D. R. Wimalasurendra Commemoration Lecture:
THE NEW ROLE OF THE CONSULTING ENGINEER IN HYDRO POWER DEVELOPMENT

by

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1.0 Introduction

I thank the Institution of Engineers for inviting me to deliver this prestigious lecture. To begin with I would like to talk in appreciation of the great Galeian Mr. D J Wimalasurendra. He pioneered the Norton - Laxapana 25 MW hydroelectric project which later developed into a storage backed 100 MW project as envisaged by him, Saving a colossal amount of foreign exchange. The 25 MW project has operated for 50 years . There is no doubt that it will continue to operate for the next 50 years.

The effort required by Mr Wimalasurendra to push his project under a colonial administration which held sway would have been indeed a Herculean task. He fought in this Institution on technical issues single handed with a colonial administration until it cost him his job. He continued to fight after winning a seat in the state council and won.

After half a century of independence we still talk about unreliability of hydroelectric power . These statements are repeatedly made in the media and can go unchallenged only in an ill-informed society. Our energy policy makers are yet to be convinced on the reliability of hydroelectric power.

In this lecture I will try to describe the changing role of the consulting engineer in hydroelectric power development. Also, how consulting engineering practices has adapted to the new requirements. The observations are based on my experiences in hydroelectric power development in Sri Lanka and abroad.

2.0 Role of the Consulting Engineer

Consulting engineers are mainly engaged in two different ways.

- A client who engages a consulting engineer because he lacks the knowledge and the expertise to do the work
- An educated client who does not wish to divert his resources from his core business of production to do development/project work

Into the first category falls private investors who wish to invest in a new project or wish to buy an operating project and banks and financiers who needs to know the viability of a project for which an investor has applied for a loan. In the second category are utilities who wish to start a new project, rehabilitate old installations or augment/ improve existing transmission systems

Services needed from the consulting engineer are mainly:

- Inception reports - that describe the intentions of the investor, location , access routes, previous studies, alternative sites, available maps, surveys and data that could be useful to the project.
- Pre - feasibility studies - that determine the preliminary technical and economic feasibility of alternatives and selects one or two alternatives for detailed investigations and studies.
- Feasibility studies - include complete surface and sub-surface investigations, hydrology, selection of best alternative, equipment selection, operation studies, system integration studies, optimising of project parameters, system stability studies, protection studies, environment impact assessment, market studies, licensing, power purchase agreements. costing, pricing, risk assessment, financial and economic analysis etc.
- Due diligence - needed by an investor to purchase an existing installation or required by a Bank to finance an investor who wants to acquire an existing installation. The study will enable the investor / Bank to assess whether the investment will give the expected return and be advised of the risk he is taking in making the investment. The consultant has to estimate the maintenance and operating costs and income from the project during the specified return period of the investment, the expected market value / cost of dismantling the installation at the end of the return period. The consultant has to investigate ex-

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isting licensing agreements and cost of new licensing agreements that may be required. He should examine probable future constrains in operating. Strange as it seems the investor is not interested in the value of the assets he is going to invest in. He is, however, interested in the condition of the plant, design defects, service history of each item of equipment, forecast of anticipated problems, availability of services from the manufacturer and most importantly estimated cost of maintenance and /or refurbishment of the plant during the return period of his investment. He will be also be interested in a forecast of the market demand, likely price variations in existing purchase agreements or outside such agreements and a forecast of interruptions to production by way of internal and external plant outages. He will be interested to know of marginal benefits and costs of possible improvements to the project.

- Environment Impact Assessment - to study the effects of the project on the environment during construction, in the lifetime of the project and afterwards. Measures that could be taken to mitigate the undesirable effects on the environment.
- Risk Assessment - natural or man made risks to the investment during construction and during the life of the project.
- Rehabilitation - studies required by Owners to rehabilitate and refurbish old installations in order to extend their life and to increase outputs and efficiencies and to reduce operating costs taking advantage of new technology. Project management - supervision of design and construction, progress, contractual and financial management to completion

3.0 New challenges to the Consulting Engineer

After the fall of the planned economies in Eastern Europe, governments of several countries started to apply free market concepts to public utilities such as electric power, water, health, transport, gas etc. Governments realised that they could encash the enormous capital locked up in the assets of state owned utilities and still have the supplies available to the people at competitive rates. The capital released by the sale of the state utilities was available to offset public sector burrowing requirements for other purposes. The bonus was that the state did not have to fund new projects for the privatised utilities or subsidise inefficient state owned utilities. .

