INTERNATIONAL

Water Power & DAM CONSTRUCTION

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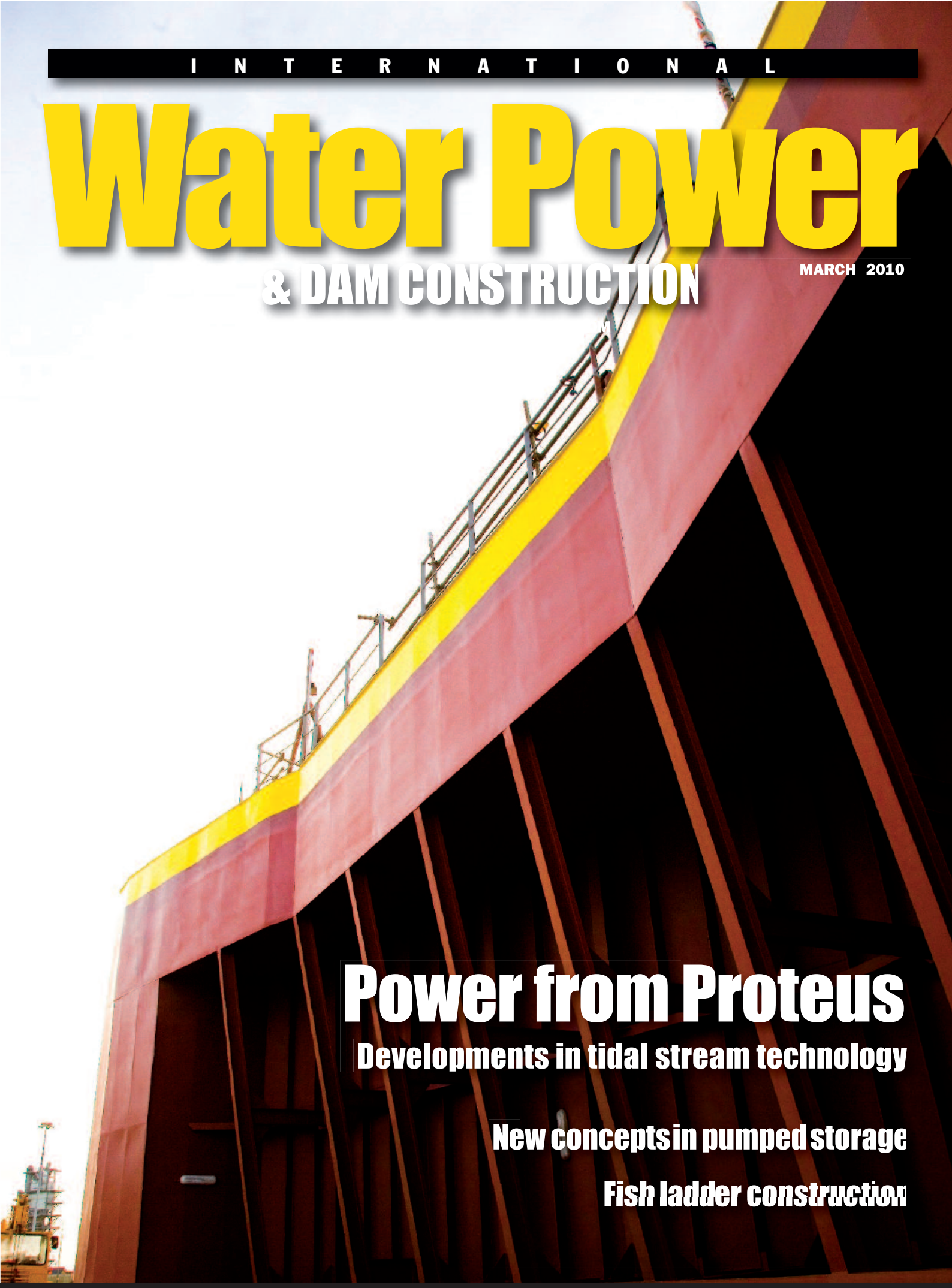

