than planned and reduce the cost of the civil works. Tepekisla has the most powerful SAM units in operation in the world.*



HORIZONTAL FRANCIS

Creating value in challenging conditions

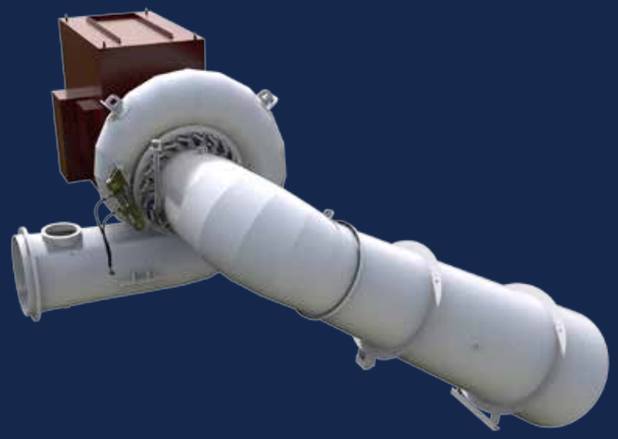
Horizontal Francis small hydropower plants are suitable for up to 350 m heads and output up to 30 MW. Compared to the vertical configuration used for larger units, horizontal Francis units reduce civil works, lead time and turbine-generator unit submergence. They also provide a simplified installation and easier access to the machine for maintenance. Our range of products has been designed to deliver the highest level of performance while operating over a wide flow variation to accommodate the seasonality of the river.

THE GE DIFFERENCE

Spring connection between the operating ring and the wicket gates that protects the wicket gates in case an object is blocked between the wicket gates. Once the object is removed from the distributor, the wicket gates realign automatically without manual intervention.

GE'S EXPERIENCE

- 196 unit/524 MW horizontal Francis small hydro installed base



CUSTOMER SUCCESS

*GE designed, manufactured and installed (6 x 40 MW) horizontal Francis turbine and generator units for **Devoll** in Albania, increasing the electricity production in Albania by about 17%.*

VERTICAL FRANCIS

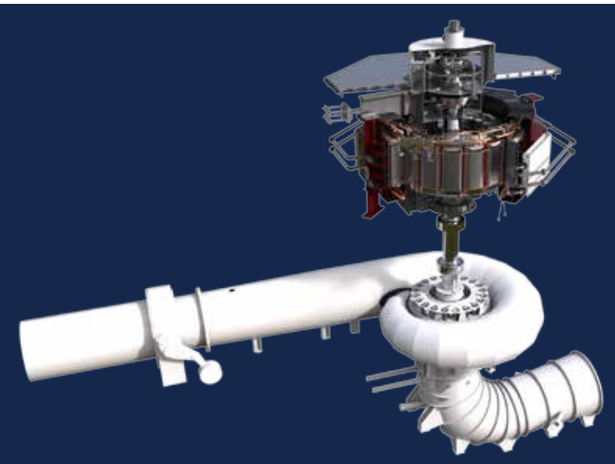
High output applications with standardized equipment

Vertical Francis small hydropower plants cover sites with a range of heads from 30 to 420 m and can generate outputs from 10 to 60 MW. Francis turbines are the most widely used hydro turbine and GE is a world leader in this technology having achieved the world highest level of performance. GE's small hydro customers benefit from years of extensive R&D on Francis turbines to have state-of-the-art hydraulic profiles.

As for all the standardized product range, the unit reliability is the primary objective of our engineering team. For horizontal Francis for instance we generally use our hydrostatic water bearing as turbine bearing. By combining the turbine bearing and the shaft seals this reduces maintenance cost while ensuring the best environmental performance by suppressing the use of oil close to the river.

GE'S EXPERIENCE

- 99 unit/941 MW vertical Francis small hydro installed base
- Only vendor with outputs as high as 60 MW with a standardized solution



