Water & Energy
The Economic Background

Dr. Janaka Ratnasiri*

Water stored at high elevation has potential energy. When the water is allowed to flow down a steep penstock or a shaft, the potential energy gets converted into kinetic energy. A turbine installed at the end of the penstock can convert the kinetic energy into mechanical energy. This energy could be used as it is by coupling the turbine to a transmission shaft, or as electrical energy by coupling the turbine to an alternator. Water flowing in a stream also has energy in the form of kinetic energy, which could be made use of by installing appropriate devices such as water wheels.

Water stored in reservoirs is also used for several other purposes such as irrigation, flood control and municipal water supplies. Often, a reservoir may be a multi-purpose type serving one of the above purposes in addition to generating energy. The energy produced in a hydropower plant depends on the product of the head and the volume of water released down the penstocks. The largest power plants in the world depend more on a large volume of water fed by a large catchment area than on a high head.

Global Scenario

The total electrical energy generated in the world in 1998 by hydropower amounts to 2,643 TWh/year (9,515 PJ/y) (1) (see Box 1). The technically feasible hydropower potential is much more, being about 14,370 TWh/year (51,732 PJ/year). While North America and Europe have exploited over 40% of the available sources, the global average is only about 18%. The distribution of these among different continents is given in Table 1.

The above total electrical energy produced from hydropower is only 2.4% of the total commercial energy produced globally in 1998, which is 397.10 EJ (2). It is however, 20% of the total electricity produced globally (3). Of all the nations in the world, only 2/3 generated any hydro-electricity. Almost 50% of the hydro-electricity generated globally in 1998 came from 5 countries; Canada, USA, Brazil, China and Russia (2). The contribution of hydropower to national grid in countries varies from zero up to about 99%. These countries are vulnerable to power shortages during periods of lean rainfall, as experienced in Sri Lanka in recent times. An exception is Norway, which totally depends on hydropower for electricity generation from reservoirs, which get filled by snow-melt.

Hydropower Systems in Sri Lanka

The major hydropower generation in Sri Lanka commenced with the construction of a 25 MW plant and a pond at Norton Bridge in late forties. It provided electricity to a larger segment of the population through the establishment of a national grid. The waters of Kelani tributaries, Kehelgamuwa Oya and Maskeliya Oya, collected in reservoirs built at elevations of 1,077 m and 1,200 m, respectively, generate electricity through several power plants built over several decades. This system, known as the Laxhapana Complex, has 5 power plants operating from waters cascading in each river and across them. The installed capacities and the average energy generated by these power plants are given in Table 2 (4). The last in this cascade, planned at Broadlands, is yet to be built.

Under the Mahaweli Development Scheme, which commenced in early seventies, six hydro-power plants were built for generating electricity as well as for regulating water to feed an irrigation network supplying water for agriculture. The first was built on Kotmale Oya, a tributary of Mahaweli, and three were built on Mahaweli river downstream of Polgolla where water is diverted for irrigation. The other two are operating from the diverted water. Their locations and other details are given in Table 2. Another major hydro-power plant was built on the Walawe river. These power plants, along with 3 other small plants, have a total generating capacity of 1135 MW.

Table 2 gives the plant factor of each plant for 1999, as well as their average values for previous years. This factor gives an indication of the percentage utilization of the plant during a given period. A plant operating at maximum installed capacity continuously for 24 hours a day for 365 days will have 100% plant factor. It is seen from Table 2 that the plant factors for 1999 have been varying widely from as low as 17% to 73%, while the averages for previous years have been consistently low, with a maximum at 57%. There are many reasons for this situation. The inadequacy of water to run the plants at full capacity, the low

Table 1: Distribution of Hydro Power in the World (1998)

Continent	Hydropower Potential TWh/year	Hydropower Production TWh/year
Asia	6,800	753
Africa	1,750	62
Europe	1,225	552
North & Central America	1,660	700
South America	2,665	534
Australia & Pacific	270	42
World	14,370	2,643

Source: Report of the World Commission of Dams, 2000 (1)

* Dr. Janaka Ratnasiri graduated from the University of Ceylon. He has also obtained a MSc. degree in Electrical Engineering from the Ohio State University and a PhD degree in Electrical Engineering from the University of Illinois. He was a Research Officer in the Applied Physics and Electronics Section of the CISIR and later its Deputy Director. He was the Chief Technical Adviser in the Ministry of Environment from 1993 to 1999. Dr. Ratnasiri is a Fellow of the Institute of Physics, Sri Lanka and the General President of the SLAAS for 2002.