To provide competition the state owned utilities were broken up and sold to several investors. With the breaking up of the large monopolies, the planning and design of these utilities were thrown into the market place. It was not economical for the private companies to have in - house planning , design and project departments. Instead they commission consulting engineers to do this for them. The private investor wants to run his core business efficiently and hires the experts when needed.

Electrical power and energy water and gas began to be treated as any other commodity as grain, metals o r oil, subjected to the same market forces. Electrical power and energy is bought by the transmission and distributing companies and users at auctions and by negotiated contracts. Consulting engineers help private investors to study market demand plan, design and locate new profit making projects.

Previously consulting engineers provided limited services to national utilities. It was a limited clientele who themselves had planning and design departments. Consulting practices had to be contended with the overspill or limited to provide very specialised services. Often jobs went to favourites. The new scene brought with it a sudden increase of clients. The type of clients changed from the mandarins to the entrepreneurs who were familiar with market competition. The new type of client demanded competitive prices and quick decisive answers. Investors require firm recommendations with risk assessment of their investment - not elegant technical solutions.

The new concept opened new opportunities to the consulting engineer.A new field of finance was open to provide services. Electrical power and energy was bought and sold and transported as a commodity.
Consulting engineers who were familiar with generation planning, load forecasting , generation scheduling , transmission, costing etc. were best suited to formulate the trading rules for this commodity. Privatisation brought with it a whole new field of financial activity for the power engineer. To be a main player in this field the engineer has to be adept at using financial tools that was the domain of the accountant.

A block diagram of an electricity trading system is shown in the slide.

Private sector utility companies find that they have excess cash. They might find investment in the power sector abroad more attractive. Regulating laws on price may be less severe and operating costs lower than in their own country. Consulting engineers are commissioned to produce due diligence reports of the targeted installation.

Private sector investors do not want to be involved in the details of tendering, project design and construction. The consulting engineers took on the challenge to construct Engineer Procure Construct (EPC) projects. In this they were prepared to risk capital which previously was unknown to them.

4.0 Changing Climate in Hydroelectric Power Development

Major hydroelectric projects were developed either by state owned utilities or by large power companies in which the state was a major shareholder. These organisations had sufficient assets or backup required to take the attendant risk in making a long term investment in a new hydroelectric project. The following risks can be associated in an investment in a large hydroelectric project.

- Geology is not totally determinate.A geology report is an estimate made from a sample.
- Hydrology studies forecast water inputs to the project from existing conditions. Climate changes, deforestation, changes in land use, environmental changes etc. could affect inflows.
- Change of government political and financial policy.
- New environmental laws that could reduce production. Change in market demand.

The private investors are either independent power producers (IPP) or non utility generators (NUG) such as municipalities. They may not find it attractive enough to invest in a new large scale hydroelectric development because of the above risks, some of which are unfamiliar to him. On the other hand an IPP may like to invest in buying an existing project or in developing small scale hydroelectric projects whereby distributing his investment risks.

In the former case the consulting engineer is required for due diligence of the targeted project and in the latter case feasibility studies are required from him.

5.0 Small Scale Hydroelectric Projects

Small scale hydroelectric project (SHP) development came to its own in recent years due to several reasons, which are:

- Uncertainties of environmental cost and benefits of large reservoirs and river diversions.
- Increased value of land due to population pressure.
- Unwillingness of lending agencies and banks to get involved in environmental controversies
- Fewer economically attractive large scale hydroelectric project sites available for development.
- Availability of environmentalist organisations that have the capability to whip up public and political pressures against proposed large/ medium scale hydroelectric projects.
- Comparatively smaller investment needed brought SHP projects within the reach of a larger group of investors.
- Reduced risks to the investment.
- Less environmental controversy.
- Plant manufacturers realising that equipment formed a large share of the cost of a SHP are willing to supply equipment for a share of equity.

Geological risks connected with large reservoirs and long tunnels are not easy to manage. Extensive subsurface investigations required for risk management are expensive. On the other hand geological risks connected with a weir across a river, a head race channel or a short tunnel are not expensive to manage. This is a great incentive for the private investor. He can understand that risks to his investment are manageable and he does not have to spend large sums upfront for subsurface investigations.