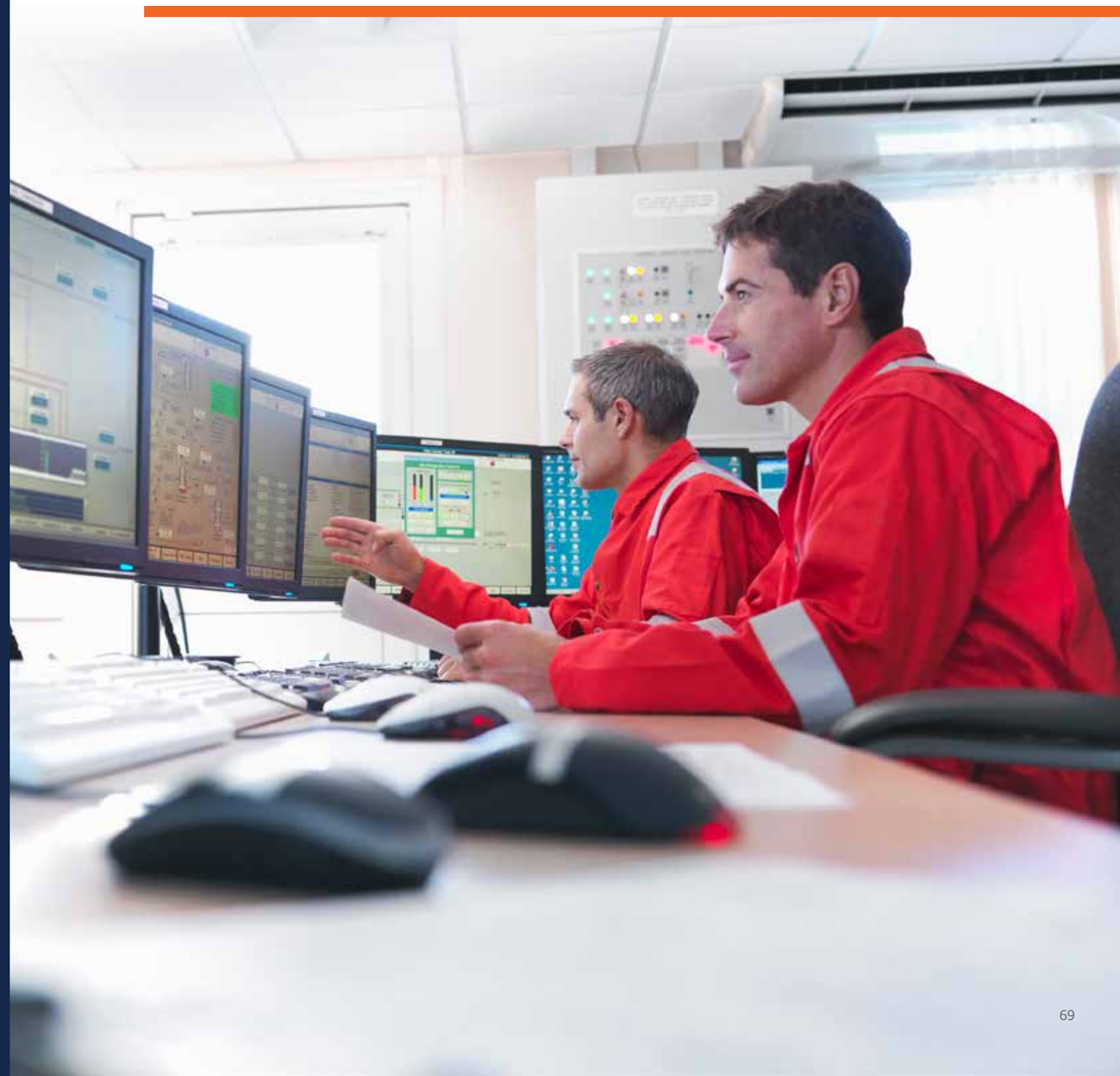
CUSTOMER SUCCESS

*GE designed, manufactured and installed (1 x 45 MW) vertical Francis turbine and generator unit for the **Iveland II** hydropower plant extension in Norway. This hydropower plant includes one of the largest hydrostatic water guide bearings in the Nordic region and this bearing technology helps to ensure the plant conforms to stringent environmental standards. The equipment for the Iveland hydropower plant is in an underground cavern which required the GE team to design and plan the installation of the equipment to millimeter precision.*

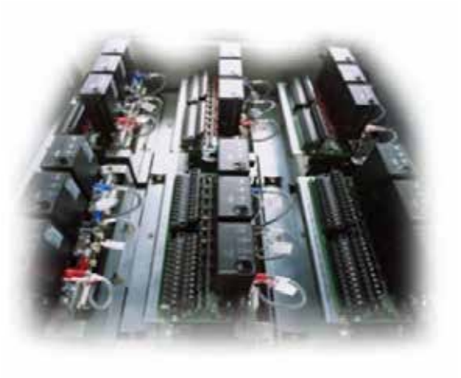
Control Solutions

The nervous system of a hydropower plant

Your ability to understand, control, protect and monitor your hydropower plant is necessary to obtain all the productivity and reliability possible from your assets. Our tightly integrated distributed control solutions provide total plant control at a single level, combining the turbine, generator, protection, monitoring and balance-of-plant equipment control in a single distributed architecture to deliver robust process control with seamless connectivity and automated real-time information management.



MARK VIe*



As a global leader in automation, control and industrial digital, the Mark VIe series of controllers has earned a reputation for superior reliability based on implementations in thousands of power generation and infrastructure systems globally. GE provides cyber security management and digital capability as an inherent feature of the Mark VIe control family. It assists with the implementation of an effective security policy to ensure system confidentiality, integrity, availability, running edge and cloud analytics and providing real-time change monitoring and audit capabilities.

GE's CIMPLICITY Software provides user friendly HMI screens and intuitive navigation among all components of the power plant, with each machine interface having access to all plant equipment, enabling full functionality from any point in the plant. The plant-wide Historian provides time coherent data collection and analysis, fully integrating the turbine, generator, and BOP equipment. Additionally, GE's robust ControlST serves as a single software configuration and diagnostic tool on all DCS-controlled equipment, ensuring smart integration and providing powerful plant performance analysis capabilities for high maintenance efficiency. All GE's control solutions are covered by a comprehensive set of life cycle management services that includes training, maintenance, spare parts, upgrade and rehabilitation.