Table 2 — Major Hydropower Plants

Power Plant	Installed Capacity MW	1999 Energy Generation GWh/y	Plant Factor in 1999 %	Average Annual Plant Factor %
Laxhapana Complex	**335**	**1,663.0**	**56.7**	**41.2**
Canyon	60	179.4	34.1	22.8
Wimalasurendra	50	104.3	23.8	24.3
Old Lakshapana	50	271.5	62.0	55.1
New Lakshapana	100	626.8	71.5	47.3
Polpitiya	75	481.0	73.2	56.7
Mahaweli Complex	**660**	**2,114.9**	**36.6**	**32.4**
Victoria	210	841.7	45.8	34.2
Kotmale	201	454.0	25.8	26.1
Randenigala	122	381.8	35.7	31.7
Rantambe	49	191.9	44.7	42.5
Ukuwela	38	185.9	55.8	48.0
Bowatenna	40	59.5	17.0	11.6
Walawe	**120**	**320.0**	**30.4**	**14.5**
Samanalawewa	120	320.0	30.4	14.5
Small Hydro	**20**	**54.1**	**30.6**	**21.4**
Inginiyagala	11	34.3	35.6	22.7
Uda Walawe	6	10.0	19.0	2.5
Nilambe	3	9.8	37.3	38.9
Total	**1,135**	**4,152.0**		

Source: Sri Lanka Energy Balance 1999 (4)

Table 3 - Variation of the overall plant factor during 1988 ~ 1998

Year	88	89	90	91	92	93	94	95	96	97	98
MW	938	968	1017	1017	1137	1137	1137	1137	1137	1137	1137
GWh/y	2597	2858	3145	3166	2900	3796	4089	4514	3249	3443	3909
PF %	31.6	33.7	35.3	35.5	29.1	38.1	41.0	45.3	32.6	34.6	39.2
Hydro %	92.8	98.0	90.8	92.3	81.9	95.4	93.2	94.0	71.8	67.0	68.9

Source: CEB 1988-1998 (5)

demand requiring reduced output and shut down for maintenance are some of these factors. It is seen from this table that the plants in the Laxhapana Complex have been operating at higher plant factors than those in the Mahaweli Complex. The former has been built solely for power generation, whereas the latter is a multi-purpose system requiring part of the available water to be released for irrigation, which could also contribute to this disparity.

Table 3 gives the plant factors for the entire hydro system over the period from 1988 to 1998 (5). These values vary from a minimum of 29.1 % (1992) to a maximum of 45.3% (1995), with an average of 36.0%. These give the year-to-year variation in the availability of hydropower. The impact of extended power shedding enforced in 1996 due to the prevailing drought is reflected in the sudden drop of the plant factor from 45.3% in 1995 to 32.6% in 1996. The continued low value beyond 1997 compared to that during 1994-95 period could be due to the fact more thermal power plants came into operation. The values in the last row under Hydro% gives the percentage electricity generated from hydro plants with the balance coming from the thermal plants. While the long term performance of the hydro plants has been below 50%, during the design stages, plant factors of about 75% had been forecasted (6). Though two plants achieved values close to this figure in 1999, their long-term values were again only slightly above 50%. Such high plant factors assumed would have shown an enhanced (unrealistic) viability of the project during the feasibility studies.

The hydropower component in the overall primary energy supply in the country has been worked out as 12% (4), but this is an overestimate (see Box 2). When the hydroelectricity is converted into the common accounting unit of Joule according to international practice, this component will contribute only 5%, with the other two supplies, petroleum and biomass contributing 40% and 55%, respectively.

Plants under Construction and Planned

Currently, a 70 MW hydropower plant is being constructed at Kukule River. It is more a run-of-the-river project with a rather small reservoir. Originally, it was planned to have a high dam with a large reservoir with provision to divert water through a trans-basin canal to the South Eastern region for irrigation. In another project to be carried out at Upper Kotmale Oya, work got delayed due to planners not considering options available to minimize environmental impacts, and subsequent protests from the public. This is a rather complex project, where water from six streams are collected through tunnels at a common underground point and then taken to an underground powerhouse along an underground pressure tunnel. Detailed design work is being undertaken only now. Their installed capacities, energy generation forecasted and the expected plant factors are given in Table 4 (7, 8).

A study made in the 80s found that the country has a total hydropower potential of another 1000 MW approximately (9). These included both large and small (<10 MW) capacity plants. Out of these, four have been included in the CEB's current Long Term Generation Expansion Plan 1999-2013 (LTGE Plan) (8), and their details are given in Table 4.

