Repurposing hydropower generation for the 21st Century

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Innovation is necessary today to achieve a fully decarbonized and reliable grid. The Cat Creek Energy & Water Storage renewable power station (CCEW) is based on a Trybrid© technology, comprising pumped-storage generation, variable renewable energy (VRE) resources (wind and solar PV), and large volume, long duration (LVLD) pumped hydro energy storage.

Although pumped-storage plants continue to provide more than 95 per cent of electrical energy storage around the world, the emphasis by governments, utilities, and the media is increasingly on battery energy storage systems (BESS). The purpose of this paper is to establish that a properly designed off-stream pumped-storage facility is a superior method to surmount the challenges of full decarbonization. The project described here is not only a short-duration and time-tested alternative to massive BESS installation, but also fulfills the increasing need for long-duration storage to accommodate increasing VRE resources. In this way a properly integrated renewable energy facility can perform as a functionally complete substitute for rapidly retiring fossil-fuel baseload and natural gas peaking generators.

1. The route to full decarbonization

A global energy transition is both necessary and well underway. The latest report (9 August 2021) of the Intergovernmental Panel on Climate Change projects that global warming will increase by 1.5° C by 2040, but halt and level off at that number by 2050 if there is a massive and coordinated effort now to curb carbon emissions (see also pp 24 and 25). The CCEW project will offset 2 770 845 tonne/year of CO_2.

Questions remain about the best route to full decarbonization. The available way forward is through increasing penetration of VRE resources. The obstacle is to incorporate them in such a way as to ensure a secure and reliable transmission grid and dependable power supply.

New technologies, for example based on hydrogen, capture the headlines. But almost all are still at the proof-of-concept stage, and others not at a scale that can provide a realistic solution to the VRE incorporation problem. In the end, it remains to be seen if any will be functional or cost effective. Simply adding more natural gas peaking plants to accommodate VRE intermittency does not lead to fully decarbonized generation, and such plants have had a clear environmental and social justice downside. Half of California's gas plants are located in communities that rank among the 25 per cent most disadvantaged [PSE, 2017[1]]. More nuclear plants are being retired or left unfinished than are coming online. Small nuclear reactors (SMRs) are at best decades away, and the all-in costs remain a mystery. Despite governments assuming almost all liabilities for installations and their inevitable retirement, nuclear still raises cost effectiveness questions and, especially, the issue of the disposal of waste fuel, as yet unsolved in 70 years in the USA. When nuclear plants are shut down, they too must be firmed with LVLD storage.

While it is well established that the lifespan source-to-sink carbon footprint of VRE resources is a fraction of that for other generation technologies, the on-going advocacy by some experts to overbuild these resources as a cure-all for their intermittency is economically inefficient, wasteful, and unnecessary. According to Ming *et al* [2019[2]] "Renewable overbuild is the most economical solution to replacing carbon-emitting resources completely, but requires a 2× buildout that results in a curtailment of almost half of all wind and solar production." Even on the basis of this brief examination, it is clear that properly sized energy storage is the best way available to reach present and future critical decarbonization goals. While energy storage comes in many forms, Li-ion battery storage is being deployed more than the other systems as the 'quick fix' by US utilities and the Federal Government. But it is still relatively unproven at grid scale, where it is being utilized at less than 50 per cent of its duration capacity of 4-6 hours, and lithium will be in short supply for energy grids as electric vehicle mandates ratchet up (see Fig. 1.).

Components of the Cat Creek 'Trybrid' project in Idaho

Module	Capacity (MW)	Generation (GWh/yr)
Pumped storage hydro module	745.0	3202.5
Wind CCE module	110.0	355
PV solar module	40.0	94
PV Floatovoltaics module	110.0	258.5
LVLD (PHES) module	720.0	87.12
Transmission capacity to intertie	1,746.0	

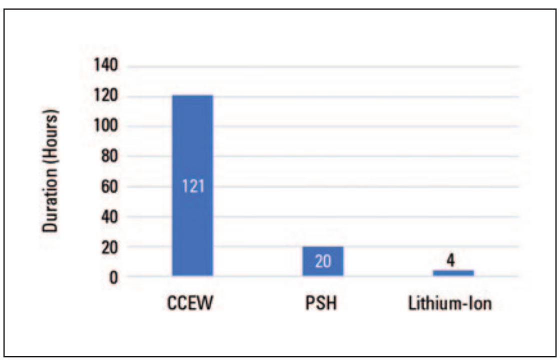

Fig. 1. A comparison of storage duration for CCEW, conventional pumped storage, and Lithium Ion.