THE GE DIFFERENCE

- Connected: 100% Ethernet at all levels
- Flexible: Distributed or centralized I/O
- Reliable: Simplex and dual redundant operation
- High Performance: Local process on each module, computing power grows as system expands
- Rugged: Hardware rated up to 65°C
- Secure: Achilles Level 1 certification
- Digital capable: native connectivity to Predix Cloud, Predix edge analytics in controller
- Life cycle: 20 years

EXCITATION SYSTEM



The EX2100e Excitation Control is GE's advanced platform for generator excitation systems. The platform supports static, compound, rotating AC and DC, and brushless excitation systems. Because of the wide variety of hydro turbine-generator excitation systems, the EX2100e family is designed to support most generator control configurations. The EX2100e controls are complemented with a set of scalable power converters (35A and 120A IGBT, thyristor bridges) and Ethernet based protocols matching excitation system capabilities and initial cost to unit requirements. EX2100e systems can be configured with available redundant controls, power converters, and cooling fans to allow owners to further tailor the system to meet both control and budgetary requirements. GE digital exciters have been successfully applied to specialty hydro turbine-generators including pumped storage with a range of starting methodologies with reduced voltage, across-the-line and back-to-back configurations. The EX2100e control also provides native support of advance Reactive Differential Compensation software, PSS and electric braking. The EX2100e uses the same Mark VIe ControlST engineering software ensuring seamless integration and can also be integrated with GE's cyber security solution.

GE'S EXPERIENCE

- Over 2,000 EX2100 units in hydro, gas and steam power plants
- Over 6,000 excitation systems deployed in the last 50 years in more than 70 countries

TURBINE SPEED GOVERNOR



The governing system is an essential part of the overall plant control system. It provides the turbine with the feedback mechanism to control its speed under all circumstances. By regulating the flow of water passing through the turbine, the governor adjusts the power output being sent to the grid. The speed governor controls the turbine start-up and shutdown sequences and synchronization of the turbine with the grid. The governing system is comprised of electronic and oleo-hydraulic parts including the turbine speed load governor controller and the oil pressure unit. Based on Mark VIe hardware, GE Hydro's governor is designed for use on all types of hydro turbines, with an unlimited power range, for both new and refurbished power plants. For oleo hydraulics, GE has developed a range of single-stage, double-stage and flanged actuators that control all types of turbines regardless of the oil flow required to move the servomotors (from a few liters to several cubic meters per minute).

THE GE DIFFERENCE

- Modular platform
- Native cybersecurity capabilities
- Application software with advanced functions for virtually all process requirements including:
  - Precise rotation speed regulation for synchronization with the grid
  - Power/load adjustment
  - Frequency regulation
  - Integration of 2D and 3D laws
  - Jet dispatcher for Pelton turbines
  - On-cam operation for Kaplan and Bulb turbines
  - Individual wicket gate control for Pump Turbines

Installed **Base**

Total hydropower plant optimization solutions

The global hydropower installed base is a massive 1,212 GW (including pumped storage). And, of this, about 30% has been in service for over 40 years. It is clear that we must take care of this precious renewable energy asset.

GE provides the full scope of support for the hydropower-installed base—for plants anywhere in the world and for equipment from any vendor. This includes:

- Service agreements: contracts tailored to your operation and maintenance strategy
- Training to update your team and keep them at the top of their game
- Parts: a flexible service that provides genuine parts when and where you need them
- Monitoring & diagnosis empowers you with accurate asset information that helps you make informed decisions
- Maintenance & repairs keep your plant running at optimum performance
- Catalogue retrofit: a portfolio of standardized upgrade solutions can be rapidly implemented during one of your planned outages
- Retrofits provide your plant with a second life, making it better than new

SERVICE AGREEMENTS

Focus on your core compentencies while GE manages your power plant needs

Utilities and independent power producers are all looking to maximize their asset return on investment by optimizing operations and managing risk. Fully-tailored contracts, GE service agreements are designed to maximize maintenance strategies balancing availability, reliability, performance and cost.

Aligning with operator's business goals, GE service agreement portfolio runs from framework agreements to performance oriented contracts with flexible guarantees, incentives and risk sharing.

- Frame agreement: agreed time & material. Negotiated rate and reactivity. No extra time wasted in administrative constraints.
- PRIME Assistance agreement: permanent service support and immediate response. Dedicated support team.
- Maintenance contract: operation & maintenance supervision. Technical assistance.
- O&M: full operation and full maintenance program. Fee-based contract with risk sharing mechanism.

Aligning with operator's maintenance and operation needs, it covers all equipment – Turbine & Governor, Generator & Excitation, Control system & BOP, Hydro-mechanical & Lifting Equipment, GE and other OEMs, and all services – technical support, emergency services, maintenance & repairs, diagnosis programs, digital, parts.

THE GE DIFFERENCE

- **O&M: outsourcing risks and responsibilities**
  - As owners are primarily interested in the commercial performance of their plant, O&M contracts contain performance goals governed by guarantees and incentives. Using this partnership approach, GE contracts deliver measured results aligned with client business objectives.
- **Focus on flexible programs: Prime Assistance Agreement**
  - 'Pick & choose' approach, customers set up their own ideal program from a wide range of solutions
  - Clear & simple mechanism with clear benefits based on strong commitment from GE
  - Simplification: one-time shot administrative work, dedicated support team, one single point of contact