A large /medium scale hydroelectric project takes 8 years or more from inception to production. The SHP has a short gestation period. From inception to production it can be as short as 3 years or even less if funds are available. The private investor finds the quick start of production and consequent quick return of his investment attractive.

Most SHPs are within the construction capability of local contractors. This avoids construction of expensive camps to suit the requirements of expatriate construction personnel. For a SHP the basic construction materials such as cement and steel requirements are usually within the production scope of the country and need not be imported. The transport weights of generating plant such as generators and transformers of small scale hydroelectric projects are usually within the capacity of existing roads and bridges. The above advantages in SHP development encourages private sector investment.

The increasing interest shown by the private sector in small/medium scale hydroelectric power generation was recognised by some governments of developing countries. These governments encouraged private sector investment by providing a favourable environment for investment. Consultants were engaged to prepare feasibility reports and specifications for developing small/medium scale hydroelectric projects on a BOT basis for available project sites. Contract documents were drawn up to enable the government to implement these projects on a BOT basis These studies were made available for the private investor. The favourable ratio of equipment cost to civil engineering costs expanded the market for equipment manufacturers. Equipment manufacturers and contractors find that the market can be opened up by financial participation.

6.0 New Role of the Consulting Engineer

To perform in this changed scene the consulting engineer had to learn tricks to a new trade. He had to adjust to provide the requirements of the new environment. The requirements of the private investor was different to the requirements of the state owned utilities. State owned utilities planned, built and selected the type of power stations according to their own forecast of the market demand. The thinking was limited to a single department. Forecasts were often inaccurate and the chosen type of plant was not the most economical. E.g. in England and Wales at the time of privatisation the power stations under construction were in excess of the demand and of the wrong type. After privatisation several of the coal fired thermal plant were abandoned or sold abroad. The private generators choice was the more economical gas fired combined cycle power stations.

The state owned utilities were answerable to politicians who were advised by the utilities themselves. The IPP is governed by the market which is a very demanding master. There was now a feedback control loop which previously did not exist. The private generator has to get it right or quit the scene. He in turn hired a consultant to advise him. The consultant himself is governed by market forces and has to be good to survive.

Consulting practices had already started to change from partnerships to limited liability companies in the '80's. The entrepreneur needed a single consultant to advise on all aspects of the project and management of the project. Consulting practices merged to form bigger groups. Some even went further to be taken over by or to form alliances with foreign companies that were already operating in a market environment to form multinational groups.

In the field of hydroelectric engineering, the consulting engineer had to learn new skills and to innovate

7.0 Availability of Hydroelectric Power and Energy

In this country we have often heard statements made on the 'unreliability' of the power supply because of its dependence on hydroelectric generation. Let us define unreliability as we know it. Unreliability of a piece of equipment can be defined as the percentage of time/ no of times the equipment failed to give its designed output/duty. The well known bath tub curve illustrates the failure characteristic that can be expected of a piece of equipment during the course of its life (see slide).

A hydroelectric power station is designed and evaluated to give a calculated firm energy and firm power out put. Hydroelectric projects are designed on the basis of 98% - 99% reliability for both energy and power. Utilities choose their own reliability levels. The choice is usually made on economic grounds. During the planning stage of the Mahaweli power stations the agreed figure was 98.5%. The following table will illustrate the performance of two of these projects for the last 10 years.

Table 1 - Annual Generation of Energy at Kotmale & Ukuwela HPSS

Year	Kotmale (Firm Energy 310, LTE* 483) GWh	No. of failures	Ukuwela (Firm Energy 132, LTE 175) GWh	No. of failures
1987	10.37#	x	120.33	x
1988	434.82		146.14	
1989	330.26		109.44	x
1990	419.78		180.57	
1991	348.10		193.57	
1992	479.94		171.55	
1993	448.51		179.75	
1994	513.56		146.13	
1995	572.96		174.30	
1996	459.27		159.85	
Total failures		1		2

Notes # Reduced output due to failure of pressure shaft. * LTE - Long term expected

Evaluated in terms of designed firm energy output the performance of both the above projects are good. However, if their performance is evaluated in terms of Long Term Expected (LTE) figures the number of failures for Kotmale and Ukuwela would be 8 and 7 respectively.

