Role of Hydro in Support of Modern Power Grids

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Abstract

This paper summarizes the features of hydropower developments and compares hydro with other renewable energy sources for supply to electric power grids. The particular advantages that hydro plants typically provide for grid operation and reliability are then described. Challenges that hydro developers face are then noted and discussed. The paper then addresses the question about sustainability of hydro power developments particularly those in Canada. The meaning of sustainability as currently presented in public discourse is examined and popular applications of this concept challenged.

Keywords: hydropower, renewable energy, electric power grids, sustainability.

Introduction

Popular discussion about renewable energy largely focuses on wind and solar energy sources and ignores the contributions of the oldest renewable energy source - hydropower. Additionally, the popular discourse rarely addresses the question of integration of wind and solar power into utility grids. Some so-called authorities even argue that hydro is not a sustainable energy source! These issues will be challenged in this paper.

Renewables for utility application

There are three types of renewable energy that are widely developed for utility scale applications: hydro, wind and solar (photovoltaic). All three share some common characteristics:

- Availability of all three energy sources is intermittent
- Economically feasible development is site dependent

Features of Hydro Developments:

The feasibility of a hydro project depends on a satisfactory hydrologic regime and favourable site topography. Sites favourable for hydropower development are often located at topographic anomalies: falls, rapids, canyons, river bends, plateau to ocean drops and the like. Multi-purpose developments may also be located at dams built for other purposes, such as: recreation, irrigation, flood control and water supply. These features both natural and man-made concentrate energy intensity and enhance the economics of developments. Typical developments include:

- Falls Site: Churchill Falls Development (5,225 MW)
- Rapids: Rapides des Cœurs, St. Maurice River (76 MW) – Québec
- Canyon: Paradise River (8 MW) – Newfoundland & Labrador
- River Bend: Kali Gandaki 1, (144 MW) – Nepal
- Plateau to ocean: Cat Arm Development (127 MW) - Newfoundland
- Multi-purpose irrigation/power: Chin HPP (11.7 MW), Alberta
- Multi-purpose power/flood control: Temengor HPP (348 MW) Malaysia

The benefits of hydropower generation can be substantially increased by constructing upstream storage dams to regulate variable inflows to better match power system loads. The Canadian Shield and Appalachian formations in Canada provide many opportunities to develop relatively large reservoirs at very low cost. Nonacho Lake Reservoir (NWT) is an interesting example with a live storage of 855 million m^3 of storage which was created by raising the natural level of Nonacho Lake by only 2 m behind a very small “leaky” rockfill dam. High head projects with low flow are generally more economic than projects of similar size with large flows but low heads. Typical unit efficiency is 85% for medium to large units of modern design.

Wind Power:

Musgrave (2010) dates the start of the modern era of wind turbine design from the 1973 oil crisis. While there was interest in this technology in several counties, including Canada, much of the initiative for technology development occurred in Denmark. Today wind turbine technology can be considered mature although some challenges remain in design for extremely frigid climates. Wind energy conversion is subject to the Betz Limit first elucidated by Albert Betz in 1920. Betz showed that the maximum energy that could be extracted from the wind would be 59.3% of the kinetic energy of the wind (45% for best designs). As a rule of thumb integration of wind power into power systems is limited to 10% due to power quality issues.

Solar Power:

Utility scale solar power is based on the photovoltaic phenomenon by which visible light is converted to electricity. This phenomenon was first observed by Alexandre Becquerel, a French physicist in 1839. A photovoltaic cell is in the form of a sandwich confining a semi-conductor material that exhibits the photovoltaic effect. This phenomenon remained a scientific curiosity for more than a century but was revived as a subject of renewed interest for application on space satellites. The basic element in a solar power system is a cell. The most common types of cells are based on mono crystalline silicon or cadmium telluride materials. The cells respond to visible and near infrared light. The conversion rate from incident light energy to electrical energy for commercial cells ranges from 10% - 15%. A utility sized system involves the connection of cells into panels and panels into arrays interconnected to collect the aggregate output from the system. The output from a photovoltaic system is in direct current which subsequently is converted via inverter units into alternating current compatible with a utility's grid. Usually, panels are oriented toward the sun and tilted to the latitude angle of a site, or sometimes a bit more, to capture maximum energy. Additional production is possible by controlling the orientation of the panels/arrays "to follow the sun", but the additional complexities (and cost) have not been economic.

