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Objectives for Small Hydro technology

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de

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ACCORD DE COLLABORATION SUR LES TECHNOLOGIES HYDROELECTRIQUES

Annexe II - Petite hydroélectricité

PART I Objectives for small hydro technology

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Table

1. Introduction

Hydropower is a mature technology developed since more than 100 years. The criterion generally adopted to define the type of hydroelectric power plant is as follows :

Micro and mini hydropower plants:	up to 100 kW
Small Hydro Power plants	100 to 10 MW
Large Hydro Power plants	> 10 MW

Hydro energy has very interesting properties compared to other sources of energy :

- it is one of the cheapest renewable source of energy. Hydropower energy is mainly in competition with thermal sources of energy. Because of falling prices on the electricity market during the recent past years, small and medium-sized hydropower plants are coming under increasing pressure
- thanks to the good actual forecasting tools for hydrology resources, long-term planning for hydro energy is possible and long-term assurance of viable payments for supply to the network and stable costs can be guarantee, compared to fluctuating prices of the fossil energy
- impact on environment is minimal if sufficient precautions are taken
- due to the fast start or stop of hydraulic turbines and the large operating range of these machines, hydro energy permit easy control of load on the grid. Comparable flexibility is only possible with gas turbines
- the possibility of energy storage in a reservoir permit to manage the production in the best economical interests, to store energy during off-peak hours and to release it during peak hours (these property is particularly interesting in complement of other sources of energy like nuclear power or wind and solar energy,...)
- hydro plants are well adapted to decentralized energy production in remote area and easily adjustable to local energy demand
- hydraulic power permits very secure regulation techniques, that permits to guaranty high quality of current in comparison of others sources like wind energy where rapid unpredictable fluctuations are present

Future of Small Hydro is directly connected to need of new energy sources, to the relative economical position of the Small Hydro energy to the other sources of energy and to the importance of environmental concerns which are often contradictory between interest in renewable energy and environmental values associated with rivers :

- a fundamentalist environmental policy is more and more creating obstacles to rational and environmentally-friendly development of hydropower. However the contribution of hydropower to sustainable and renewable energy is major and adequate solution can be and must be founded to guaranty environmental protection and hydropower development
- gigantic hydro projects built without regard to nature and man discredit hydropower and reduce its international social acceptance; small and medium-sized hydropower plants on the other hand can be extended in a sustainable environmentally-friendly and socially-compatible manner
- complex and costly licensing and financing procedures designed for major projects discourage potential builders of small and medium-sized power plants and not infrequently result in the abandon of these projects which in fact make the best sense. The legislators, authorities banks and financing institutes must simplify the procedures

and improve the background conditions, so contributing to the development of the great potential which exists, especially in the developing countries

- the free access to the grid with the liberalization of the electricity market are threatening the economic basis of even the large existing plants. Only far-reaching accompanying measures (CO² levies) can ensure the competitiveness of hydropower plants facing of fossil fuel-fired plants in periods where gas or petrol prices are low. Nevertheless investing in small hydro is not for ″fast money″ but for ″sustainable money″.

2. Condition of development of small hydro in developed countries

In developed countries, the easiest part of the hydropower potential is exploited and the corresponding unit energy costs competitive to other sources of energy . Without governmental incentive the development of small hydro is directly connected to the energy unit cost of new equipments.

For instance in E.U. a prospect for Renewable Energy in 30 European Countries from 1995 to 2020 has been established by the TERES II group [1] . This analysis shows that Hydropower is one of the few economically significant renewable source of energy (see table 1).

Technology group	Unit Costs 1 995	Unit Costs 2020
	€ cents/kWh (Electricity)	
Fossil fuel/ centralised electricity	4 - 6	
Fossil fuel/ decentralised generation	8 - 12	
Large Hydro	3 - 13	2,6 - 11,2
Small Hydro	4 - 14	3,6 - 10,1
Wawe/Tidal	6,7 - 17,2	6,1 - 11
Residues	4 - 10	2,5 - 6
Energy Crops	10 - 20	4,5 - 13
Wind generators	5 - 9,8	2,5 - 7,3
Solar thermal	20 - 24	8 - 10
Solar PV	31 - 29	8 - 22
Wastes	4 - 5	4 - 6
Geothermal	5 - 8	5 - 7

Table 1 Unit energy costs (TERES II[1]). (1€~1US$)

The hydropower potential in E.U. represent 11.8% (48.6 Mtoe) _ see figures 2 _ of the total renewable energy potential. In 1995 total hydro energy represent 24.9 Mtoe (36.1% of exploited renewable energy). Small hydro (<10 MW) accounted for about 3% of the total hydro capacity only, i.e. 0.75 Mtoe The TERRES II group estimates that if the unit cost of small hydro energy should decrease of 20% from here to 2020 the hydropower will represent 13% of the renewable energy exploited, i.e. 29.6 Mtoe, what corresponds to an increase in 4.74 Mtoe. This growth is only possible via small hydro owing to the fact that large possible hydro plant are at present mostly in exploitation. That estimation correspond to about five time the actual small hydro installed energy.

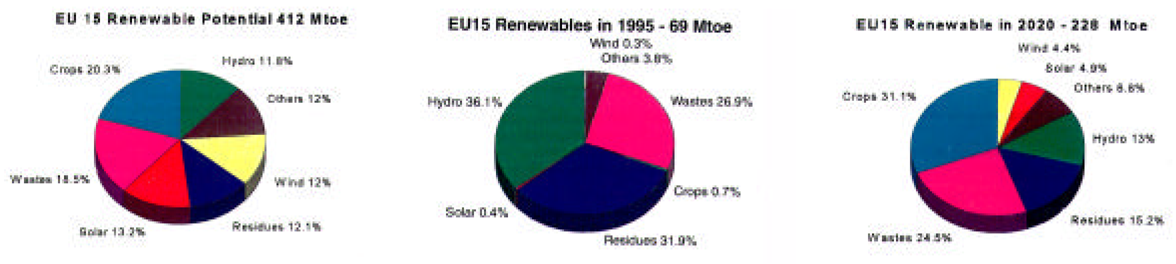


Figure 2 Potential and estimated evolution of renewable energy from 1995 to 2020 in E.U. (TERES II [1]).

The new market related to the 20% drop in hydro energy cost correspond mainly to ***low head power plants*** and also to ***marginal hydro potential development*** such as the *drinking water* or *wasted water* supply networks or *complementary to irrigation* or *offshore turbines* for see currents or very large rivers (Darieus or propeller _see ANNEX I).

In region like Europe, many plants are relatively old and now arise the problem of the ***rehabilitation*** of the existing plants. The technical-economical assessment of the period of exploitation must then be carried out carefully. It is often noted that the existing power plants are badly adapted to the hydrological potential of energy or to the request of energy on the grid, the reason is that the corresponding hydrological and economic data evolved or moved since the start-up of the power plant, or, and it is often the case, because these data were badly evaluated at origin. The operating conditions must also be analysed to reduce to the maximum the costs of maintenance and monitoring of the plant. In many cases these analysis justify a modernization of the equipment and overall this market is interesting for the small-hydro manufacturers on the condition of placing at their disposal the ***tools*** which make it possible to make a success of the rehabilitation.

3. *Condition of development of small hydro in developing countries and remote area.*

In the developing countries, isolated island and Eastern Europe, the growing demand for energy is being met for the most part by thermal power plants; this has unforeseeable consequences for the global ecological balance. Development of the vast hydropower potential all over the world requires sensible statutory provisions, economic incentives and optimum financing potential. If the technical point of view is considered, to allow the development of the small hydro power plants, it is also necessary systematically to search a reduction of the costs of the equipment to improve competitiveness and enlarge the economical market.