I will illustrate the point I wish to make with a little story as an analogy. I earn a monthly salary of Rs1000/= (firm energy} and I usually work 40 hours overtime per month which gives me an additional income of Rs400/ per month (wet hydrological year secondary energy). I ask the payroll supervisor to send it to my bank account. I get used to writing cheques to the value of Rs1400/= every month (Generation). This is fine until my boss on instructions from the Board of Directors limits overtime to 20 hours. My income is now Rs1200/= (average year). I write a cheque for Rs1400/= and the bank does not honour it (power cut). The options left for me is: get another job that will get me a firm income of Rs1400/

= a month (increase system firm energy), go to the Bank manager and get an overdraft (power purchase by negotiated contract) and get progressively poor. What I should have done is: during good times invested the additional income I earnedby working overtime to earn myself a firm monthly income (construct a new hydroelectric project). My plight would have been worse if my employer cut all overtime (dry hydrological year) and my income was limited to my salary.

The basic technology required in hydroelectric engineering is long established. The operation and maintenance of a hydroelectric plant is very simple. Consequently the

forced outage rate (FOR) of hydroelectric plant is the lowest. Estimated availability of different types of plant including planned maintenance outages are shown below.

- hydroelectric plant - 95%
- gas turbine plant - 85%
- Diesels - 94%
- Steam turbines - 88%

The private power generator would want the consultant to provide him with an estimate of the availability and marketability of the production output from his installation.

SHPs are usually associated with run of the river plant or with small reservoirs with low regulation coefficients. The firm output as defined previously will be the output from the base flow in the river. This is not a good estimate of the economic worthiness of the project. The consulting engineer is required to device a method to estimate the true economic worth of the project to the investor in terms that he can understand. There are different methods of approach used by consulting engineers to solve this problem.

A simulation method was used to justify the economics of investing in Ukuwela hydroelectric power station in the Polgolla diversion project. The base flow of the Mahaweli Ganga at Polgolla could only give a firm power out put of 9 MW. One of the alternatives considered was to divert the water to a point further upstream of Dun oya with a shorter tunnel. This alternative shortened the construction time by an year which enabled additional income from 2 cultivation seasons priced at world market prices of agricultural produce. The utility fixed the purchase price of power at Rs. 0.05/ kWh of firm energy at the busbars. The additional cost of the longer tunnel to Ukuwela plus the cost of the power plant and loss of income from 2 cultivation seasons could not be justified with the income from 9 MW of firm power. The consultant used the concept of 'added' firm energy to justify Ukuwela hydroelectric power station.A model was developed by the consultant to simulate the operation of the existing power system from historical inflows at all the power stations connected to the system (Table 1). The integrated firm power out put of the existing system was determined for 20 hydrological years. The model was run with the output from Ukuwela power station added for the same hydrological period. The 'added' firm power from Ukuwela power station increased to 15 MW. This enabled the economic justification of Ukuwela power station.

Historic hydrological data is usually available on a monthly basis. Small/medium scale hydroelectric projects are either ROR or with small reservoirs that do not have monthly regulation. To estimate the power output from these projects to the degree of accuracy acceptable to the investor daily inflow data will be needed. Consulting engineers have developed very elegant statistical methods to correlate observed daily flows and historic monthly flows to obtain valid daily estimates of the output from these projects.

8.0 Dependable Capacity

Utilities used to consider dependable capacity of a hydroelectric power station as the capacity that would be available all the time. This is possible in hydroelectric projects with seasonal storage reservoirs. SHPs which are either ROR or with small reservoirs do not have this capability. Peak power is only required during peak time. Therefore in the evaluation of the dependable capacity of a hydroelectric project it is not correct to require "dependable capacity" to be available 24 hours a day 360 days in an year. If this were so, none of the pump storage plant operating in many countries would be economically viable. Credit should be given to SHPs and mini hydroelectric project for being able to supply dependable capacity to meet the peak requirements of the system To be marketable dependable capacity should be available at system peak time, usually 3 hours.

In a recent evaluation of small scale /medium hydroelectric projects that were offered for private sector investors in the Philippines the Asian Development Bank accepted the definition of dependable power suggested by Biggerstaff (Ref. 2). Installed capacity that was available for 3 hours a day was given credit. The investor should be paid for all the marketable products he produces from his investment. The electricity consumer pays not only for the energy he consumes but also a maximum power he uses. The Utility should in turn pay the IPP for providing dependable capacity. This is very necessary for encouraging private sector investment in hydroelectric power generation.

