HYDROELECTRIC POWER AND LOSSES - RUN-OFF

František Lizák, Martin Kanálik

ABSTRACT

The development and deployment of renewable energy technologies are important components for the future of a balanced global energy economy. The aim of this article is to provide an accessible scientific facts of hydroelectric power. In article is description of energy conversion principles, economics aspects and environmental considerations.

1. INTRODUCTION

Hydropower is by far the most significant renewable resource of energy exploited to date. According to the International Energy Agency’s (IEA’s) ‘World Energy Outlook 2006’, hydropower output worldwide is projected to increase from 2,809 TWh in 2004 to 4,749 TWh by 2030, representing an increase of 2% year to year on average. Against a projected growth in global electricity generation of 2.6% on average to 2030 practically doubling from 17,408 TWh in 2004 to 33,750 TWh, the share of other non-hydro renewable sources in total electricity generation is predicted to increase from 2% now to almost 7% by 2030. This anticipated increase in the use of other renewable resources occurs largely in OECD countries [2].

In 2001 hydropower was the world’s second largest source of electricity. Now it ranks fourth behind coal (40% now, increasing to 44% in 2030), gas (20% now, increasing to 23% by 2030) and nuclear (16% in 2004, but dropping to 10% in 2030). According to the IEA, with the growth of conventional generation, the share of hydropower in electricity production will fall from 16% to 14%, yet only about 31% of the economic potential worldwide had been exploited by 2004. In the OECD countries the best sites have already been exploited and environmental regulations constrain new development. In developing countries many large hydropower projects have been adversely affected by concerns over environmental and social effects of building large dams. The rapidly expanding demand for electricity, the need to reduce poverty and to diversify the electricity mix, however, are leading several countries to focus again on this domestic source of elektricity where the economic potential is still very large [3].

2. Energy Conversion Principles

Hydro-electric engineering is concerned with the efficient and economic conversion of energy ‘ freely available’ from a supply of water deposited at a suitable head by the action of the cycle of evaporation and rainfall produced by the effect of solar radiation. An essential requirement is, therefore, that the water should be at a suitable height above a lower reference point to where the water could flow and be discharged. The difference in levels between the water and discharge point represents the potential energy that would become available for use should water be allowed to flow between the two levels.

Since earliest times the direct conversion by gravity of the potential energy existing in differences in heights of water levels has been employed in the shape of the bucket water wheel [1]. The efficiency of conversion is not very high as only a part of the potential energy is available due to water spilling out of the buckets efore they reach the lowest part of travel. The undershot paddle type of water wheel has also been used; here, the water strikes only the bottom of the wheel, and the water, in falling down a channel or flume, has its velocity increased to provide more striking force on the paddles. Although the workings of such schemes are self evident, it should be noted that conversion of energy from one input hydraulic form to another rotating mechanical output is taking place. Hydroelectric plants, on the other hand, convert the potential energy of water into an electrical output. The process involves flow of water from the source, through the turbine to the turbine outflow (tailrace), which acts as a sink. In the process of conversion, use is made of water turbines, of associated civil structures and of rotating electrical machinery.

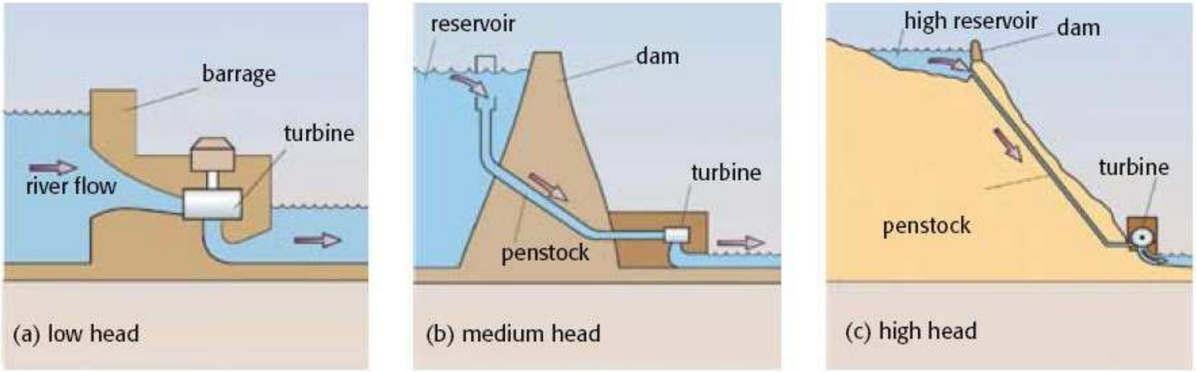
The power supplied to the turbine, P (kilowatts) is given by the product of the rate of mass flow ζQ (tonnes per second) and of the net head across the turbine H (net) (meters) corresponding to this flow:

$$P = 9.81\ \zeta Q\ H(net)$$

where ζ is specific mass (tonnes per cubic metre) and Q is the volumetric discharge (cubic metres per second). Power output is, therefore, a function of head and flow [1].