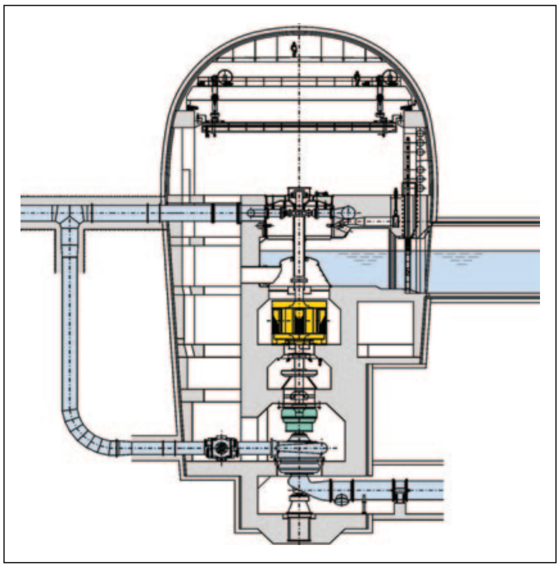

Fig. 2. An example of Voith's ternary unit, in cross section.

Other storage technologies under development or at a limited number of installations worldwide (including compressed air and flywheels) still need to make a scale-up leap. Only pumped storage and especially off stream pumped storage, provide the grid-scale and time-tested 'battery' as pumped hydro energy storage to ensure grid reliability. Seven years in development, CCEW is expanding the functionality of pumped storage to deliver increased energy and grid services, and by implementing this now, is mitigating the high cost of anticipated solutions to the problems of the 'last mile' intermittent VRE resource integration (> 75 per cent VRE resource penetration), in the transition to the fully decarbonized electricity generating economy. This paper aims to show how CCEW accomplishes the integration of multilevel services in a power station, to deliver dispatchable, flexible, secure, and reliable clean energy, while allowing for increased VRE resource penetration and replace decommissioned polluting baseload and peaking generation.

2. The Cat Creek Energy and Water Storage plant

2.1 Purpose

CCEW is designed to create inherent value in power conditioning to address the intermittency of increasing VRE resource penetration at all levels, and when VRE resource penetration exceeds 75 per cent and more than 10 hours of diurnal storage are needed. With large volume, long duration energy storage capability, backed by onsite and otherwise curtailed VRE resources, the ability to operate as a baseload facility addresses current grid operators concerned about how to phase out fossil-fuel generation.

The Voith Hydro ternary designed hydro turbines enable load absorption (charging) and load following of the VRE resources to be completely manageable (see Fig. 2). With these turbines, VAR support is consistent, whether in the pumping/charging or generating/discharging mode. The flexibility of the project-specific ternary design is the basic reason why CCEW is capable of delivering energy services with considerable scope and integrity compared with other generation or storage facilities.

Monitoring and managing power quality when multiple generators and technologies are present is equally important to ensure constant and dependable grid resources. The Voith ternary technology and design offer excellent grid management. The CCEW collector/switchyard complements the Voith technology. The CCEW collector station switchyard consists of six 230 kV circuit breakers making up a six-position ring bus managed by FlexGen HybridOS electronics, an appropriate replacement for capacitor banks in safeguarding grid integrity at all levels of delivery onto the Western USA grid.

2.2 Functional parameters

The main functional parameters can be summarized as follows:

- varying dispatch or charging complemented by onsite VRE resources;
- multiple turbines and ternary design allow for pumping and dispatching simultaneously;
- response times at frequency regulation level and full ramping in as little as 30 s; and,
- the pump-to-generate-to-pump mode time is minimized by the multiple turbines and the ternary design itself, which does not have to change rotation direction between the pumping and generating modes.