Comparison of renewables

TABLE 1: CHARACTERISTICS OF RESOURCES

FEATURE	HYDRO	WIND	SOLAR
VARIABILITY	All natural energy sources are inherently variable and are dependent on weather, region and site factors.		
	Hydrologic regime	Wind Regime	Solar Regime
	Produce mainly secondary energy with little or no firm energy,		
PERSISTENCE	For perential rivers $\frac{Q\ 90\%}{Q\ mean} = 0.2 - 0.45$	Nil	Nil
PREDICTABILITY	Days to seasonal	Few days to week	Days to seasonal

TABLE 2: COMPARISON OF TECHNOLOGIES

FEATURE	UNIT	HYDRO	WIND	SOLAR
MATURITY	-	Mature	Mature	Some way to go.
ROBUSTNESS	-	- usually unaffected by weather - vulnerable to water borne sediment - rotating equipment life: 15 to 30 years - dams and structures life: 50 to 100 years	- cut-in wind speed = 4m/s - cut-out wind speed = 25m/s - min operating temp: - 20 °C nominal - rotating equipment life: 20 years with replacement of gear boxes and bearings at 8 to 10 years - towers & foundation ~ 40 yrs	- potentially long life few moving parts - durability of materials will control longevity - invertors most vulnerable component.
AVAILABILITY READINESS	% time	95% to 98%	98% claimed when wind is available, but probably less.	~ 100% when sunlight is available
ENERGY CAPTURE	% of capacity	50% run-of-river 80% plus with long term storage	~ 30%	10% to 15%
ECONOMICS	-	- water-to-wire equip't designs available - civil works unique at each site - subject to economies of scale.	- developments use standardized equip't and tower designs - benefit from industry wide economies of scale. - unit costs improving	- developments use standardized equip't designs - benefit from industry wide economies of scale. - unit costs improving

The above tables summarize important facets of the characteristics and state-of-the art of hydro, wind and solar (photovoltaic) technologies. Both hydro and wind turbine technologies are mature technologies where technological break-throughs are unlikely. Future development work will likely focus on standardization of designs, cost reduction and performance enhancement. Solar energy is a less mature technology where there may be opportunities for significant break-thoughs in the science and engineering. Unit costs for wind and solar energy production have fallen significantly over the past two decades and some cost improvements have been obtained mainly for small hydro machinery. Reducing the cost of civil works for hydro remains a challenge as there is little opportunity for standardization of civil structures, which are often site dependent. These efforts have improved the cost competitiveness of all these renewable energy sources.

The variable nature of renewable energy sources is usually manifest in a mismatch between electrical load and supply. This problem could be mitigated if there were practical means of storing surplus energy output for use in periods of high demand or low supply. For hydro it is often feasible to regulate the flow though reservoir storage to match flow and system load. The degree of regulation is dependent on the relative size of reservoirs, the variability of river flow and system loads, and the characteristics of the electrical system. In systems with large base load thermal units, the system peak loads can be conveniently supplied by hydro units. Such units run the gamut between run-of-river units with small “daily pondage” reservoirs and larger seasonal to multi-year reservoirs. In Canada, where the topography has been shaped by glaciation to produce a landscape characterized by many lakes, the cost of storage is relatively low. The opportunity to exploit the full capacity of hydro units on peak adds a significant value to the benefits from hydro projects. Table 3 gives some examples of storage reservoir development.

TABLE 3: CLASSIFICATION OF RESERVOIR STORAGE

STORAGE RATIO = LIVE STORAGE VOLUME / MEAN ANNUAL FLOW VOL

CLASS	RATIO	EXAMPLE	STORAGE RATIO (%)	REMARKS
DAILY PONDAGE	~ 0.1%	Franquelin HEP	~ 0.1%	For 4 hours peaking, a longer peaking period will require more storage.
SMALL RESERVOIR	> 5% < 20%	Portland Creek	14.40%	Short term "temporary storage".
INTERMEDIATE RESERVOIR	> 20% < 40%	Tarbela, Pakistan	25%	Seasonal storage
		Snare Rapids, NWT	30%	Seasonal/annual
		Hinds Lake, NL	39%	Multi-year regulation
LARGE RESERVOIR	> 40%	Cat Arm, NL	47%	Multi-year regulation
		LG 2, Quebec	89%	Multi-year regulation
		Aswan, Egypt	300%	Multi-year regulation

Contributions to power grids

Hydro power plants provide flexible support to the operation of power supply grids in several ways:

- Supply of peaking capacity
- Provision of "virtual" storage
- Rapid dispatch
- Frequency control
- Reliability

Supply of peaking capacity:

At many hydro sites the incremental cost of hydro capacity is relatively low and is therefore attractive for installation of peaking capacity.