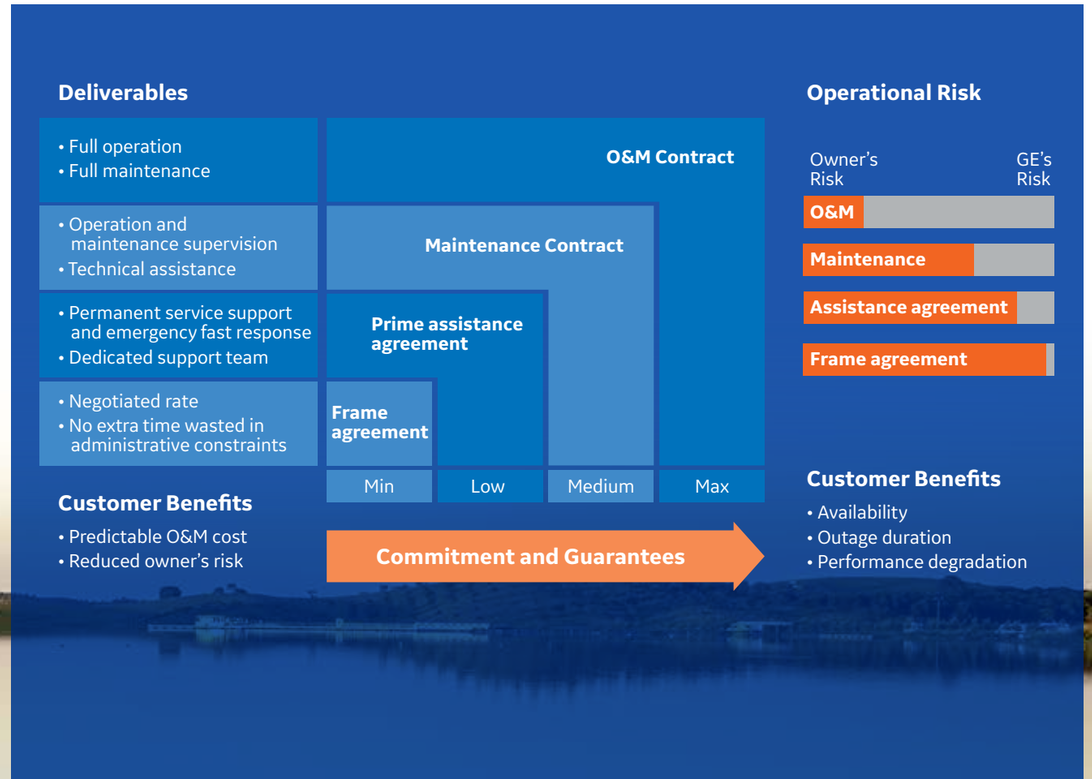
KEY BENEFITS

- Increase revenues: reduce unplanned downtime (permanent service support and emergency fast response) and increase cost predictability (cost-predictive servicing without endangering product quality & reliability)
- Boost reliability and availability: maximize maintenance strategies (preventive, digital) and optimize your staff knowledge and reactivity (regular on-site cooperation with OEM team & custom-made trainings offering)
- Meet plant performance: benefit from the latest technologies, including GE advanced digital solutions

GE EXPERIENCE

GE has more than 10 years of experience in O&M.

- **Beni Haroun, Algeria**: O&M since 2004 for pump storage plant suppling drinking water for more than 6 million people and irrigation for agriculture
  - Scope: all operation and maintenance
  - Engagement: operation regime (# hours/day; #days/year) + availability rate
- **HEPP, Turkey – Prime Assistance agreement**
  Emergency service on excitation system: contact and remote support to plant in 24 hours and mobilization to site in 72 hours
- **Brazil – O&M contracts since 2002 on seven power plants**, Da Ilha, Jararaca, Criúva, Palanquinho, Autódromo,São Paulo and Boa Fé
  In 2014, O&M contract renewal for five additional years based on customer satisfaction and the high level of availability reached during this contract.



TRAINING

Turn knowledge into power

GE provides a comprehensive catalogue of training sessions that will help operators update the knowledge of their staff, maximize the efficiency of their equipment aiming at reducing the costly mistakes that can jeopardize their plant.

FOCUSING ON INCREASING STAFF FLEXIBILITY

The courses are designed to help maintain or improve the ability of a customer's workforce: overview of equipment systems, conduct of maintenance programs using best practices, identification and analysis of operation & maintenance issues (troubleshooting).

DEDICATED TO DEVELOPING ADAPTIVE PERFORMANCE

GE courses are designed by experts who understand that higher adaptability is key within an organization.

By mixing theoretical technology and live scenarios, operator's staff will be ready and proactive for appropriate responses to complex situations.

By developing new skills, they will be better prepared when introducing new technologies and methods.

FLEXIBLE AND EFFICIENT PROGRAMS

GE has a complete offer, running from project preparation to plant commissioning. Plant owners can choose from a variety of courses to suit a specific team's needs.

- Standard or customized programs
- Correct balance between theory and practical training
- Real-life examples shared by senior engineers, experts in their field
- Worldwide wherever you are: On site or in a GE training center



PARTS

Secure production availability with high quality certified spare parts

Reliable plant operations depend on access to a flexible parts service at a competitive price. Supporting customers anytime anywhere, our local Hydro Service Centers are committed to deliver timely genuine parts exactly when and where you need them. GE offers genuine spare parts support, ensuring availability of components in the shortest possible lead time. No more worries about interchangeability, compatibility and/or quality of spare parts. No more unsafe forced outages.