In remote area where the energy demand of rural communities is mostly limited, this need can often be met more appropriately by small or micro schemes and is not adapted to large-scale schemes. The plants are often operated in isolation or are connected to local grids. Small hydro is well adapted to this local demand. In remote areas, the main competitor to small-scale hydropower is mainly diesel generation. The oil price are usually very low but the critical parameter are not only the price of oil, but the problem of maintenance , witch is a big difficulty in many countries.

New researches are again necessary to adapt small hydro design to the local characteristics, notably ***to reduce the economic limit for the head***, that is a brake for many potential projects.

Many potential plants exist under this limit, for instance in Amazonian region, or for tidal energy applications, where plenty of water is available, but with only very low head (1.5 to 2.5m) _ see for instance ANNEX III a research project for economical tidal power with 1.8 to 2.5 m tidal amplitude. If the interest of such kind of tidal power turbine is demonstrated many application will be possible (50 to 100 in the Amazonia delta or in India or England or Canada , ...

4. Integration of small hydro in the ecological environment

Past hydropower projects have disrupted fish runs, flooded fishing grounds, and turned rapids and spectacular scenic areas into placid lakes. These excess are origin of the often too severe regulations.
Both renewable energy development and conservation of river resources are crucial to present and future generations. It appears now that with some precautions, small hydro power can respect environment and in many cases can improve it.
Searching a rational and beneficial balance must be the focus of broad public policy and site-specific development decision. The level of market penetration of small hydro will also depend on future policies particularly environmental and development of technologies which make it possible to respect the ecosystem of the rivers.

All these procedures to preserve and ameliorate the river environment involve a loss of profit and must be taken in account in the budget of the power plan.

Ecology and waterpower beyond the possible opposition of these notion, it is important to pay attention on the global advantages coming out of their parity.
Decentralised way of electricity with care about the ecosystem-resource. Search of appropriate solution for each case and positive motivation of the principal actors may help in minimising the costs and amplitude of its realisation.

The goals for research and technology in Small Hydro is therefore not only to reduce the total cost of the equipment, but also to propose technology adapted to the future environmental policies.

Impact of small hydro on rivers

The ecosystem of running water is based on succession of periodically flood and low water, transport of sediments and organic matter, temperature variation between winter and summer. These natural cycle allow the development of the vegetation and are the principal engines of the dynamics of the rivers. High flows of matter and energy work quantity of micro-habitats whose ecological conditions subjected to this dynamics change constantly, the development of vegetable and animal community, precisely adapted to these permanent changes, is then possible.
With an hydro power plant, impact on the river ecosystem is not always full of consequence, but become it if the river loses its functionality original.

The presence of a dam or a threshold blocks freedom of movement of fish. It is a danger in particular to migrating fish, salmon, sturgeon,... Technology for efficient fish bypass or fish ladder or fish lift exist, but in many cases the corresponding costs are very high can make the project non uneconomic, in particular in the case of low heads plants. Cheaper solution have again to be searched, for instance by developing prefabricated modules in concrete or better in low coast material who is better integrated than the concrete into the environment.

Figure 3 Made-up counter-channel [11].

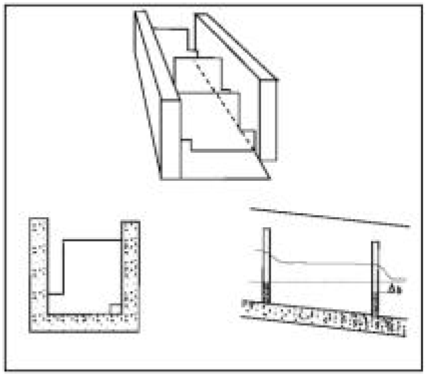


Figure 4 Prefabricated fish bypass.

Insofar as some place is available in the vicinity of the intake of water, the solution of a counter-channel is quite preferable than a fish ladder, of the biological point of view (it is the most natural solution), as from the financial one. The cost of the ground is very often relatively weak and the design is simple and easily perfectible.

Everywhere where that is possible in the vicinity of the plant, one must also develop local creation of micro-habitat favorable to the development of the aquatic life (vegetable ears and spikes, bench of gravel,...). These installation can be decides and developed in collaboration with local associations of fishermen.

Figure 5 Revitalizing of a power-plant feeder canal [11].

The improvement of the watery life in the zone of the plant can often be obtained with less expenses by creating for example favorable habitats in the feeder canal by revitalizing the banks of the monotonous channels with alive vegetable materials such as willows laid out in the form of fascines, cuttings ears, ... It is often enough to recopy the river upstream or downstream and to maintain an permanent activity of open-plan offices of the river, in connection with the angling associations, if possible.

An other important impact of a presence of a dam or a threshold is important modification of transport of sediment by the river. The sediments are trapped in the reservoir, whereas it would be transported periodically by the river. The consequences are the following ones. Downstream from the dam, the phenomena of transport of sediment are reduced and river bed which was enriched by these contributions changes, there is often a filling of the substrate the quantities of sediments accumulated in reserve must regularly be evacuated by draining off. These draining have the character of exceptional risings where water is very charged out of solid matter, which often destroys the small organisms. With these disturbances the fact is added that it often remains after the purging a large quantity of fine sediments in the bed of the river which blocks for a long period interstitial spaces of the riverbed which play a fundamental part for the aquatic life.
Actual policy is to research an optimal management of the draining. It must be studied with a specialist in the ecosystem of the river, primarily be carried out in period of high waters with a planning in details of the opening of the vanes and checking the concentration of sediments released and the incidence of the draining on the oxygen content in water. These draining must be carried out apart from the periods sensitive of the life of the aquatic organisms.
One could also try to develop a system of drainage by distributed pipes at the bottom of the reservoir to allow a draining purging of the reservoir (this draining water could be turbinate in part). This regular draining could be realized according to a cycle which reproduces the natural transport of the sediments of the original river and thus to disturb the ecosystem of the river at least.

Irregular turbine operating related to the management of the peak hours in some case causes artificial fluctuations of the flows downstream of the restitution of the water, the effects of which are measured on very long distance. The consequences are then the following ones: high and low water of the wet surface of the riverbed, which causes the death of aquatic organisms being abruptly put dry and artificial derives from the living organisms not resisting to the large quantity of water evacuated at the time of the turbine operating.
Procedures must be developed to operate the reservoir to keep the changes of river eco-system to a minimum and within an acceptable range.

Researches to define fish-friendly turbines or water-friendly turbines must be carry on.
One knows already fish-friendly turbine shapes , in particular for the low head plant which respect the passage of the fish, indeed the probability of being cut out by the blades is relatively weak, on the other hand it is especially the pressure gradient which are dangerous for the swim bladder of fish. By adapting the shape of the blades it is then possible to allow the passage of the majority of the fish which cross the grids of the water intake.
Techniques must also be developed to use turbine operation to ameliorate quality of water which could be polluted upstream. For instance turbine used as device to enrich the oxygen rate of water. River with bad oxygen level need to be re-oxygenated especially in summer during the low discharge period. Re-oxygenation is possible through mixing and turbulence with weirs on the crest of the dam. This technique is not very efficiency with hot water in summer. By introducing air in the upper part of the draft tube, the turbine flow, with his rope is a real mixer and represent a very efficiency device for water aeration _ see J. FONKENELL Thermie Project. This device could also be used to introduce chemical treatments to improve quality of water.