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A weighting game

A fresh step in closed, modular hydro power concepts comes in US firm Gravity Power LLC's shaft-and-weight piston system. Report by Patrick Reynolds

FOR Jim Fiske, who has been working with a variety of energy storage technologies for more than 10 years, hydro power was a new challenge. He was looking for an entrepreneurial opportunity to deliver yet another grid support system, and with some concepts to examine, a focus on basic physical principles plus reviewing swathes of publicly-available information on hydro power, out came an unusual result – a shaft-and-weight piston system that is a fresh take on closed, modular technology for pumped storage operations.

His idea is called the Gravity Power Module (GPM) and, in concept, it is like a sealed water-filled piston and so employs familiar, classic mechanical engineering. But the GPM system is enormous, the piston being an extremely large weight stack within a vertical 'storage' pipe that also holds water, and that column is housed in a shaft that has been excavated hundreds of metres into deep rock. The bored shaft also holds a second, thinner 'return' pipe. The pipes link at their bottoms and at their tops for the inlet and outlet of a pump-turbine.

When operating at peak demand times or for other grid reasons, the pressurised unit will generate electricity by allowing, through fine hydraulic control, water to be disgorged from the bottom of the storage pipe under the force of the weight stack drifting down under gravity in a plunger-type action. The water flows up the return pipe to drive the pump-turbine and is discharged continuously back into the top of the storage pipe, above the stack, in the closed system.

During off-peak times, the pump-turbine reverses the flow to inject water at the bottom of the storage pipe and push the stack back up, locking-in the desired potential, or gravitational, energy until the next call from the grid. The pipes always remain full of water, including above and below the stack, whether it is stationary or moving.

Armed with the core idea, for which patent application has been made (US Patent Application – US20090193808), and keenly aware of its business potential as a fast-response grid support system, Fiske raised initial capital, recruited a team and is adapting the concept, refining designs. As work continues with strategic partners and investors, this year could see construction begin for a commercial prototype, likely in Texas.

Concept

GPM might be a fresh look at hydro power but the driving force behind its development is traditional pumped storage – charge your system with cheap energy, sell it back when the market needs it and is paying more.

Electricity is generated when the weight stack descends, and is stored when it rises in the storage pipe. The former sees the stack eject water to drive a generator, the latter sees the pump-turbine inject the flow to raise the weight. There is no buoyancy involved in the GPM system.

With buoyancy not a factor to either maintain or change the position, or elevation, of a weight stack within a pipe, holding that position will depend on integrity of equipment as well as seals. Research is also underway into the fit of the stack against the pipe wall to limit leakage and drift, or loss of stored energy, in effect, but the system is said to be able to tolerate some peripheral seepage.

Beyond the focus on single shafts there is the significant possibility of clusters of such installations being constructed from the modular GPM system, and they could be charged individually with stacks set to different elevations. The variety could provide varying responsiveness to grid demands.

Elevation of a stack does not, however, determine the head, or driving pressure, in the system. The position within the pipe only serves to set the maximum time a stack could drift down, and hence the duration of the power output. For example, a unit could be designed to give power output of, say, 15MW with half an hour of storage – meaning the GPM system would deliver constant power of that amount as the stack was in a controlled drift down the column for 30 minutes. Typical drift rates are anticipated to range from 0.2m/sec-0.4m/sec, depending on the service to be provided to the grid.

Fiske comments that it can sometimes elude some hydro power people that the operating head is not influenced by the elevation of the stack. Instead, the head is determined by the size of the weight, or more precisely given the constants of cross section and material density, its vertical dimension – height. As such, it is unchanged over the cycle, he says. As a gravity-based operating system, weight equates to force. Then, multiply by velocity, or drift rate, and the power of the system can be calculated and established, he adds.

The weight stacks are to be assembled from locked concrete blocks, and their underside will have shaped docking plates, or boxes, to fit the base of the shafts.

GPM is a different take from regular hydro power systems although both are driven by gravity: the more common, water pushes on water; and, in the GPM concept, a concrete weight pressing on water.