- Increase availability by having replacement parts readily available, keeping your outages shorter
- Enhance reliability with OEM critical parts specifically engineered to work with your assets
- Elevate your performance while reducing maintenance costs with more durable and efficient components: benefit from genuine parts ensuring compatibility & quality
- Reduce cost by minimizing tied-up capital, reducing storage, inventory areas and delivery cycle

THE GE DIFFERENCE

- Full coverage: both fleet and single plant (safety stock management), for all equipment (Turbine, Generator, Controls & BoP, HME) and all over the world (presence in 70 countries).
- 'Speedy' delivery: service contracts, such as Prime Assistance Agreement, will guarantee delivery of standard parts in 48h.
- Large experience and reconditioning expertise due to our large installed base (25% of the world's hydro installed base is equipped with GE technology).

CUSTOMER SUCCESS

Following the failure of a governing valve spring on a Turkish hydro power plant, GE delivered an identical part within only a week of the incident. This saved the plant weeks of electrical production that would otherwise have been jeopardized.



MONITORING & DIAGNOSTICS

Connecting people & machines for smarter operations

GE's monitoring and diagnostics portfolio empowers customers with accurate information that leads to better decisions. With proactive and increased asset information, customers can improve reliability, reduce maintenance expenses, proactively manage performance and lead-time or reduce capital expenditures

Our comprehensive portfolio runs from continuous monitoring, detection of impending issues, accurate diagnostics, root cause analysis to recommendations of mitigation actions to help maximize critical asset operational uptime.

Using Robust methodologies and advanced tools (3D Finite Element Calculation & Analysis – FKM or ASME, Reverse engineering – ProE, PDMS, 3D visualization with HydroVisu), the GE diagnosis program is designed to fit customers' production requirements: offline and online systems, short outage approach solutions, applicable for a quick response in case of emergency troubleshooting or preventive periodical inspection, for unit, plant or fleet.

- Diagnosis: determine the status of key components with a short outage approach
- Digital condition monitoring: move from reactive to predictive maintenance and get a real time understanding of your machine behavior
- Condition Assessment & Audit: assess the state of the whole plant or of one of its components
- Material Fatigue Management: get a comprehensive analysis to estimate the remaining lifetime of generators

THE GE DIFFERENCE

Hydro Edge Analytics

GE developed the innovative Hydro Edge Analytics, to detect incipient failures and monitor in real time the degradation evolution of critical equipment in a hydro plant.

- Avoid unplanned downtime: detect incipient failures and plan needed corrective actions at the right time
- Improve operations: understand exact equipment status and consequences on the assets so operation can be adjusted accordingly and recommend operation & maintenance actions

Material Fatigue Management

Recognized expertise with strong experience & more than 100 assessments conducted worldwide, GE is a main contributor to international conferences (HVI, Hydro, CIGRE) & working groups (IEEE, CEATI).

GE Remaining Lifetime Assessment will evaluate the residual lifetime of generators by indicating the number of cycles before crack initiation. Based on advanced calculation, the methodology allows to prevent failure & recommend mitigation actions to avoid catastrophic failure with long term forced outage. Comprehensive solution, it goes from fleet assessment, through risk identifications to recommendations and repairs (temporary or permanent).

GE EXPERIENCE

Material fatigue assessment:

+100 assessments

WidiPro®, Generator Winding Diagnosis Program:

6,000 assessments over 2,000 generators (all OEMs)



MAINTENANCE & REPAIR

Keep your plant operating at optimum performance

A comprehensive asset management portfolio, the GE PlantLife® platform aims at making plants more competitive, maintaining plant availability, keeping plants running at optimum efficiency, and increasing plant performance throughout their lifecycle. Covering all Installed Base operation and maintenance requirements and challenges, from commissioning to end of lifetime, GE offers time-saving and value added repairs, replacements and outage support services for all equipment, helping to increase availability, optimize performance, and save costs before, during, and after outages.

With 70 sites all over the world, GE's global Field Service Network supports customers with strong technology and engineering capabilities with quick access to experts. Whether it is routine maintenance, component repair and replacement or major maintenance, our Field Service teams tailors specific maintenance programs with preventive & pro-active mitigation plans for components or the entire plant, always keeping in mind interfaces and interaction within the unit and plant.

THE GE DIFFERENCE

- More than 100 years of experience with a large technology heritage leading to a strong technology expertise, strong integration & interfacing experience: capability to integrate all equipment regardless of original technology and unit configuration
- Lifetime management: covering all types of equipment, all types of services with a deep understanding of the full plant lifecycle & economics to optimize the full asset
- Proximity with a quick access to experts: 70 sites all over the world
- Outage time compression with standardized field machining operations

70 field service sites around the world

GE EXPERIENCE

- **Emergency services, China: corona discharge on a stator bar – 4 days**
  The GE Field Service team arrived on site one day after the customer's call and provided a first assessment, conducted a root-cause analysis, and proposed a repair solution. Repair work was completed by winders and supervisors only four days after the initial Corona discharge detection.
- **Generator general overhaul** (Vertical Motor-Generator, 165 MVA) + Supply of 70 stator bars + Stator winding repair, Anapo, Italy
- **Engineering support for turbine overhaul, Prudencia and Lorena, Panama**
  Specialist with extensive on-site experience arrived on site within 3 days of the customer's call. Effective support that kept downtime to a minimum.
- **Emergency services for stator ground fault, Churchill Falls, Labrador, Canada – 2 weeks**
  As a result of a stator ground fault, the customer requested immediate support. The next day, a GE Field Service team arrived on site to investigate, troubleshoot, and propose a repair solution. A bar replacement was conducted with winders and supervisors. Working two 12-hour shifts, seven days a week, in close collaboration with the client team, the unit was back in operation in two weeks.