SHPs are usually located in remote regions. IPP or NUG development can take place in these locations where the utility may not be interested because of their smallness and remoteness. Such SHPs have a commercial as well as a social advantage in serving local areas where they are located than centrally located thermal plant

Utilities should quantitatively assess the reliability cost /worth of IPP or NUG capacity additions to the system. This can be evaluated either in terms of change in risk, Loss of Load Expectation (LOLE) approach or by using customer interruption costs to evaluate the total system costs and assess capacity inputs for an optimum level of reliability (Ref.3). Evaluation of capacity injection can be done at two hierarchical levels (HLI) and (HLII). HLI estimates generating capacity required for the desired level of reliability. HLII evaluates composite generation and transmission facilities and takes cognisance of location. Utilities generally are satisfied with HLI evaluation. However, future capacity inputs from IPP/ NUG can be significant and the evaluation of potential benefits should be by a reliability cost/ worth of the composite system.

To give due credit to the distributed location of SHP in the network, consulting engineers should determine the extended benefits associated with injection points of IPP/NUG projects by evaluating these projects in terms of HLII.

Utilities that have a number of hydroelectric projects having reservoirs connected to their power system may take measures in the wet season to improve the level of reliability during the dry season. Midway during the wet season the utility can reduce the outputs from generating stations with reservoirs. To compensate the utility will buy energy from the IPPs on the basis of avoided costs applicable to the wet season. The actual avoided cost payable to the IPP is the price for energy supplied plus the equivalent capacity cost of a gas turbine or a diesel.

9.0 Design Innovation

In a project with a large reservoir, silt is not a problem during the life of the project. Silt is usually deposited in the upper regions of the reservoir. Consequent reduction of reservoir volume can be acceptable. In these projects silt does not reach the intake therefore the quality of water available for running the turbines is good. However in a SHP silt becomes a problem. Turbines are very vulnerable to silt. The acceptable silt particle size a turbine can live with varies from 0.5mm to 0.2mm depending on the shape and hardness of the silt particle. If the material is quartz with sharp edges then only the smaller size is acceptable. Turbine blades are designed and manufactured to a optimum hydraulic shape and surface roughness less than a limit value. The limit value is defined by a function of the hydraulic head and the specific speed of the turbine as shown in the slide (Ref.4). Eg. for a turbine working under a head of 200 m and a specific speed of 150 the limit roughness for a hydraulically smooth surface is 10(m Silt erodes critical turbine water passage ways such as trailing edges of guide vanes, runner blades and top/bottom cover cheek plates. Once the limit value of roughness for a hydraulically smooth surface is exceeded the process of loss of metal is progressive by a mechanism of combined erosion and cavitation. The turbine soon becomes inoperable. Several cases have been reported where maintenance had become uneconomical and the project abandoned.

It is left to the ingenuity of the consulting engineer to device a site specific de-silting facility. The simplest solution is the automatic de-silting basin. However, these are long (about 80 m depending on the permissible particle size) and expensive. Often space does not permit construction of a de-silting basin to the required length. Some very economical de-silting facilities have been designed by consulting engineers by co-ordinating the design and location of the intake, de-silting facility and turbine specifications.

Technological improvements in microelectronics in recent years has opened up a opportunities to innovate on controls needed for a SHP. A significant economic advantage can be gained for the governing, voltage control, and protection of a SHP using current technology.

SHPs are often located in remote and environmentally sensitive areas. IPPs are very cautious not to be involved in environmental controversies that would put their investment at risk. Some very attractive projects in developing countries are located in environmentally sensitive places like national parks and wild life reserves. Governments lacking capital to develop these projects like to offer these projects for private investors. However, they want designs to be least intrusive to the environment of the parks. Consulting engineers have innovated designs mitigating the intrusive effects of such projects. Eg. In the Visayas group of islands in the Philippines the intake of a very attractive project put out for private sector investment was located well within a very special moss forest. Environmentalist groups did not want any surface access road to be built either for construction or for operation of the project. The consulting engineer designed the water conveyance tunnel so that it can be used as a access road during construction of the intake and subsequent use as a waterway and man access for maintenance (see slide). Environmental groups were satisfied that status quo was maintained, i.e. easy access to the public that would have destroyed the moss forest was denied. Only the few true enthusiasts could view the moss forest the hard way.

10.0 References

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