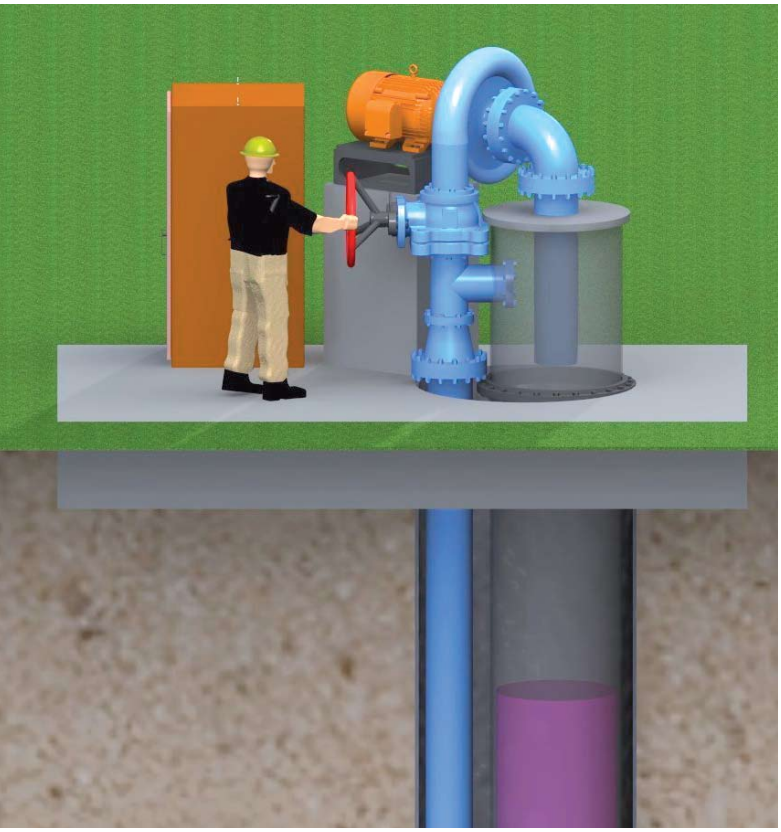
R&D

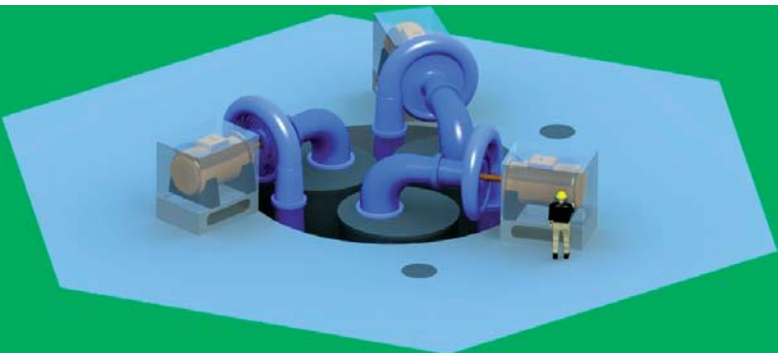
Rights to GPM are held by Gravity Power LLC, which was founded by Fiske, and he is chief executive and a co-owner. The firm was launched late last year as a spin-out from LaunchPoint Technologies Inc, a California-based venture engineering and hi-tech incubator company in which Fiske is also VP of the Advanced Systems division. Before its launch, Gravity Power LLC was previously called LaunchPoint Innovations LLC.