CATALOG RETROFIT

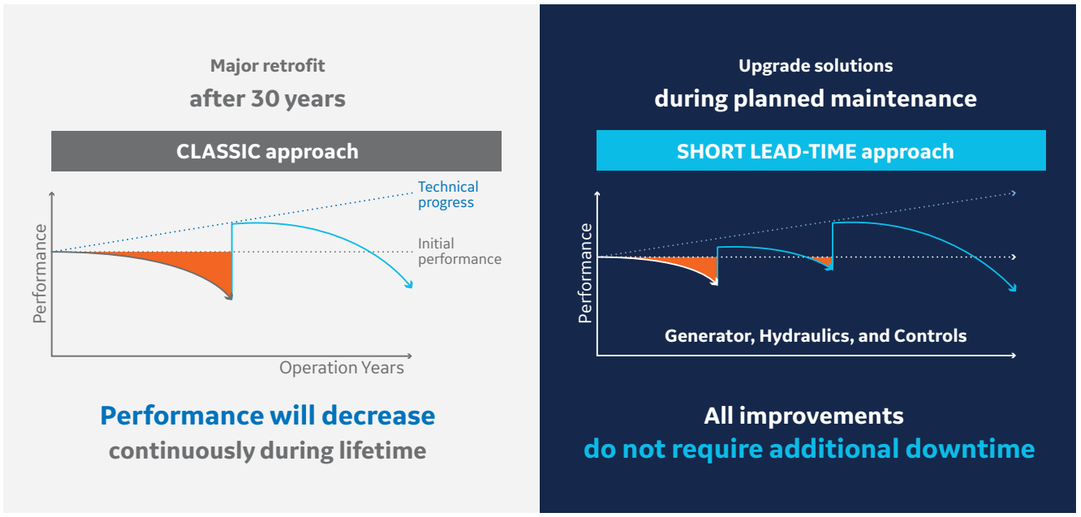
Upgrade your plant during planned maintenance

Today, main hydropower plant components have a lifetime in the range of 30 – 50 years depending on the operating mode. However, due to cost and loss of production, operators may somewhat delay opportunities to quickly adapt the installed base to the new challenging environment they are facing.

Today, thanks to technology improvements—computational fluid dynamics design, advanced manufacturing processes and new materials—it is possible to provide upgrade solutions with fast implementation. These improvements match major planned maintenance schedules and require no additional downtime, thus allowing operators to faster adapt their units to changing market conditions.

Covering the entire asset, generator, hydraulics and controls, GE has developed a portfolio of standardized upgrade solutions that can be implemented during planned maintenance, allowing execution and commissioning in one month or less.

This short lead-time approach opens new opportunities in asset management: no need to wait for a rehabilitation to improve efficiency.



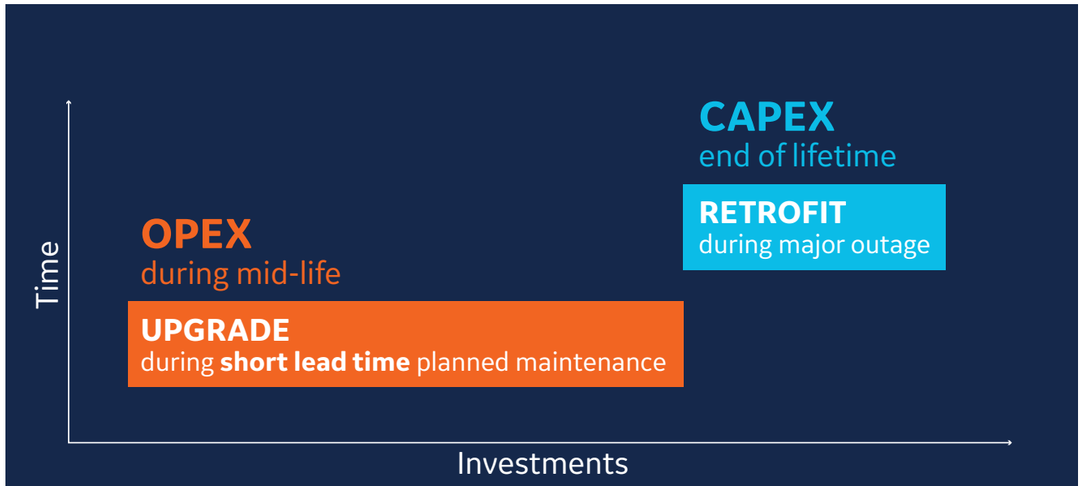
Installed and commissioned during main maintenance or overhaul period, in parallel to usual maintenance works, these standardized upgrade solutions improve performance and:

- Increase reliability, availability and operating performance (time response)
- Reduce total cost of electricity with less downtime and lower and more effective maintenance
- Respond to environmental aspects

EXAMPLES	Increase Performance	Reduce Maintenance	Adapt to New Operating Patterns	Lower Environmental Footprint
Composite Stay Vane Extensions	Hydraulic efficiency up to 2%			
Plug & Play Speed Governor		Consumables and spares cost reduction Diagnostic tool for monitoring and troubleshooting	Increase response time to the grid Engineering simulation for best implementation under realistic conditions	
Ventilation Losses	Generator efficiency up to 0.3%			
Plug & Play Hydrostatic Water Bearing		No shaft seal No spare oil to store and no oil monitoring		No more pollution with oil
Brushless Excitation		Stator and rotor winding cleaning reduction Consumables and spares cost reduction		No more pollution with carbon dust
Speed Governor: FCAS			Faster response after wide frequency variation	
Hydro-Optic™ Water Treatment	Better cooling	Increase intervals between cleaning cycles		Chemical free
Biodegradable Oil				Biodegradable and low toxicity