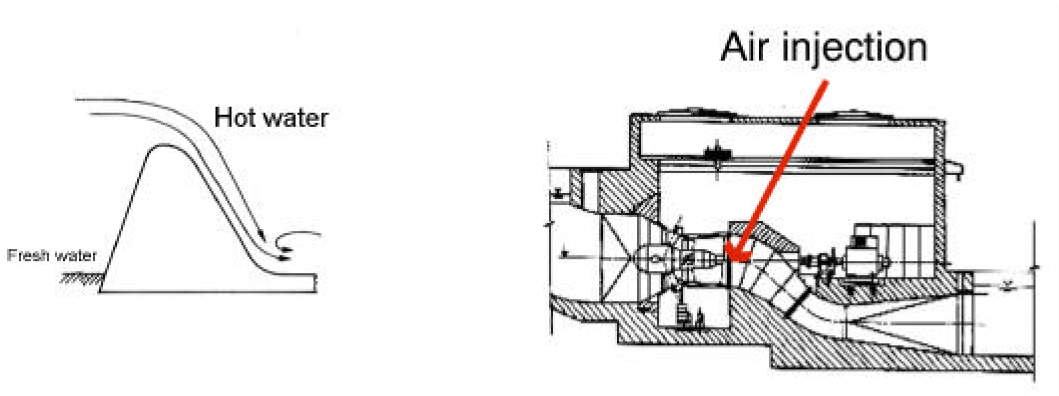


Figure 6 Turbine used as re-oxygenation device.

The management of the floating refuses accumulated at the water intake must also be taken in account within the framework of the power plant operation by automatic or manual cleaning. It must make it possible to leave a maximum of floating matters in the river necessary to the living organisms. With adaptation of the river morphology it is also possible to limit the accumulation of floating refuses like dead leaf on the water intake.

The determination of residual water flow imposed by legislation must also be defined on scientific bases and it would perhaps be necessary to define norms on a scientific basis acceptable by all partners of the river.

A detailed attention relates also to the use of toxic or polluting products for the operations of lubrication and cooling of the hydro and electro machines of the power plant. Eco-friendly products on natural or synthetic base must be chosen and research. Use of rapidly biodegradable lubricating fluids of water hazard category 0/1 is mandatory. If other toxic products exist in the site, safety procedure must be clearly be established.

Some solution has been developed to disturb a minimum acoustical environment and efforts has been done to reduce acoustic pollution of acceptable manner for sensible zones. The same problem exist for visual pollution of environment and solution must be research to adapt as good as possible the power plant to the landscape, for instance underground or integrated to landscape plant can be designed.

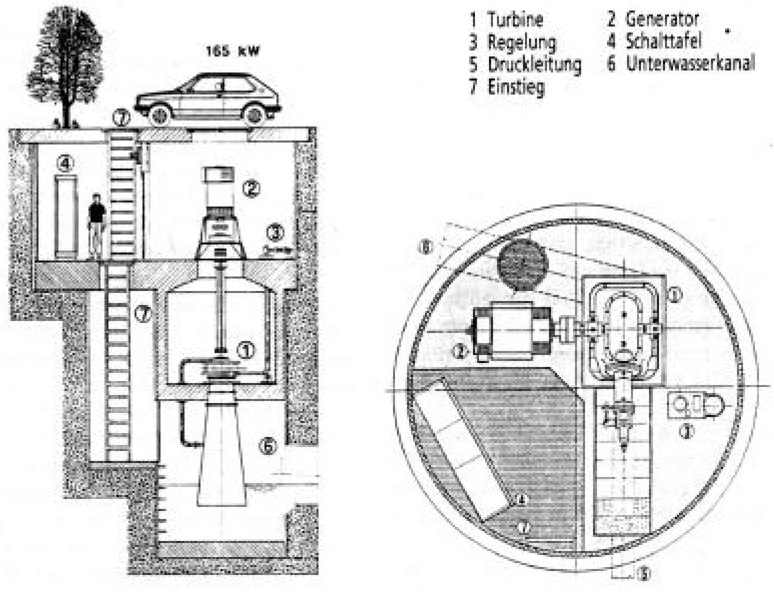


Figure 7 Underground power plant.

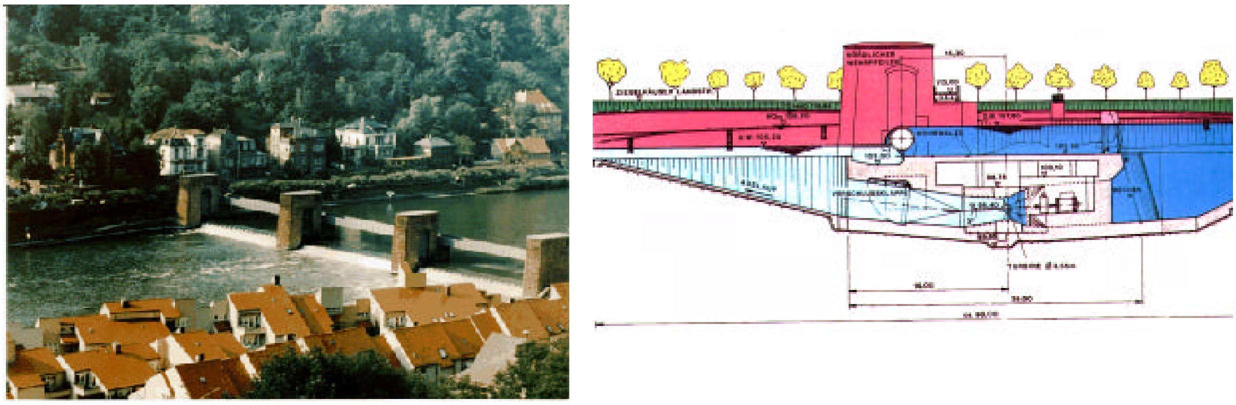


Figure 8 Example of integrated of a power plant in the historical site of Heidelberg.

It is also important to underline to require the highest as possible quality of the studies of ground and corresponding impacts. Errors in this field which can give place to irreversible damage, which are harmful to the global small hydro image.

Figure 9 Landslide on a small hydro building site.

5. Relative importance of the different parts of a small hydro power plant : how to open new markets for small hydro by reducing installed kWh costs.

Typical costs of the different elements of a power plant are shown on table 7 below. Three type of small hydro power plants are considered : a high head plant, a low head plant and a plant corresponding to marginal hydro potential development (complementary to irrigation or an industrial process or to drinking water supply or on sewer for waste water). These figures permit to precise the crucial elements on which it is important to make efforts in particular via research incentive actions, to make overall reduce the cost of the power plants.

	exemple 1		exemple 2		exemple 3	
Type of plant	hight head		low head		complementary to irigation	
General description						
total Head (m)	100		7		50	
Discharge m3/s	2,0		25,0		1,5	
Installed power (kW)	1 675		1 500		630	
Mean annual production (kWh/year)	5 000 000		6 000 000		2 600 000	
(1€~1US$)	**Cost k€**	**%**	**Cost k€**	**%**	**Cost k€**	**%**
Civil engineering						
Dam	108,18	5,4%	495,83	26,3%		
Intake and gates	6,01		90,15			
head and/or tailrace channel			84,14			
penstock	937,56	46,7%			48,08	
powerhouse	132,22	6,6%	222,37	11,8%	126,21	16,0%
access road	18,03		3,61		0,00	
total	**1202,00**	**59,9%**	**896,09**	**47,5%**	**174,29**	**22,2%**
turbine	**300,50**	**15,0%**	**480,80**	**25,5%**	**240,40**	**30,6%**
generator	**72,12**	**3,6%**	**72,12**	**3,8%**	**42,07**	**5,3%**
Transfo	42,07		42,07		24,04	
control and protection system	228,38		228,38		210,35	
access line	12,02		27,65		24,04	
total electricity	**282,47**	14,1%	**298,10**	15,8%	**258,43**	32,8%
engineering	**148,57**	**7,4%**	**139,77**	**7,4%**	**71,52**	**9,1%**
TOTAL	**2005,66 k€**		**1886,88 k€**		**786,71 k€**	
Power unit cost €/kW	**1197,41**		**1126,49**		**469,68**	
Energy unit cost €/kWh	**0,40**		**0,38**		**0,16**	

Table 10 Typical decomposition of costs of small hydro power plant (adapted from [6]).