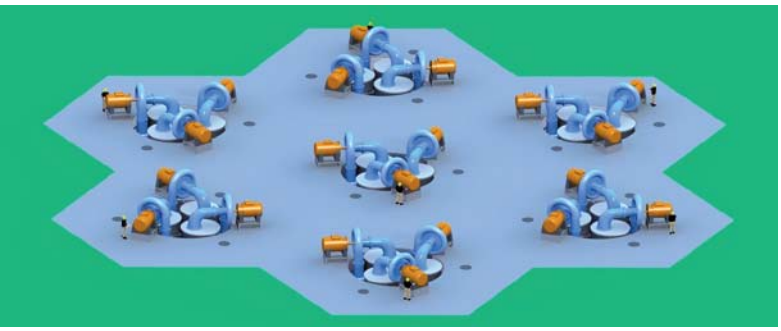
The genesis of the GPM concept extended over several years, and the focus of the venture was always to develop intellectual property (IP) for a business to offer profitable energy services to the grid. A variety of concepts were examined before GPM, as an underground system, was selected as the most viable to initially pursue.

While the excavated shaft system is the main focus for the present R&D effort, which is supported by strategic partners in a development team, the firm's patent application also covers both more general, and other, versions the GPM concept – i.e., gravitational storage of cheap energy using weights. Those variations are mostly based on water recirculation for pumped storage and include constructing offshore steel towers, either floating or placed on the seabed. But, separately, the concept also extends to a wind power-driven system of gears to move a weight.

For the underground GPM system for pumped storage, excavation is a challenge but geology is not viewed as presenting an overly restrictive barrier. The system's small footprint would offer a marked degree of flexibility in choosing site locations and help to reduce construction risk. Favoured rock, though, includes limestone, chalk and







Left, from top to bottom: Artists Perspective of the GPM concept
GPM headworks, top view;
Surface view of the array assembly

gypsum – 'great media', says Chris Grieco, executive vice president.

The main GPM shaft in a commercial-scale operation could be between 500m-2000m deep, the firm says. However, this range is not fixed at this stage, and the depths that will be achievable will be determined as processes and methods are proven.

Energy storage capacity in a GPM shaft and pipes-system increases with the square of the depth. However, the merits of deeper shafts versus, instead, opting for cluster farms of shallower units would be analysed case-by-case with clients, such as utilities or independent power producers (IPPs), or possibly even considered by Gravity Power LLC when taking investment views with partners on potential markets and sites.

The company is examining potential business models to help exploit the core IP of the GPM system. But R&D effort surrounding the concept has also given rise to opportunities for an in-house project on pump-turbines. There is potential for serial production of smaller-than-usual units in hydro power through a standardised approach, the firm notes. It adds that there could also be bonus opportunities beyond their use in GPM installation.

Funding partners

An initial funding round to help the R&D work raised US$2M in January 2009. The equity stakes in Gravity Power LLC were taken by 21 Ventures and Quercus Trust, and are confidential. The funding support helped with concept development, patent work and also detailed engineering, siting and permitting studies. The funds also helped towards business development and operational costs.

Employees and LaunchPoint Technologies are also shareholders in the firm, and funding rounds continue with presentations being made to potential equity investors.

"We are making strong progress on attracting venture and strategic investment for our Series B Round, which will fund the commercial prototype Phase I in Texas, plus allow for R&D on improving shaft boring technologies and some corporate branding, marketing and more," says Grieco.

The firm is also pursuing grant funding, such as under the US Department of Energy's (DoE) push for Smart Grid technologies. Pumped storage hadn't been listed as an application category in the recent awards, and so the non-conventional approach of GPM, while interesting, didn't clear the hurdle that time. However, other opportunities with DoE are anticipated, such as the forthcoming solicitation for grid-scale energy storage via the ARPA-E initiative, and again matching funds could come from investors and strategic collaborators.

Future opportunities exist on federal and also state levels in the US and other countries, Grieco adds.

While the business case for investment does not count on tax credits, the bolster from achieving them is a recognised as a potential bonus. The system works well in the wind power sector, which Grieco has had some entrepreneurial experience in through his previous business development work while engineering director with Dehlsen Associates LLC, which develops renewable energy systems. He joined Gravity Power LLC a year ago.