THE GE DIFFERENCE

- GE is the only company offering upgrade solutions during planned maintenance
- Innovation that focuses on short implementation solutions unique to GE: composite stay vane extension, Plug & Play hydrostatic water Bearing (in two-part bolted shell), governing system frequency control ancillary system (FCAS), ventilation loss optimization, brushless excitation, Plug & Play speed governor
- Tangible performance increase with short return on investment
- Stand-alone modernization solutions with cost-effective OPEX budget: operating expenses are better suited for operators anticipating rapid growth or changes in technology requirements. Thanks to GE's cost-effective standardization approach, most of the modernization solutions require OPEX budget, thus avoiding the CAPEX budget.



GE EXPERIENCE

Ventilation losses optimization: 1 month

- 58% reduction of ventilation losses for the refurbished generator in Edling (Austria)
- 45% for refurbished generator in Nendaz U6 (Switzerland)
- 63% reduction of ventilation losses, +0,3% efficiency increase for Fionnay generator (Switzerland)

Plug & Play Hydrostatic Water Bearing: 2 weeks
Innovation: Stainless steel sleeve in two-part bolted shell, complete construction before machine outage, easy maintenance: no disassembly of the shaftline

West Kiewa, Australia, 2011, refurbishment project aiming at extending the lifetime of their 4 Vertical Francis machines (15 MW each), improving performance and reducing maintenance needs.



Stainless steel sleeve in 2 bolted part shell

Plug & Play Speed Governor: 2 weeks
A standardized digital speed governor at minimized time and minimized price: reduced lead-time between RFQ & Manufacturing/Programming, 2 day installation/2 week outage time, reduced specification drafting, reduced engineering studies

France: Bissorte and Revin, Luxembourg: Vianden; Guinea: Grandes Chutes

Stay vane extension made of composite material: a few days to a few weeks
Shorter installation time: a gain of 86% in installation time versus steel stay vane in a stand-alone operation, no turbine dismantling, no need for machining and grinding

Chief Joseph, USA: 3 days to install 2 composite stay vane extensions.

RETROFIT

Give your plant a second life

A hydropower plant modernization is more than restoring the initial performance; it is upgrading the turbine, generator, control system, excitation and/or speed governor with the latest and highest performing technology as a turnkey or customized package. Efficiency, power output (with additional discharge), compliance with new environmental regulations and safety standards can all be improved with an upgrade.

A successful upgrade requires a global approach and a broad range of skills and expertise – something where GE is very well positioned. Computational Fluid Dynamics (CFD) and Finite Elements Analysis (FEA) are used to analyze existing units and optimize the upgrades. The design of new components must consider the existing plant layout and anticipate future operating conditions.