The three example are typical small hydro plants : 1 to 2 MW for high head or low head plants and roughly less for complementary hydro equipment added to an existing installation for irrigation or drinking water supply or wasted water sewer.

For the three example, the power unit cost is about the same : ~105 €/kW. The Energy unit cost depends of the annual duration of production which is related to available hydrology.
The electrical equipments, generator, transformer, controller, protection system and access line, has about the same weight for the three cases (25 to 30% of total plant cost). Civil engineering has a preponderant part for the high head plants (60% of total cost) and the turbine represent only 15%. For low head plants Civil engineering and turbine represent respectively 47% and 25%. For the third case Hydro power is only a marginal added device and civil engineering has a minor role. In this case the turbine is the prime cost and must be adapted to the operation of the principal objective of the plant.

6. Civil engineering

For high head plants the Civil Engineering represent about 60% of total cost. It mainly the penstock cost which is preponderant (46,8%). Researches for lowering cost of this element permit to influence directly the cost-effectiveness of this type of plant. One can for instance report the development of fibreglass penstocks which are very interesting up to 2 MW power. Technique to provide the economical diameter are now well used. For this type of installation one can also search procedures to reduce the cost of the implementation of the penstock, which represents also a considerable part of the price.
For many plants the sand decant device is also a very important equipment which must be well dimensioned to be effective and avoid erosion problems and for minimizing maintenance.

For low head plants the dam or threshold represent this time the most important part of the Civil Engineering (26% of Total plant cost). For this category of power-plant research efforts to lower this element are profitable. Recently interesting solution are proposed by using inflatable threshold.

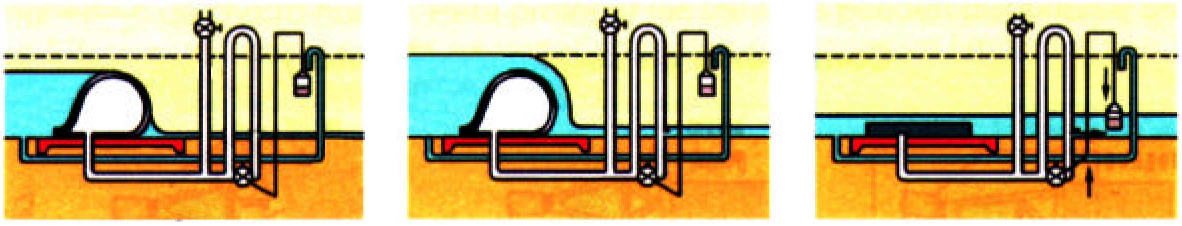


Figure 11 Inflatable threshold [6] and [9].

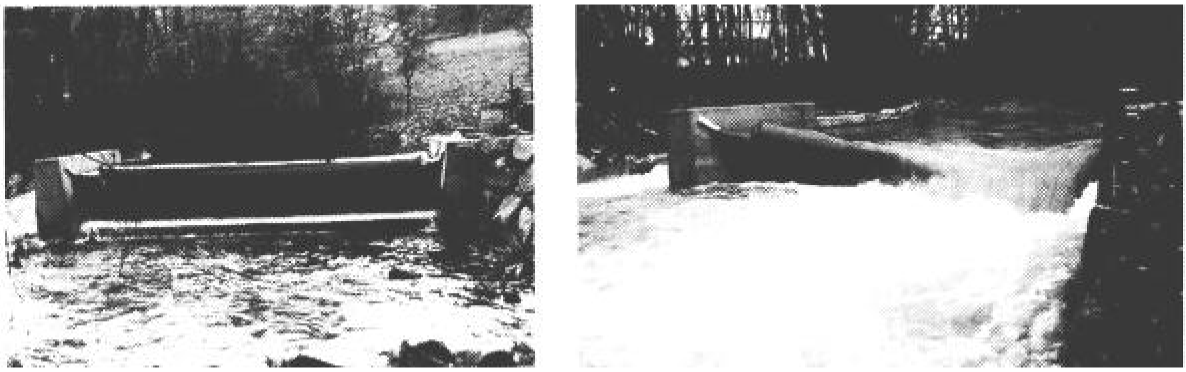


Figure 12 Well and bad controlled inflatable threshold [9].

This type of device represent lower investment than classical threshold, but need control using compressed air or water and financial balance taking in account maintenance must be considered.

For low head plants, the power house represent also an non negligible cost and adapted low cost building must be chosen.

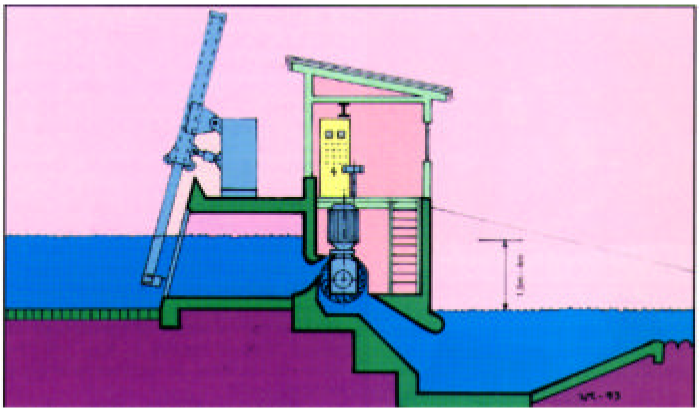


Figure 13 An adaptet plant for very low head : cheep turbine, shelter, civil engineering, automatic control.

7. Hydropower as marginal equipment of existing device

For these case, energy production is not the prime objective of the plant. Hydropower is only a marginal equipment for instance of a dam constructed for agricultural irrigation, for dinking water supply or other industrial equipment, for instance on figure 14, a brine energy recovery Pelton turbine is adapted on a pressure feeding system for reverse osmosis.
For these plant cost of civil engineering are minimal and the major part of cost concern the hydomechanichal and electromechanical elements. The installed power is rarely important.

Most of the time, the operating point and the operating range cannot be imposed by the turbine and important flow or head fluctuation are present. For these type of application, **variable speed is often very well adapted.**

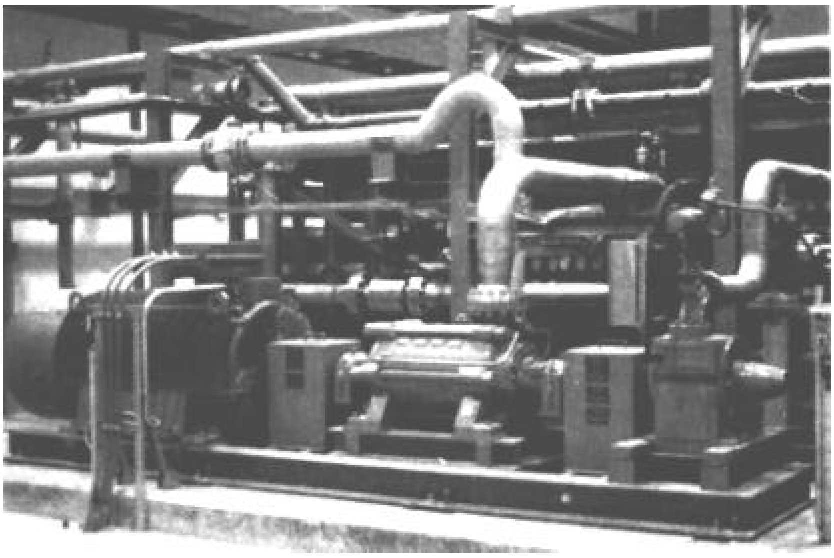


Figure 14 Reverse osmosis plant equipped with a brine energy recovery Pelton turbine. [10]

8. Electrical components

The electrical fittings (transformer, controller, protection system and access line) represent about 15% of the total cost of classical small hydro power plants. These costs grow regularly owing to the fact that the requirements for increasingly severe quality of supplied energy on the grid. The filtering techniques to set up represent increasingly important costs.
For this domain, specific developments for small hydro with an effort of standardization is crucial.
The electrical generator represent a relatively low percent of the total power-plant cost. These costs can be easily controlled via standardization of equipments. It is however very important to adapt adequately this machine to the power of the turbine by taking in account all the particularity of hydraulic turbines, for instance relative high runaway speed for instance up to 2 times the nominal speed for low head turbines (propeller or Kaplan turbines) and for instance synchronous motors working as generators are seldom adequate. New interesting solution, in connection with electro-technical component evolution, can now be proposed, in particular for low head plants (see PART II).