"Virtual storage": For hydro dominant systems with large reservoirs, hydro plants would be operated in conjunction with renewables (wind, solar or run-of-river hydro) to provide "virtual" storage. Essentially, during periods of high production from renewables, hydro plant operation would be curtailed and water stored in storage reservoirs and later, during periods of low production from renewables, this water would be used to meet system demands. This would minimize or eliminate energy loss due to mismatch between production and demand on such systems. Under this scenario renewable energy would be valued at the marginal hydro energy rate. This is the strategy that Hydro Quebec is pursuing in their support of wind power projects in that province. For renewables, supplying a mixed thermal dominant system, the inherent value of energy produced is the avoided cost of fuel. In other words renewable plants function as a "fuel savers".

Rapid Dispatch:

Hydro units can be dispatched rapidly, within 5 seconds to 1 minute +, compared to:

- 15 minutes for gas turbine plants
- 15 minutes for diesel plants
- 6 – 8 hours for coal fired thermal plants
- Few days for nuclear power plants

Frequency control:

Except for hydro units on long penstocks, most hydro units are able to respond quickly to load changes and thereby attenuate frequency swings on the grid. Hydro units also contribute significant inertia to a system which contributes to system stability. Finally, appropriately designed hydro units can operate as "synchronous condensers" to facilitate control of grid power factor.

Reliability:

Hydro units are more robust than other types of generating units which contributes to system reliability. On the other hand, long transmission lines sometimes associated with hydro developments introduce vulnerabilities that may compromise reliability. Whether the reliability contribution of a given hydro plant is positive or negative is dependent on its location and grid configuration.

Challenges to hydro

Hydro projects are subject to demanding and costly regulatory regimes which typically can add 5% to 10% to project cost currently, compared with 1% some 40 to 50 years ago. This situation can be attributed to more detailed attention to environmental and socio-economic issues than was formerly the case. Another factor is the size of a project footprint. Footprints of hydro projects are tend to be larger than most other energy projects (comprising reservoirs, site access and construction roads, transmission line corridors, camp sites, reservoirs and power plant proper) and attract more attention from regulators. In densely populated countries, flooding of farm land and villages, and resettlement are huge issues. Large developments face the greatest challenges, but even run-of-river hydro developments may have relatively large footprints but without the added complexity of reservoir development. In Canada the regulatory process is complicated by the involvement of federal, provincial and sometimes municipal/first nation governments. The process is convoluted and, dare I say it, incoherent. There does not seem to be a clear pathway through the process.

For the purpose of this discussion it should suffice to list some of the issues that may have to be addressed in the environmental, socio-economic and technical investigations to meet the concerns of regulators.

Environmental:

- Shoreline inundation
- Sedimentation
- Hydrothermal (sometimes)
- Biochemical, mercury and greenhouse gas emissions from reservoir flooding
- Alteration of river and lake regimes
- Impact on aquatic habitat

Socio-economic:

- Impact on other resource users
- Health, primarily in tropical countries
- Re-settlement, re-routing of roads or railways, etc.
- Economic benefits: construction and operation jobs, opportunities for local service providers, source of power with connection to grid, wealth producer for stake holders and communities.
- Other benefits may include: recreation and reservoir fisheries, flood control and flow regulation, etc.

Site issues:

Important technical issues related the site environs are normally part of a comprehensive feasibility study. These investigations normally include: assessment of water supply and flood hydrology, site geotechnical investigations (bedrock, soils and seismic) and site topographic surveying. These findings will also be of interest to the regulators.

Findings of the investigation phase usually provide recommendations for mitigating works that may involve structural and/or operational solutions. Where mitigation is impossible (or only partial) compensation in cash or kind would be assessed. At the end of the process the regulators have to decide whether the benefits out-weigh the costs and make their decisions accordingly.