For all types of hydroelectric plant the gross head, H(gross), is defined as the difference in elevation between the water levels at the upstream (intake) and downstream (tailwater) limits of the installation when there is no flow. The net head, H(net), represents only a fraction, however large, of the total or gross head.

The difference between these two heads represents the losses within the plant, but outside the confines of the water turbine. These losses are either due to flow related phenomena or arise because of the need to set certain types of impulse turbines well clear of the tailwater level. The ratio H(net)/H(gross) is designated as the hydraulic plant efficiency (%) and represents a significant parameter when evaluating the worth of alternative designs of the civil work (Fig. 1).



(a) low head (b) medium head (c) high head

Fig. 1. Types of hydroelectric installation [3].

Hydroelectric projects are normally considered in terms of the gross heads they create. Exploitable heads vary from a few metres to 2000 m.

In terms of the use of water even at the highest heads the available energy levels per unit of mass flow of water, are substantially lower than those associated with thermal plants. Typically a conventional 660 MW thermal unit converting water to steam would require a water mass flow of 2000 t/h to achieve its full output. A similar rate of water flow in a hydroelectric unit, operating at 2000m head would produce an output of under 10 MW. At this flow, and at a head of 20m, the output would be below 100 kW, the capability of a small mini hydroelectric unit.

The greatest outputs, on modern units, have been achieved at net heads of around 120m where flow rates of 700 t/s yield outputs of 715 MW. Similar rates of flow have been considered for some feasible low head, tidal installations. Given a reasonable amount of rainfall and run-off, the essential physical requirements are: provision for collecting water at a suitable head and means for taking it to a piece of machinery for conversion of energy to power output. There are only two basic types of arrangement of the powerhouse within a scheme either ‘run-of-river’ or ‘diversion’, although there are variations. In run of river schemes the power house is local to the dam, i.e. is built into in the dam or is situated alongside it, whereas in diversion schemes the water supply is taken from a dammed river or lake and flows through a head race canal to a head pond or forebay in the vicinity of the remote powerhouse and thence down through a system of pressurised pipes (penstocks) to the turbines.

3. Losses - Run-off

Having made an estimate of the amount of rainfall, it is necessary to allow for certain losses. Some of the rain is lost by evaporation from soil water and vegetation surfaces, some absorbed by vegetation and some lost by percolation, which, depending on the geology might reappear as springs outside the catchment area. In the Highlands temperatures are moderate and humidity high which, combined with a high degree of cloud cover, means that evaporation losses are small particularly in winter. Evaporation, nevertheless, accounts for the major proportion of loss amounting to some 30 cm (12 ins.) of which 22 cm (8 1/2 ins.) is lost during the period April to September [2]. Due to the presence of impervious rocks and absence of serious faults in most of the development areas, losses due to percolation are small. The higher rate of evaporation in the summer has the effect of altering the distribution of monthly run-off compared with rainfall. The winter run-off is nearly twice that occurring during the summer. River flow records, representing run-off, are used to plot a flow duration curve. A typical flow duration curve for a Highland river shows such rivers as “flashy” i.e., have a large ratio of maximum flow to minimum flow, and few of them carry their average flow for more than one-third of the year. The extent of the diversity of flow gives a measure of the amount of storage that has to be provided to ensure continued operation during dry periods.

4. Economics

As with most renewable energy projects the costs per kWh of output from hydroelectric stations have historically been higher than for conventional coal/gas or oil-fired stations. This is entirely due to the initial capital costs of the extensive civil engineering works involved and to the very long periods of construction, during which costs are incurred and interest on financial investments (loans) has to be paid, without receipt of any compensating income. In contrast, operating costs are very low because there are no fuel costs and the additional fixed costs of running the plant are [comparable] with a thermal power station. Because a very large portion of the lifetime costs is incurred before a scheme is operational, the cost of borrowing is one of the major parameters to be considered when assessing the viability of any scheme. As a result, the construction of many hydropower schemes can only be justified by incorporating them within larger schemes producing additional benefits such as irrigation, flood control or navigation [3].

5. Environmental considerations

Hydroelectric schemes often provide excellent recreational facilities, first-class roads and river crossings. However, they lead to flooding of valleys, interfere with the migration of fish and can lead to the deposition of substantial amounts of silt upstream of dams. Tidal schemes can badly affect the ecology of an estuary, especially during the construction period, and on any such future schemes it will be necessary to ensure that at no time will a tidal reach of a river be turned into a temporary sweet water or brackish lake [2].

6. Conclusion

Notwithstanding the difficulties arising from the need to assess the ecological consequences of major hydropower project, their effects must be seen to have been taken into account in the assessment of the viability of any future scheme. Renewable energy can make major contributions to the diversity and security of energy supply, to economic development, and to addressing local environmental pollution.

7. REFERENCES

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Addresses of authors:

Ing. František Lizák
Technical University of Košice
Letná 9
042 01 KOŠICE Slovak Republic
E-mail: frantisek.lizak@tuke.sk
Tel: +421 55 602 3560

Ing. Martin Kanálik
Technical University of Košice
Letná 9
042 01 KOŠICE Slovak Republic
E-mail: martin.kanalik@tuke.sk
Tel: +421 55 602 3560