The Master Plan referred to above has identified several more sites for developing medium size hydropower plants of capacity 10-40 MW, with minimum inundation of land and resettlement of people. In view of the current shortage of generation capac-

Power and Energy

Power and Energy are two terms, which are often used loosely in connection with energy. But, they have specific meanings. Energy is equivalent to work performed and is measured in Joules (J), whether electrical, mechanical or heat energy. The rate at which work is performed is referred to as Power, and is measured in Joules per Second or Watts (W). Sometimes, for convenience, energy is expressed as a product of Watts and hours, or Watt.hours. The unit of electrical energy consumed is generally expressed as kiloWatt.hours (kWh), which is equivalent to 3.6 MWs or 3.6 MJ. Power plants are rated by their maximum power generating capacity expressed in MW. The heat energy is also expressed in Calories, where 1 Calorie = 4.184 J. The SI system prefixes used here are: Mega (M) = 10^6, Giga (G) = 10^9, Tera (T) = 10^{12}, Peta (P) = 10^{15} and Exa (E) = 10^{18}.

ity, it is suggested that detailed studies including environmental impacts be undertaken for their early implementation. According to the power sector policy directions of the Ministry of Irrigation and Power, the development of large hydro systems will remain under the Government, while the mini systems will be developed by the private sector (10). However, in view of the urgency of the matter and the inadequacy of the Government mechanism to undertake these projects early, it is suggested that the Ministry policy be reviewed to allow the private sector to develop these midi-hydro plants too.

Small Hydro Plants

During the late 18th and early 19th century, the estate plantations made use of water energy to run their factories by directly coupling the water wheel to the factory transmission shaft, which drove all the machines. These systems continued to drive the factory machinery until the national grid supply was given to them. It was reported that by the end of the first half of the last century, the country had over 500 such water driven systems, which were later abandoned (11). With the escalation of the cost of grid electricity, some of these plants have been rehabilitated and currently, about 60 such micro-hydro plants are in operation mainly in tea plantations.

The Government recently made a policy decision to permit the private sector to participate in the energy generation process by building small hydropower plants of capacity below 10 MW. Both off-grid and grid-connected plants are being developed by the private sector. Already 10 such plants have been completed and connected to the grid with a total capacity of 6 MW (11). More than 40 other plants with capacity of about 95 MW have been approved. In addition, more than 100 micro hydro plants, each having capacities in the range from a few tens of kilowatts to a few hundreds of kilowatts, have been built in remote hilly areas as stand alone units supplying power to more than 3,000 households. Financial assistance for the development of these small hydropower plants is available through local development banks from a grant given by the Global Environment Facility.

Table 4. Hydro-power plants under construction and identified for future development

Site	Capacity MW	Forecasted Generation GWh/y	Plant Factor %	Unit Cost Rs/kWh
Kukule	70	306	50	
Upper Kotmale	150	536	41	
Gin Ganga	49	209	49	3.86
Broadlands	40	145	41	5.11
Uma Oya	150	456	35	5.66
Moragolla	27	110	46	5.72

Source: CEB, 1996, 1999

Cost of Hydropower

It is generally believed that hydropower is a cheap source of energy as the fuel, which is water, is available free of charge. However, the utilization of this source of energy requires building of high dams to create large reservoirs, long tunneling and other infrastructure facilities such as roadways. All these need high capital investments, which have to be raised through loans. When the cost of financing the project is included, the unit cost of electricity produced from hydropower becomes comparable or even more than that produced from other sources of energy. For example, the Ceylon Electricity Board has estimated the unit cost of electricity produced from the proposed hydropower plants to be in the range Rs. 3.9 – 5.7, while that for thermal power plants to be in the range Rs. 2.4 – 5.0 (8).

These estimates of life cycle costing, however, depend on various assumptions including discounting rates, which are subject to many uncertainties, and may not be valid when long-term benefits are considered (12). Most of the plants in the Laxhapana Complex are now over 25 years old, and their capital investment may have already been recovered. Under such situations, the cost of production will include only the cost of routine operation and maintenance and occasional overhauling. As such, a unit of electricity generated should cost much less.

Environmental Considerations

The building of hydropower reservoirs affects the environment adversely. The large reservoirs inundate large extents of fertile agricultural land and forests, displace households and other settlements, interfere with the aquatic life in the river, increase the incidence of vector borne diseases, affect the ecology and microclimate of the surrounding area and cause other environmental impacts such as leakages due to poor geology of the area. These impacts could be mitigated by avoiding building of large reservoirs and instead making use of the normal flow of the waterway to drive the turbines, known as run-of-the-river systems. This is however possible where the flow is more or less uniform throughout the year. Large hydropower plants also emit methane, which is a greenhouse gas, but the quantities are negligible compared to emissions from thermal plants (13).

It is important to identify environmental and social problems that could arise when large hydro projects are undertaken, and to incorporate mitigatory measures into the designs. The present environmental laws require both small and large hydro plants to be subject to Environmental Impact Assessment process with public participation. However, at the time of development of Laxhapana and Mahaweli complexes, such regulations were not in place, and work was commenced disregarding any damages to the environment. The Laxhapana Complex resulted in the two waterfalls, Laxhapana and Aberdeen being deprived of water for most parts of the year, but no one protested unlike in the case of the Upper Kotmale project. Perhaps the public concern for the protection of the environment was absent at that time.