9. Turbine technology

Among the different element of the plant, the turbine is at the earth of the energy production; it's the same for the electric generators. For these crucial elements witch are directly connected to the positive column of the financial balance of the plant, it's very important to search the highest efficiency without weighed down the budget.
For high head plants the turbine represent only 15% of the total cost. For these turbines it is therefore possible to adopt the highest as possible technology to improve efficiency. The corresponding cost increase has minor importance if being reasonable.
For low head or for marginal equipment machines, the relative importance of the turbine is respectively 25.4% and 31.3%. For these plants, cost corresponding to efficiency improvement must be taken in account in the global financial balance and cheapest as possible technical solution has to be searched. For instance, for drinking water supply turbines pump working as turbine are often a very good solution to diminish the corresponding cost.

Turbine technology is now mature in small hydro. The analysis of concrete situations shows that mini-turbines can be neither scale models of large machines nor an extension of very small ones (pico-turbines) the constraints being different, exhaustive and systematic research is necessary in order to optimise and produce the equipment specific to small power plants. This must comply to the 3 fundamental conditions: simplicity (limited cost), high efficiency, maximum reliability (minimum and easy maintenance).
Small hydro has now its own technique and methodology and many of the newly designed turbines are a solution in search of a problem because they usually have substantial advantages over traditional turbines. The orientation given in the last years permits to reduce costs of design, manufacture, control and maintenance of turbine. Simplified and typical design has been adapted for most of practical cases and operation range has been well defined. For instance, if speed reduction is necessary, driving belt are systematically used instead of reduction gear box for power less than 150 to 200kW. Drive wheel are often adapted to facilitate control for runaway speed and damp down oscillation.
Many arrangement of small hydro turbine _see for instance ANNEX I _ are possible and the advantages and disadvantages of all type are not totally known. Due to the fact that low-head developments are inherently expensive because the high flows need large machines, important efforts has been done on the design of low head turbines that minimize both civil and equipment costs. Typical schemes are : Inverted Kaplan turbine (with fixed guide-vanes and an inverted draft tube acting as a siphon), Semi Kaplan turbine (adjustable blades and fixed guide-vanes), Straflow turbine, Right angle drive bulb turbine, Bulb, Tubular turbines, Open-flume Francis, Vertical Kaplan, Francis, Banki-Mitchell, Impulse turbines (Pelton and Turgo), Derriaz turbine, pumps operating as turbines, Free flow turbine (Darieus, Propeller,...), matrix turbines for modular low head plants. For these machines many ideas exist. But the small hydro turbine constructors don't have at present the adequate tools to choice the best adapted turbine for a specific plant.

Standardization. or ***rationalization***

In the past years, many companies developed the concept of standard design, that is the production of a range of machines of identical design as is done with pump design. The difficulty is that to cover the total operation range of small hydro and the opinion of G. Mc Hamissh at the First Conference on Small Hydro organized in 1982 is always valid:
"To cover the market you are talking about 100, 200 standard designs and, with the market as it is at the moment one manufacturer can receive in one year an order for maybe 10 to 20

designs. As time goes on, he will change his idea about how to design those machines. So, if he has already made 50 or 100 designs, many will already be obsolete before he has a chance to use them. So I don't think it will be much benefit to the customer to write a specification which is intended to take some advantages from standardization from a particular manufacturer".

Standard turbine can only be applicable to micro and mini turbines where cost is important and efficiency is not.

In most cases, the end-user has no advantages of standardization, because standard design don't fit well to the site characteristics and the consequence can be important losses of energy.

Rather than standardization, the key lies in ***"rationalization"***. Where the design procedures, the general arrangement and most of the elements are standardized but the global size and the principal elements related to power production (turbine runner, high pressure part,...) are individually calculated and manufatured to optimised the available potential. With computer and **CNC machinery**, it is now possible to manufacture very rapidly, with cheep costs and global standardization is no more needed to master and reduce costs.

Adequation of turbine to specificity of plant

One of the biggest difficulty in small hydro is to adapt the equipments to the specificity of the plant : to the hydrology, the geology and topography of the site. The first difficulty is to collect the detailed corresponding data. Error in these data or lack of data involve important risks for the security of the plant (flooding, landslide, ...) or under or over estimation of plant mean head and mean flow discharge what involves a bad choice of the turbine and loss of profit due to non optimal turbine efficiency. Longest as possible statistical hydrological series must be systematically collect in all potential plants and/or completed in order to be able to construct annual mean average river discharge series and decennial and centenary flooding levels. This type of data exist in developed countries for most of rivers, but must be often precise for small hydro potential plants. In developing countries, there is mostly very few available data and correspondent risk are very important. International agencies should develop efforts to create these hydrological data banks.

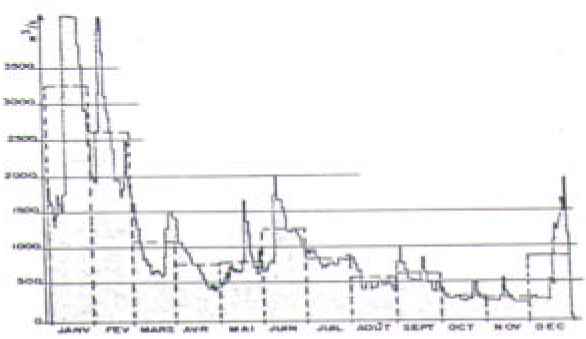


Figure 15 Typical annual river discharge serie.

Design tools for small hydro constructors

With the development of C.F.D., large hydro constructors has developed codes to help the turbine designer [12]. These codes integrate statistical data to define the principal geometrical parameters of all parts of the turbine and propose a geometry of all parts of the machine (spiral casing, distributor, runner, draft tube). Automatic meshing procedures permit to calculate very quickly the flow in all parts of machine and also mechanical stresses and strains. Analyses of flow

and mechanical defaults permits to the designer to modify easily the proposed geometry and this numerical procedure permit to obtain the final acceptable design in 1 or 2 days. Small hydro constructors don't have access to such kind of codes and are depending to large hydro designer for runner and machine design. With the actual development of CFD on PC NT computer, it's at present possible to propose such kind of ***tools specifically developed for small hydro turbines***. These tools can integrate ***optimal design techniques*** in order to permit to obtain automatically the best design corresponding to criteria defined by the user (cavitation, cost and performance criteria).
These C.F.D. tools can also be extended to design civil engineering shapes like power-plant feeder canal, inlet gate and grids, draft tubes, ...

Rehabilitation

The same kind of the previously presented tools can be proposed for rehabilitation project. For these kind of project only one part of the machine is generally replaced (runner and high pressure elements). The corresponding ***geometrical constraints*** can be taken in account in the proposed numerical procedure and the initial geometry can be the old one acquired via ***reverse engineering techniques***.