3. Performance

3.1 Flexibility in grid integration to increase efficiency

The grid needs reliable and flexible transmission to load centres so that generation and charging cannot be compromised. Dual 230 kV conductor sets of bundled 2 × 1272 Bittern ACSR conductors on tapered tubular steel structures from the plant are each capable of managing the entire output of the power station and terminate 33 km away, intertying to multiple 230 kV and 500 kV lines. Each 230 kV facility line terminates at the new RattleCat substation with individual 230/500 kV, 1000 MVA step-up transformers onto the 500 kV transmission system, while the 230 kV lines also connect to the existing 230 kV Rattlesnake collector substation. This new RattleCat substation offers the grid operator, Idaho Power Company, an additional tool to manage power through its system, by allowing an important crossover between the 230 kV and 500 kV levels that serve southern Idaho and the Western USA power grid.

Because of its remote location (see Fig. 3), the CCEW plant will have cyber security and hardening built into its main transmission components. The possibility for its onsite and offsite conductors to be buried, and its substations, generators, and other high value components to be shielded (in accordance with government policy), enables it to remain online in the case of a high intensity, low frequency grid event.

Combined with CCEW's bulk inertia, the plant is thus a reliable resource in restarting the grid after such an incident. The huge energy storage capability, combined with onsite VRE resource generation, can allow CCEW to power up the grid for weeks until normal grid operations are resumed. Redundant fiberoptics, satellite, and cellular communications schemes, shielding against cyber threats, all safeguard reliable grid communications in perilous times.

Other advantages of the system are as follows.

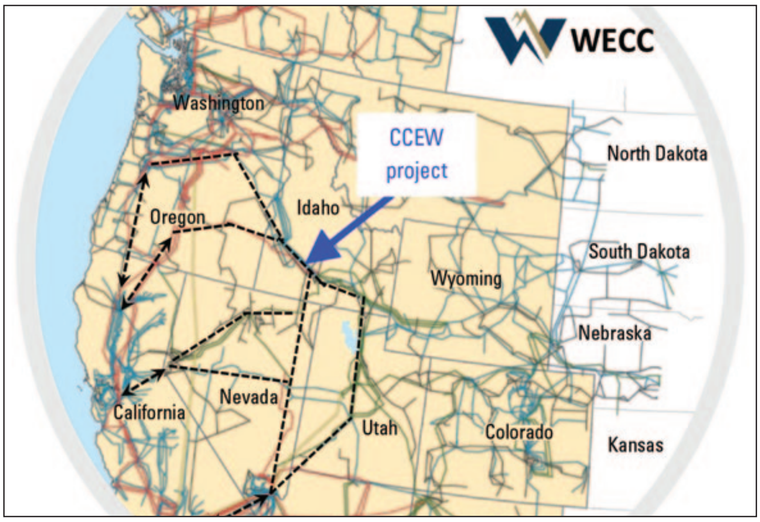

Fig. 3. Location of the CCEW project, in Idaho, USA.

3.1.1 Maximum flexibility in energy services

- Sized for current maximum efficiency, the plants's full potential design output was restricted to accommodate many factors, including its water volume and transmission control area operating limitations.
- It is designed to address not only current grid operations, but also those that will arise during the transition to 100 per cent decarbonization.
- It is not limited by motive force fluctuations, a characteristic of other natural powered generators, allowing full performance even in extreme weather conditions.
- It does not have any outside pumping/charging resource, and is able to deliver maximum capacity output for more than five days, and even at a steady output of 120 MW for more than 30 days.
- It provides a rational solution to the so-called 'Last Mile' grid integrity concerns, reducing both overbuilding and curtailing of VRE resources, in the final build up to a clean energy society.

3.1.2 Technology to improve efficient operation

- Power management in the move to 100 per cent decarbonization must be multi-dimensional. The ternary design for the pump-turbines advances system management for the pumped-storage plant, prolonging the operating life of the equipment, and also fine-tuning performance. Uni-direction rotation reduces mechanical wear. The hydraulic short-circuit is innovative, being designed to cushion the operational demands of the pump/charge and generate/discharge modes.
- Operating costs are a perceived obstacle in assessing the deliverability of pumped storage. The selection of the Voith ternary design pump/turbines is cost-effective in improving performance.