The construction of large projects without carrying out detailed studies of the geology of the area necessitated payment of heavy penalties as happened in the Lower Kotmale and Samanalawewa projects. In the Kotmale project, the pressure tunnel developed a leak after it was commissioned, and the entire length of the tunnel had to be lined with steel, at great cost, to arrest the leak. The Samanalawewa project also developed a leak underneath the dam when the reservoir was being impounded. After many trials, the reservoir bed had to be lined with a layer of special soil, again at great cost, to bring the leak under control.

Among the proposed new hydro projects, at least two, viz. Uma Oya and Gin Ganga, are likely to have adverse impacts on the environment as well as conflicts with other users of water. The waters of Uma Oya feed the downstream reservoirs of Mahaweli and meet irrigation needs of the Mahaweli farmers. If diverted to the South, the project can generate electricity and also augment the water needs of Ruhuna farmers, but it will deprive water to Mahaweli farmers as well as to Uva farmers living below the diversion point. Since the waters of Uma Oya are also limited, a decision on this project has to be taken after careful consideration of all factors involved, and not just the energy needs. Similarly, the Gin Ganga project also needs careful consideration as it is located close to the Sinharaja Forest with a highly sensitive ecosystem. It is essential that a detailed environment and social impact assessment be undertaken for these two plants with the available information, before proceeding with the detailed designs. In both cases, the current CEB Long Term Expansion Generation Plan (8) gives adequate information to initiate a dialogue with the affected parties.

The multi-purpose nature of the projects and the demand for water from the same sources for electricity as well as for agriculture, calls for the establishment of a high-level decision making authority for the allocation of water to different users. A mechanism should be put in place to compensate the farmers for loss of their production when water in multi-purpose schemes is diverted to produce electricity to meet the needs of the industry and the affluent.

Conversion to a Common Unit of Energy

The accounting of the total energy consumed by a country requires summing up of energy generated from different types of sources. The heat energy generated during combustion is obtained by multiplying the quantity of fuel consumed by its calorific value, and totaling the products in Joules, which is the common energy unit used. In the case of hydro-electricity, the annual generation is expressed in GWh. It is converted to Joules, using the relationship 1 GWh = 3,600 GJ. This is the practice adopted by all international agencies. However, in Sri Lanka, the hydro-electricity is converted to Joules on the basis of the heat energy of fuel consumed by a thermal plant generating the same amount of electricity, with 35% conversion efficiency. The 12% hydro component quoted by ECF will become 4.7%, if the international system is adopted. The ECF conversion rate becomes invalid when the system includes new combined cycle gas turbine plants with almost 50% conversion efficiencies.

References

1. *Dams, Water and Energy – A Statistical Profile, Annex V, World Commission of Dams (CD-ROM), London, 2000.*
2. *Key World Energy Statistics, International Energy Agency, Paris, www.iea.org, 2001.*
3. *World Energy Outlook 2000, World Energy Council, London, 2001.*
4. *Sri Lanka Energy Balance 1999, Energy Conservation Fund, Colombo, 2001.*
5. *Statistical Digests 1988-1998, Ceylon Electricity Board, Colombo.*
6. *Fernando, P N, Future Hydro Electricity Developemnt, in "Energy in Sri Lanka", Seminar Proceedings (Ed. M Munasinghe), 10-12, January, 1980, Colombo, pp. 148-155.*
7. *Long Term Generation Expansion Plan 1996-2010, Ceylon Electricity Board, Colombo, 1996*
8. *Long Term Generation Expansion Plan 1999-2013, Ceylon Electricity Board, Colombo, 1999.*
9. *GTZ Master Plan for the Electricity Supply of Sri Lanka, Ceylon Electricity Board, Colombo, 1989.*
10. *Power Sector Policy Directions, Ministry of Irrigation & Power, Colombo, 1998.*
11. *Sri Lanka Country Report presented at SAARC Meeting on "Renewable energy in South Asia – Status and Prospects", 12-14 June 2000, Colombo, World Energy Council, London, 2000.*
12. *Diandas, J. Some aspects of determining the cost of hydroelectric energy, in "Energy in Sri Lanka", Seminar Proceedings (Ed. M Munasinghe), 10-12, January, 1980, Colombo, pp. 156-170.*
13. *Gagnon, L and Chamberland, A., Emissions from Hydroelectric Reservoirs and Comparison of Hydroelectricity, Natural Gas and Oil, Ambio Vol. 22, 568-569, 1993.*