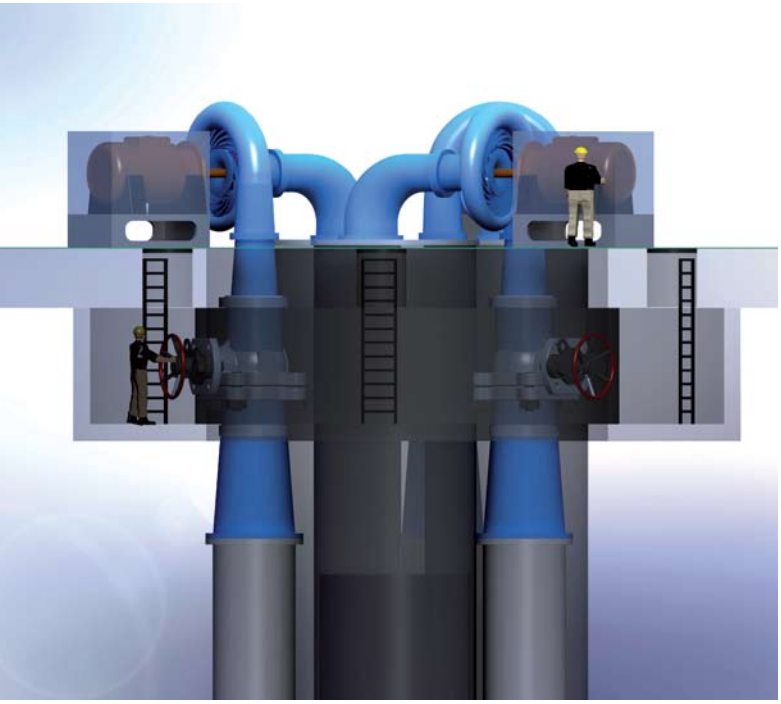
In addition to securing and pursuing funding support, the firm has also been developing relationships with a series of strategic partners, and this is an ongoing process, notes Grieco. He says that partners may be active in underground construction, equipment, technology, or have market or regional experience, or might be interested in technology licences or potentially be users of GPM installations, such as utilities or renewable power producers.

Development team

Members of the development team recruited by Gravity Power LLC have included key engineers with LaunchPoint Technologies, of course, as well as a selection from a number of other US companies: tunnel boring machine manufacturer The Robbins Co; hydro power consultant HDR/DTA; contractor Atkinson Construction; financial modelling and portfolio development consultant Competitive Energy Insight; and, contractor Granite Construction.

Their contributions to the R&D process have been varied since work began in earnest in early 2009, and range from design and siting studies to financial modelling and analyses of component capabilities. However, the nature of the formal relationships during the development phase is confidential, and there is no comment on such for the commercial roll-out and scale-up of the GPM system.

But Grieco says: 'We have spent many months looking for proactive,



Above: GPM Headworks, side view

capable development partners for this business. Many aspects of this business are not commonplace, i.e., multiple shafts in one location, serial production of hydro power equipment and more. Those that have or will someday step up and view this as a business and partnership are more likely to participate in our longer-term endeavours."

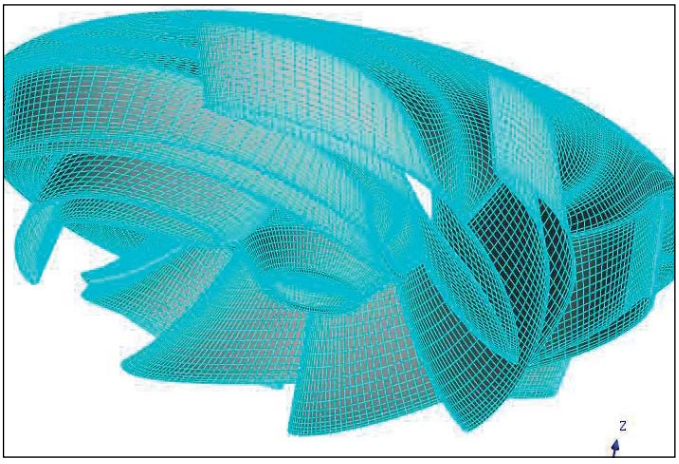
Involvement of 'many other' collaborators is anticipated, such as in construction, component manufacturing, project development and operation.