3.1.3 Structural design elements

- The hybrid approach to the design of the powerhouse, because of the extremely short (853 m) distance between the upper and lower reservoirs, was necessary for efficiency. The powerhouse is below ground, but not buried, housed at a 94 × 24 × 100 m depth outside perimeter vessel which allows for above ground installation techniques for materials handling and equipment supplied by both a tramway and an 18 m-wide roadway to the powerhouse (see Fig. 4).
- The 5 m-diameter penstocks can be constructed ex-works, and be transported to, rather than fabricated at, the site. Each turbine is linked to the upper reservoir by its own penstock, preserving the multifunctionality characteristic of the plant.
- The penstocks bifurcate within the powerhouse to accommodate the separate pump and turbine, and also to support the hydraulic short circuit layout of the ternary design.
- The natural bowl-like contour of the upper reservoir is designed for a volume of 136 × $10^6 m^3$; the upper reservoir, includes a freeboard volume of approximately 12.3 × $10^6 m^3$.

The completely lined inner and outer earth berm/dam slopes will be augmented by rolled compacted con-

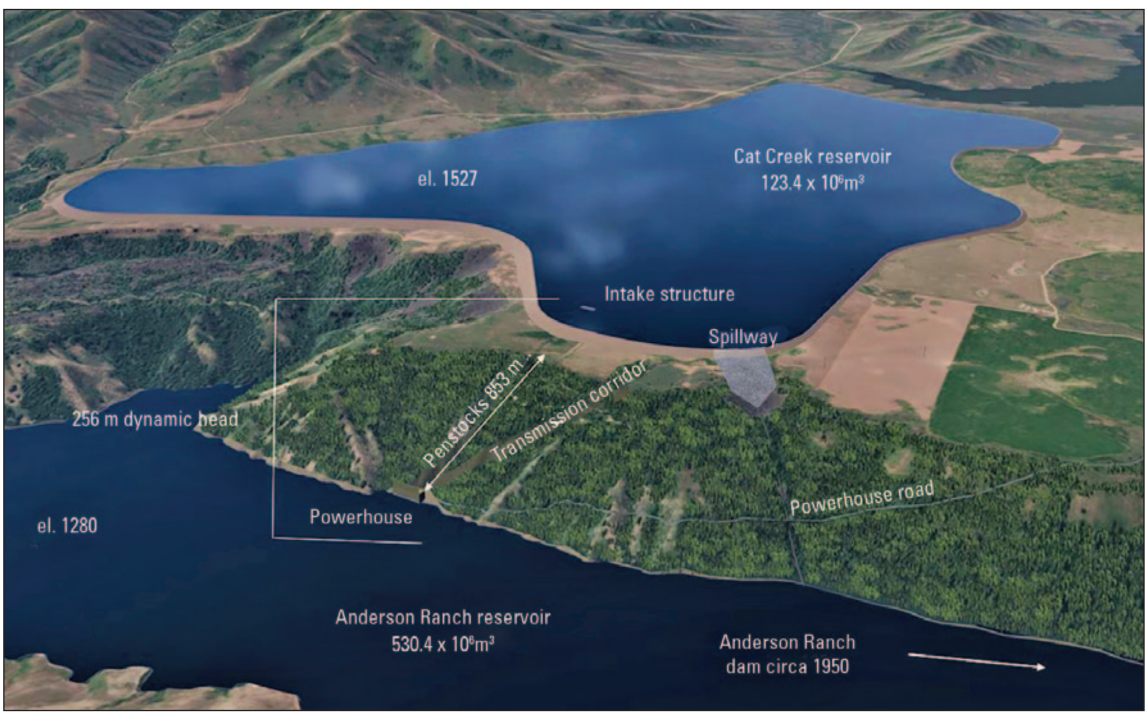

Fig. 4. Layout of the CCEW project.

crete for part of the reservoir containment, designed to the most stringent standards with respect to the geology and historic seismic activity. According to two specialist reports [Elmore County, 2012[3]; Bureau of Reclamation, 2020[4]]

4. Operating parameters

Although the emphasis in this paper is on the functional rather than structural attributes of CCEW, there is a close connection between these. This is demonstrated by considering some of the operating parameters of the off-stream pumped-storage project. Multi-energy services can be deployed simultaneously, consecutively, or repeatedly over seconds, hours, or days. There is no 'how many cycles?' question, because cycling is infinite as charging and discharge from 1 to 870 MW, and the multi-turbine capacity, instantly provide the flexibility in power reliability needed to transition the grid. Each unit can respond rapidly to large system load changes, or load follow the VRE resource capacity volatility within a minute; delivering the range of services demanded of that will be its energy mainstay. Frequency regulation, peaking, load following, and baseload, with full dispatchability, introduces a new era in major clean energy infrastructure.