New control techniques and remote control

The application of intelligent electronic devices (IED) for operation , closed loop control, protection and monitoring offers cost effective solutions. The application of a wired or unwired telecommunication link to a regional control center for ***remote control*** and monitoring enables also the establishment of cost effective maintenance strategies. The well trained maintenance crew needed and the storage of spares can also be located at one central place only.
Information technology also offers for small and medium size power plants new and revolutionary approaches for ***operation, closed loop control and monitoring*** (see for instance [2], [3], [4])

New materials

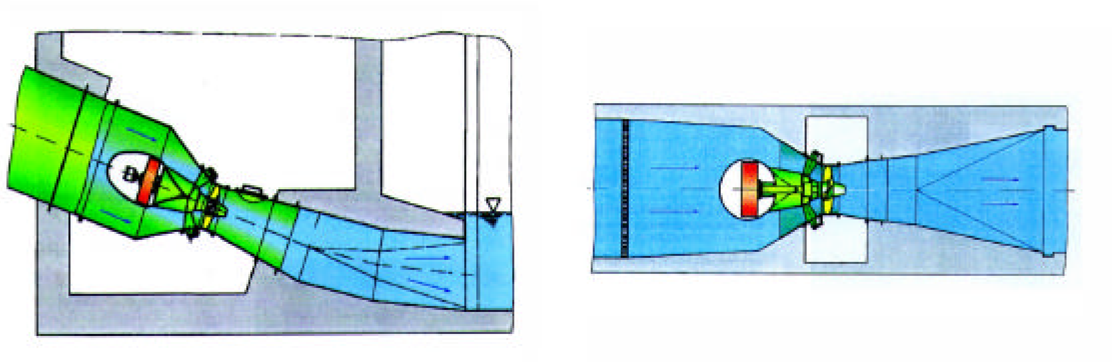
New adapted low cost materials has to bee research and used for small hydro. For instance rapid machining steels adapted for C.N.C. machines and having good characteristic for cabvitation and/or sand erosion, materials to re-cover sensible zones to erosion (ceramics,...), low cost adapted elements of machines (plastic, glass-fibre, ...). Some of these elements (spriral casing,...) could be standardized.

10. Global integrated design

Today good efficiency can be obtained for small hydro turbine (85 to 92%) and important reduction of the energy cost are no longer possible in improving the turbine design. On the other hand, the operation and maintenance can be reduced in all new projects to its minimum, thanks to an adapted design and remote control. What is necessary is to well adapt the machine characteristics to the plant characteristics. If a good hydrologic data base is available with the corresponding power load schedule of the plant, a global model based on simulation of all possible components (hydromechanics elements but also electromechanical and electric components) can be construct. This global model permit to optimise all elements of the plants with the objective of ***the global performance and cost*** of the plant. Such kind of Computer Aid

Design software are in development _ see ref 4 and 5 _ fig. 8. Different operation mode can be tested, such as variable or fixed speed, with different type of potential components, turbines multiplier, generators, transformer, civil engineering... The simulation on a typical hydrologic year permit to determine the best arrangement.

Global integrated design is very important for small hydro and many examples can prove this necessity. For instance if only the turbine cost is alone considered, one can prefer a scheme with concrete duct instead of a metallic duct arrangement (see figure 16). In a precise case, this choice has entailed an overcoats of 80 000 $ due to the fact of the complexity of the civil engineering.



Kaplan turbine with metallic duct   Kaplan turbine with concrete duct

Figure 16

11. Conclusion

To support the development of mini-hydro parallel to administrative and political inciting action four points are important:

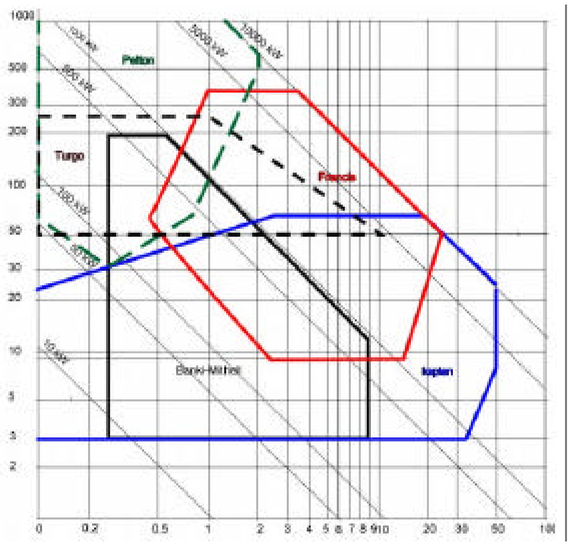
- to develop the integration of the power plant in the ecological environment
- to limit the costs and to improve the competitiveness compared to the others sources of energy by developing adapted technology and procedure to small hydro
- to open new markets related to marginal hydro potential and improve rehabilitation project
- to develop the adequacy of power plant related to the electric power needs and available hydrology

12. Bibliography

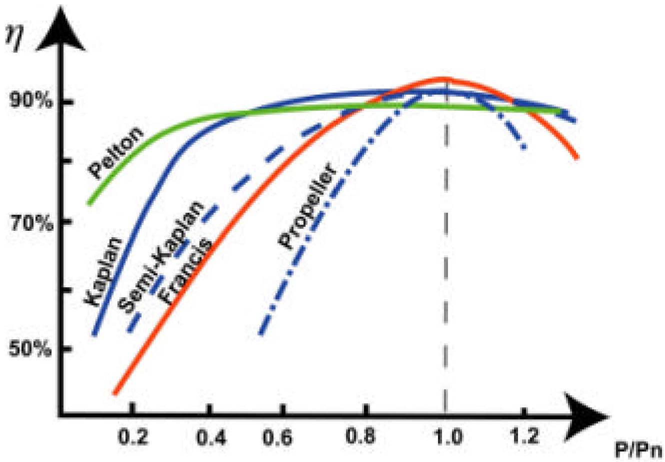
1. TERES II "The prospects for Renewable Energy in 30 European Countries from 1995 – 2020", CEE Altener Program , 1996

2. Tolea, M.F., Kueny, J.L., Pierrat, L. ,"Parametric analysis of the dynamic behavior of Francis turbines – A new approach", XIX IAHR Symposium on Hydraulic Machinery and Cavitation, Singuapore, 1998
3. TOLEA, M.F. ,KUENY, J.L.,PIERRAT, L.,″A Novel Neural Network Based Application for the Intelligent Control of a Hydro-Electrical Process″, NEURAPT98 Symposium, Marseille, 1998
4. L. Pierrat, J.L. Kueny, A.M. Phan, "Efficiency Improvement of a Variable Speed Turbine generator Set: Losses Modelling and Test Validation", Modelling, Testing &Monitoring for Hydro Power Plants II, Lausanne, Switzerland, 8-11 July 1996, pp. 319-327
5. PAN ANH MINH, "Régulation de turbines à vitesse variable, modèle technico-économique", thèse INPG, 1998
6. IDEA, "Manuales de Energias Renovables: n°1 Minicentrales hydroelectricas" – Altener Program, Madrid 1996
7. B. LEYLAND, "Recent developments in machinery for small hydro-electric schemes", Third international conference on small hydro, Watre Power, 1988
8. Jürg Krähenbühl ″Die Zukunft der Wasserkraft″ , Ausstellungskongress kleine und mittelgrosse Wasserkraftanlagen, Berne 10-13 June 1997
9. ENGEL, Arnold P., ″Erfahrungen bei der Realisierung von Kleinkraftwerken", Ausstellungskongress kleine und mittelgrosse Wasserkraftanlagen, Berne 10-13 June 1997
10. Avellan, F., ″Hydropower Rehabilitation, from large to mini-hydro power plants″, Ausstellungskongress kleine und mittelgrosse Wasserkraftanlagen, Berne 10-13 June 1997
11. 11. Pedroli J.C., ″Ecologie et force hydrauliqe″, , Ausstellungskongress kleine und mittelgrosse Wasserkraftanlagen, Berne 10-13 June 1997
12. Kueny J.L., ″Francis Turbine Design″, Inter-universitary intensive course on Hydraulic Turbine″, EPFL-INPG postgrade course, http//www.epfl.ch/formation

ANNEX I   SMALL HYDRO TURBINES



Operation range of small hydro turbines (IDEA).