Sustainability

There is widespread support for sustainable development ever since the Brundtland Report (1987). There are several definitions of sustainability, but the following definition captures this concept very effectively: *A method of harvesting or using a resource so that the resource is not depleted or permanently damaged.*

The idea that hydro is an unsustainable source of energy has gained surprising currency among some authorities from opinions expressed in the studies for the World Commission on Dams. This comes about from observations of sedimentation problems observed in reservoirs in areas where rivers transport large sediment loads, notably in South Asia. Applying this conclusion to all reservoirs in unfair. In Canada most hydropower potential is located on the Canadian Shield and Appalachian formations. These geologic environments have been exposed to millennia of glaciation which has left a landscape with unorganized drainage systems, with numerous bogs and lakes, and with a thin mantle of coarse soil. Relief is generally low and most often is controlled by geologic features that were resistant to glacial action and are often expressed as bare rock exposures even today. The combination of sparse sources of sediment and many topographic features that trap sediment results in negligible low sediment loads in most rivers; hence, the conclusion that reservoirs built in these geological environments will be sustainable. This conclusion is further supported by observing the evolution of Canadian lakes most of which are judged to be permanent, at least in a historical time scale. Studies of siltation of a glacial lake in Norway reported by Bogen (1985) which concluded that it took about 9,000 years to fill the lake with sediment produced by the Tunsbergdal glacier are consistent with Canadian experience. Meanwhile, sedimentation problems at run-of-river hydro plants can be successfully controlled by sediment flushing. The overall conclusion on this subject is that hydro sustainability is site specific and largely a function of the sediment regime.

The merits of a hydro project extend beyond the issue of sustainability and include: technical, environmental and socio-economic issues, as previously noted in Section 5. In the project preparation phase, the benefits, costs and trade-off have to be evaluated via a regulatory process which is charged with deciding whether a given project is in the public interest. It is a common assumption that environmental effects are always negative. This is incorrect as there may be positive benefits as well, such as: flood control, irrigation, domestic water supply (Mary’s Harbour – Labrador), flow regulation, recreation, reservoir based fisheries, ice control (Helwig, 2007), greenhouse gas reductions, etc.

Some authorities are claiming many issues as sustainability issues although they have little or no bearing on sustainability as generally understood. For example Electric Power Research Institute, EPRI (2013), talks about three pillars of sustainability: economic, social and environmental. Economic is basically about economic feasibility. Why pretend this is a sustainable issue when it is clearly about economics? Similarly, social and environmental issues are mainly about impacts and their mitigation and compensation. These are traditionally about acceptability issues and trade-offs and not strictly about sustainability at all. The International Hydropower Association, IHA (2010), proposes a Hydropower Sustainability Assessment Protocol that identifies 15 - 22 factors and determines relative scores based on comparisons to prescribed levels of good practice. Again most of these factors have nothing to do with sustainability. In reality the IHA encourages responsible assessment of hydro development effects, but most factors are better considered as issues of *corporate social responsibility.* Why debase the concept of sustainability by misapplying it?

Conclusions

The following conclusions are noted:

- Sustainability is a property that is a characteristic of the development of renewable resources and implies that such resources are developed and managed in a sustainable manner: whether agriculture, fisheries, forestry or renewable energy.
- In the case of hydropower with storage reservoirs sustainability may be an issue on rivers which carry large sediment loads. However, labelling all hydro storage projects as unsustainable is false. The issue is site specific. Reservoir developments on rivers transporting negligible sediment loads can be shown to be sustainable: notably, hydro power developments on the Canadian Shield and Appalachian formation. Run-of-river hydro plants are inherently sustainable as sediment deposits can be flushed.
- Hydro projects typically have multiple effects, besides sustainability issues, that have to be evaluated in the preparation of a project. Some effects can be mitigated in whole or in part by appropriate design and operation practices. Effects which cannot be mitigated may require compensating injured parties. Some effects may be positive! Applying the concept of sustainability to issues that have no bearing on sustainability is a questionable practice that will degrade this idea and undermine public confidence the process of

project environmental review. Many issues are best evaluated in the context of "corporate social responsibility" and are better described as such.

- Finally hydropower plants contribute many benefits to the operation of modern power grids including: supply of peaking capacity, provision of "virtual" storage, rapid dispatch, frequency control and reliability support.

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