While a full set of energy services might be difficult for regulators and the market to price individually, it is not difficult to realize the inherent value of a diverse facility that can be deployed in seconds and dispatch any energy service required.

5. Critical water infrastructure

Unique to off-stream pumped storage, CCEW is equally important to a changing climate as a water infrastructure purpose-designed to facilitate additional water storage for other uses, whether domestic, agricultural, environmental, or recreational. The efficiencies of dual function facilities, especially in relation to the creation of more water storage, helps to relieve the burden of the exorbitant costs of new storage for purposes other than power generation.

This is especially the case as the continuing aridification of the Western USA has not been followed by the installation of new water storage in any significant way. The resulting impacts are noted daily in the global press about how in 2019 California reservoirs were at 100 per cent of capacity, whereas in 2021 the state is experiencing what will be the worst water shortage in recent history.

6. Social and environmental justice

The implementation of energy projects now routinely takes into account their net impact on surrounding communities and the local environment. The rural location of the CCEW, on private lands, and its projected life or more than 100 years, can provide a net benefit to the local environment. Located alongside the existing 70-year-old Anderson Ranch reservoir operated by the US Bureau of Reclamation, CCEW can improve the ecological health of the South Fork of the Boise river and its aquatic life because of the impacts of the existing in-river dam. The 528-page Final Feasibility Report of the Boise river basin feasibility study by the Bureau of Reclamation [November, 2020[5]], sets out in detail both the multiple pressing needs for, and the feasibility of, additional water storage along the South Fork of the Boise river. The CCEW project is designed to complement and strengthen the Bureau's own plans to meet these multiple needs [Bureau of Reclamation, 2020[5]]. In particular:

Aerial photo of the Anderson Ranch reservoir and the land where the CCEW upper reservoir will be located. Photo by courtesy of the Bureau of Reclamation.

- This lower reservoir suffers from stratified anoxia in late summer. The units can contribute to improving dissolved oxygen levels in the Anderson Ranch reservoir. In years of low pool levels, spawning runs for salmon species suffer. The CCEW upper reservoir can temporarily raise the lower reservoir pool level to assist this vital migration.
- Subsequent to late summer flow reductions associated with the Anderson Ranch dam operations, from the afterbay to the lower reaches of the South Fork, pooling and stranding of rainbow trout occur on an annual basis. CCEW can relieve these incidents by helping increase the volume releases from the Anderson Ranch dam.
- Winter flows in the Boise river system are seldom adequate to sustain a healthy ecosystem beyond the dams on the Boise river, which is a concern to many environmental groups. Additional volume releases from CCEW can assist with this issue.

7. Conclusions

It is well known that pumped-storage plants play a major role in helping to stabilize grid systems, which is especially useful when working with intermittent

Pump-turbine being manufactured at Voith's plant in Pennsylvania, USA.

renewable energies such as wind and solar. This flexibility greatly improves the quality of energy supply in a country. Voith, which supplied the machines for CCEW, has been active in pumped-storage technology for many years and has made important contributions in this field by developing innovative solutions, and continuously optimizing them. Its investment in research and development in this area is based on the commitment to this technology as the only long-term, technically proven and cost-effective form of storing energy on a large scale, and making it available at short notice.

CCEW echoes this commitment, offering a degree of capacity flexibility, resource adequacy, and grid stability that goes well beyond load balancing, and more than rivals the services, and the benefits, that traditional utilities provide. The Cat Creek Energy & Water Storage power station represents a new way forward for carbon-free generation. Its off-stream model is a rational economic approach in combining necessary water storage with clean power generation and large-scale energy storage. CCEW is grateful to the *International Journal on Hydropower & Dams* for this opportunity to describe our project and make the strong case for our 'Not a new thing, but in a new way' approach. ◊

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