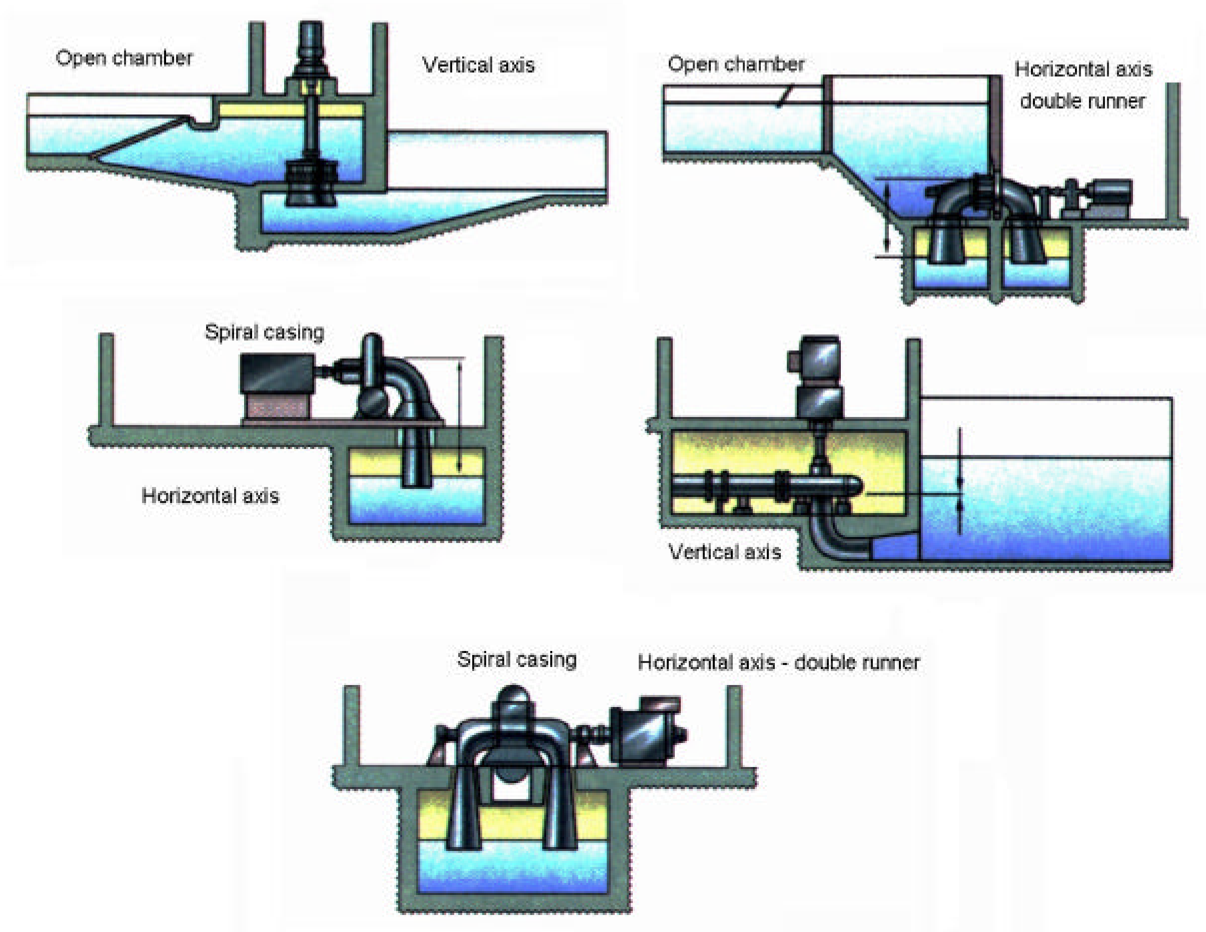


Comparison of performances.


Pelton turbine (2 jets_Bouvier Hydro)

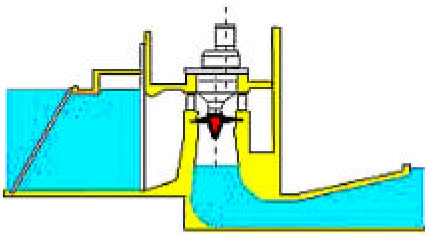

Turgo turbine. (I.D.A.E.)

SMALL HYDRO - FRANCIS TURBINE
(I.D.A.E.)

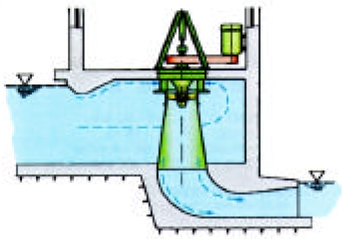


Francis vertical turbine.

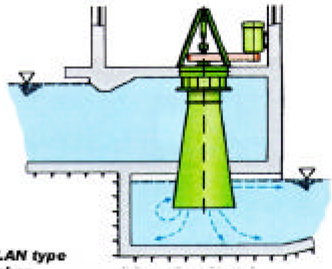
Small Hydro - KAPLAN and semi-Kaplan turbines (I.D.A.E.-H.S.I.)



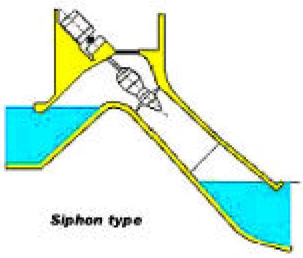
Classical KAPLAN or semi-KAPLAN type



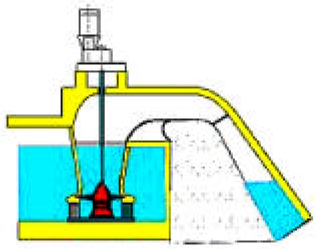
KAPLAN or semi-KAPLAN type with open chamber