Prototypes, production

Prototype testing for GPM is to be done in two phases – a field demonstration and then a full-scale test. The proposed location for the tests is Texas, at a site yet to be finalised but the company hopes to start construction by mid-year. The state was chosen for a combination of its favourable business climate, good geology and wind farms – a producer of fluctuating output, presenting challenges for the grid. Talks with potential customers are underway.

Phase 1 is expected to take about 18 months and involves construction of a relatively short shaft (approx. 100m) with a production-scale diameter (approx. 6m), piston stack of concrete blocks, and seals. The production head for tests is to be approx 300m. The minimum weight of a production-scale piston stack is more than 6000 tonnes.

Below: Runner and hub CFD surface mesh



Design work for Phase 1 is underway with assistance from a global expert in underground construction. The co-operation began recently as Gravity Power LLC changed its plan for the location of the prototype tests, switching from its planned new offices on the West coast to Texas as part of a move to reduce construction and business risk. While the assisting expert is undisclosed it is not Robbins.

Full-scale tests in Phase 2 would require the shaft to be extended to a commercial depth (at least 500m) and testing would then move to using production-scale power equipment, such as its inhouse pump-turbine. Phase 2 is expected to start at the end of Phase 1, possibly sooner, and last possibly only 20 months, depending on power equipment sourcing.

The shaft is to be capable of providing more than 15MW in Phase 2 but only a fraction of that power in Phase 1.

Production roll-out for commercial applications could start before the end of Phase 2, depending on market demand and also how risks have been eliminated through the tests in Phase I and some of Phase 2. The firm expects the largest of the single shafts to be capable of providing more than 50MW for four hours or more, which is at least 200MWh of storage.

Separately, late last year the merits of constructing an offshore GPM unit in Hawaii were being explored at an early stage but refinement of the firm's plans has since deferred that option.

Market opportunities

Charging up cheaply and discharging when electricity prices are higher, or time-shifting, is the 'holy grail' of the business model, especially in a diurnal cycle, says Grieco.

But additional, fast response services will include grid frequency regulation – which is the initial target market using 500m deep shafts – and black starts. The weights don't need to be already drifting to provide a fast response; there's no need for an equivalent to 'spinning reserve' motion. The units are being designed to ramp from zero activity to full power in well under a minute.

For such ancillary services it is possible to also have multiple pump-turbines at a shaft, such as a three-unit design.

However, the GPM installations that focus on time-shifting market opportunities will probably be the basic design, using a shaft with a pair of pipes linked at the top to a single pump-turbine. That unit would be operated at the best efficiency point (BEF) suited to obtaining maximum return on investment (RoI), says Fiske.

Given the variety and scale of different needs in grids, and the IP combinations being developed as standard, core technology to scale and adapt to sites, Gravity Power LLC is open to a range of potential business opportunities, including: being an owner-operator; selling energy services to utilities; licensing the GPM system; and, providing services as specific elements from the supply chain. Consequently, it sees many potential ways to engage with partners.

"We are not looking to tie ourselves," Grieco says, and adds that the key is not to give up control on any aspect.

Beyond the US, the firm is looking at areas such as Europe, China and South Africa – anywhere there are grid-scale opportunities.

The modular system would allow installations to be expanded with time. But, as with any localised, repeatable, modular process, the opportunity to construct a number of GPM shafts in clusters would help amortise equipment and optimise costs and methods. In addition, there can be programme benefits.

Also, in the wider economic sense, many grid-scale energy storage markets would require hundreds of megawatts at nodes or a site, and again clusters would be the most likely approach. Besides, like conventional pumped storage systems, seeking small installations can be uneconomic, even if GPM's footprint is small and would seem relatively unobtrusive, like an oil wellhead on the sea floor.

In general, for economic reasons as well as operational flexibility, it is more likely that higher power and larger storage capacities are obtained by exploiting GPM's modular concept to develop the installation in varieties of clusters. IWP&DC