THE GE DIFFERENCE

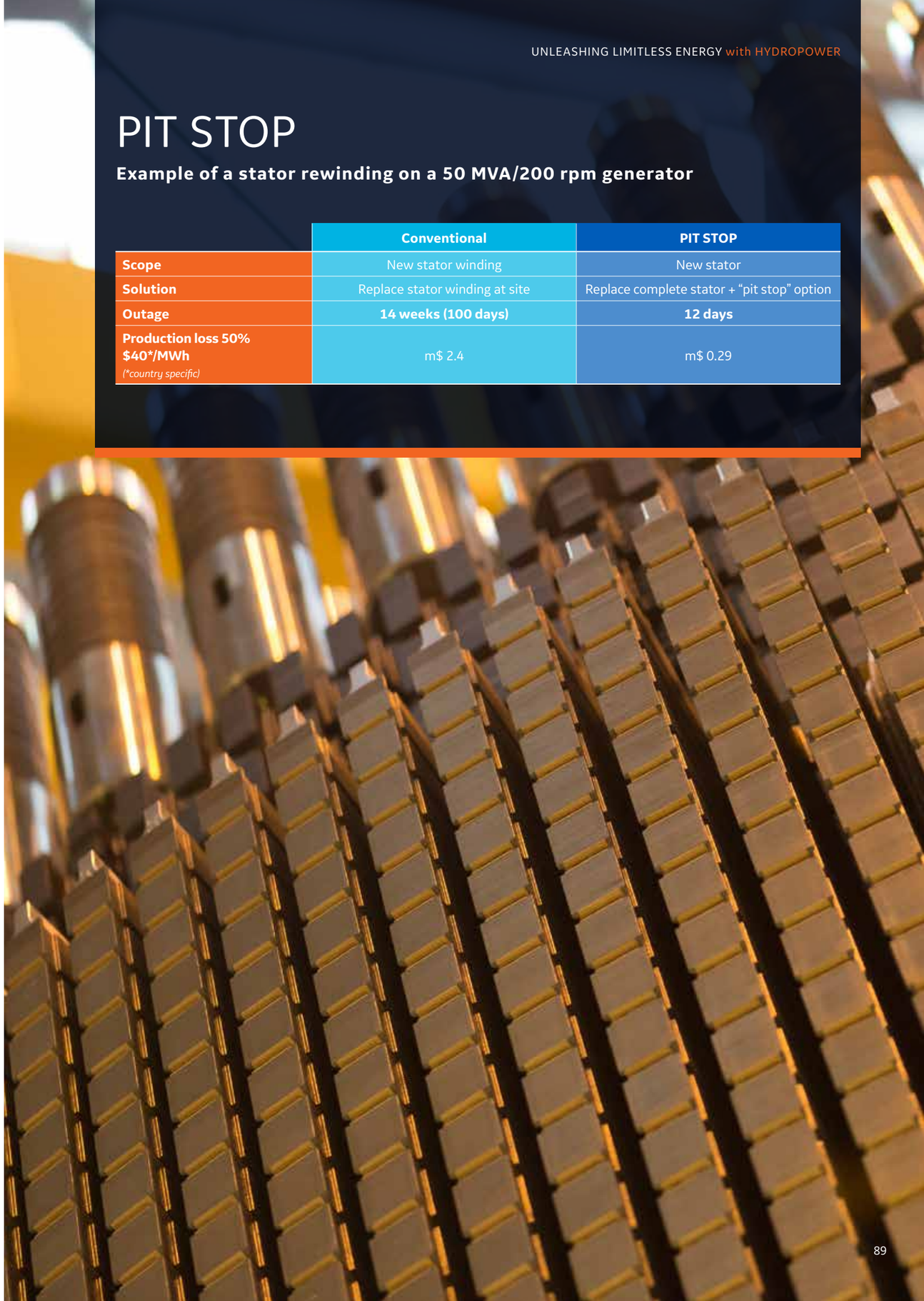
- Full understanding of overall plant lifecycle & economics to optimize the full asset, covering all types of equipment
- Strong integration & interfacing experience: over 100 years of experience with a large technology heritage leading to a strong technology expertise and capability to integrate all equipment regardless of original technology & unit configuration
- Installation time compression with “Pit-Stop” approach which reduces generator refurbishments by up to 75%.
- GE Hydro-Optic™ water treatment allowing intervals between outages to be much longer: eco-friendly solution based on next-generation UV technology for guarding against macro and micro bio-fouling and bio-corrosion: high efficiency with over 99% of micro and macro bio-organisms killed or not viable.

75% reduction in generator refurbishment time

PIT STOP

Example of a stator rewinding on a 50 MVA/200 rpm generator

	Conventional	PIT STOP
Scope	New stator winding	New stator
Solution	Replace stator winding at site	Replace complete stator + “pit stop” option
Outage	**14 weeks (100 days)**	**12 days**
Production loss 50% $40*/MWh *(*country specific)*	m$ 2.4	m$ 0.29



GE EXPERIENCE

- Significant performance improvements for runners, stay vanes, guide vanes as well as draft tube and generator
  - Up to 5% efficiency increase with same discharge with an upgraded runner
  - Up to 30% output increase (with additional discharge)

  In detail:
  - Up to 3% efficiency increase by optimizing tandem cascade behavior of stay and guide vanes
  - Up to 2% draft tube efficiency increase by avoiding flow separation and operation instabilities
  - Up to 0.3% improvement in generator by reducing cooling airflow without increasing temperature of active parts.
- Environmental friendly technologies: oil free lubrication (oil-free Kaplan runner, water bearings, self-lubricated bushings), fish-friendly turbines, dissolved oxygen, water treatment

CUSTOMER SUCCESSES

- Rocky Reach, USA, rehabilitation of 7 x 120 MVA generators
  - "Pit Stop" was implemented and allowed to reduce the downtime required for the generator refurbishment from 6 months to 45 days. The rehabilitation of 7 x 120 MVA generators in the powerhouse included the installation of completely new stators and rotors as well as modifications to the existing upper bracket, embedded generator soleplates and other smaller assets.
- Río Piedras, Colombia, 1 generator (primarily the stator): with "Pit Stop", 45% reduction in plant downtime
- Holleforsen, Sweden, refurbishment aiming at extending life by 40 years, improving efficiency and becoming environmentally friendly.
  - Significant efficiency improvement up to 5% depending of the discharge flow.
  - Installation of a "oil free hub": the several thousands of oil in the runner hub are now replaced with water. Lubrication free bushings were installed. Besides the environmental benefits, this results in no need to store oil and reduced maintenance.
- Porto Primavera, Brazil, Hydro-Optic water treatment: 99% reduction in Golden Mussel settlement, significant reduction in Hydrozoa Cordylophora Caspia.

30% output and **5%** efficiency increase

Country	HPP	Runner	Output (MW)		Output Increase (%)	Peak Efficiency Increase (%)
			Before	After		
New Zealand	Kaitawa	Francis	17.7	20.6	16	7
Uruguay	Gabriel Terra	Kaplan	34	38.9	15	7
Ireland	Ardnacrusha	Francis	24	29	21	>3
Latvia	Kegums	Kaplan	13	20	54	5
Latvia	Plavinas	Francis	90	104	16	4
U.S.A.	Shasta	Francis	133	144	8	2
Canada	Outardes 3	Francis	193	260	5	3
Sweden	Grundfors	Kaplan	45.7	53	16	3
Canada	St. Lawrence	Propeller	62	64.8	5	5
Sweden	Hölleforsen	Kaplan	50	57.9	16	4





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