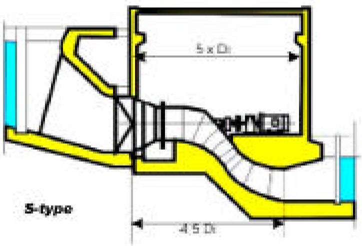
"open" draft tube



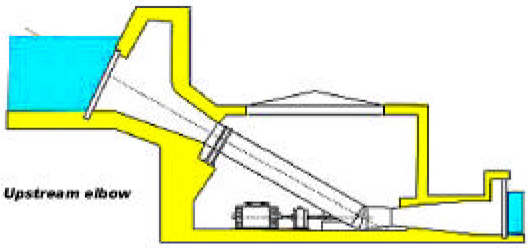
Siphon type



Inverted siphon type

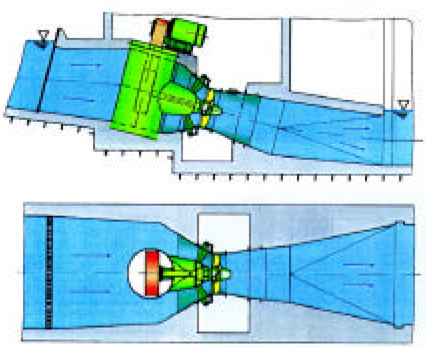


S-type

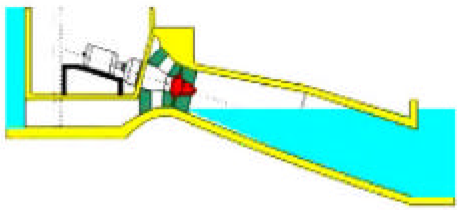


Upstream elbow

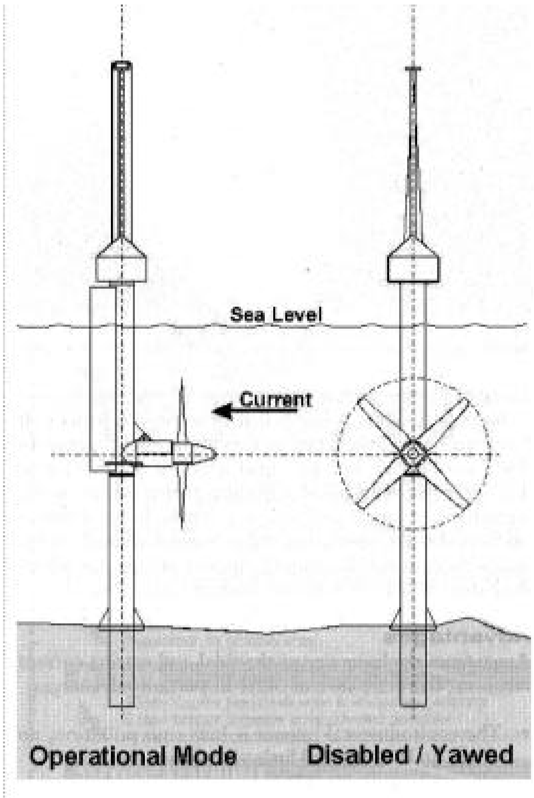
Bulb-type with open channel



Bulb-type , without speed reduction



Free flow turbines for small hydro in see current or very large river.

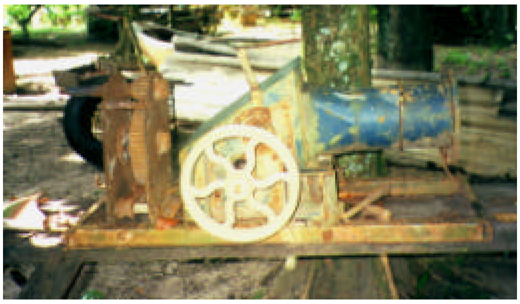


Propeller type turbine [..]

Darieus turbine.

ANNEX II   BELEM tidal power turbine : a typical low head turbine project

The damm in armed earth



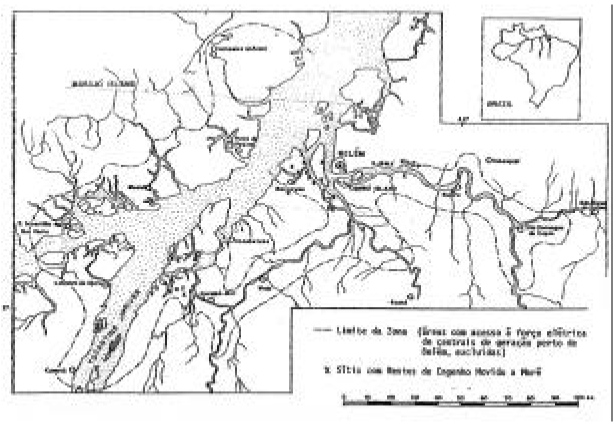
Banki-Mitchell

A diesel motor in Amazonas

The Darieus turbine

NEW OBJECTIVES:
1° To design a propeller turbine operating:
- at fixed speed (fans, fridge)
- at variable speed (electric batteries)

2° Machining a matrix -> local fabrication (20-30 potential turbines)
3° Test



PART II ELECTRICAL, CONTROL, MONITORING & GOVERNING

FOR SMALL HYDRO

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Summary

1. GENERAL CONCEPT OF A SMALL-HYDRO PLANT

Before beginning the discussions, I think it would be desirable to replace the subject in a general context of a mini-hydro plant and speak about the following limitations:

1.1. Hydro-mechanical constrains:

First, we must mention that the exploitation of a hydro-plant is based on a cascade of two energetical transformations: on one hand hydro-mechanical, on the other hand electro-mechanical.
Because we must extract the available energy from a natural plant, it's obvious that the electro-mechanical conversion stage must have a designe that allows to obtain a maximum efficiency by a minimum cost.
It results that, practically, there are the turbine characteristics (power, speed) which determine the electrical generator ones however will be their nature.

1.2. Economical constrains:

The economical handicap that all the energetical plants are comming up against, is related to the size effect; when the rated power of an energetical conversion equipment increases, its specifical cost decreases and simultaneously its efficiency increases.
On one hand, the electro-mechanical conversion stage is not excepted from this tendancy determined by the corresponding physical phenomena.
The situation is aggravated if we take also into consideration the other devices (monitoring, control, governing, protection) whose cost is practically fixed indifferent from the plant size.
On the other hand, the design of a small hydro plant can't escape today from a technical-economical approach based on the life cycle cost. So, the reliability is an important factor of the functional availability and the maintenance and service cost must be minimized.

1.3. Functional constrains:

The design and the size of the actual small hydro plants are also determined by their purposes.
First, the technical performances related to the supply of the autonomous electrical networks and/or public ones are determined by rules sometimes constraining for the operation of a small hydro-plant.
Second, the exploitation ways depend on the hydrological variability and/or the environmental constrains.
All these functional constrains depending, partly, of an evolutive legislation, have an impact on the size of the electro-mechanical components and on the complexity of the control, governing and protection systems.

2. A.C.CURRENT GENERATORS

The asynchronous or synchronous generators must assure the power supply of an autonomous network and/or a public one, maintaining a constant voltage and frequency independenly of the load variations.
Generally, their size is based on common electro-magnetic similitude laws. But their supply and absorbtion capabilities of the reactive power is different.

2.1. General rules of dimensioning

The active power (P) delivered by a rotating AC or DC machine is the product of the shaft torque (T) by its angular rotation speed (Ω):

$P = T * \Omega$ (i.e. power in kW, torque in kJ/rad and rotation speed in rad/s)

For an electrical machine the torque (T) is approximately proportional to the volume (V) so, to the cost (C) of the material used.
According to the economical point of view (investment cost), the use of a higher possible rotation speed is advantageous.
Because this rotation speed is imposed to that one of the turbine, we can study the interest of a mechanical gear (in this case other aspects connected to the inertia moment of the turbine-generator set can be considered).
The size effect occurs both on the power-to-volume ratio:

$P/V \sim \Omega * (P)^{1/8}$

and on the losses-to-power ratio :

$p/P \sim \Omega^{-1} * (P)^{-3/8}$

For the low rated power machines used in the small hydro domain, these contradictory effects (related to active power and rotation speed) on the specific cost and efficiency, can't be simultaneously compensated. Using more performant materials (i.e. permanent magnets for PM synchronous machine) it's a possible manner to improve the efficiency but the cost increases. Another way for reducing the cost could be to increase the technical constrains on materials (i.e. more efficient cooling and/or a higher operating temperature) but the efficiency decreases.

2.2. Asynchronous generators:

Taking into account their high similitude with the asynchronous motors currently used in industry, these machines are the most robust and the less expensive ones (cage rotor). However, the gap thickness between rotor and stator must be sufficiently large in order to avoid the mechanical failure which leads to a sensible diminishing of the machine efficiency and of the power factor.
Their main limitation concern the reactive power: this reactive power necessary to magnetize the machine must be delivered by the public network and/ or by static capacitors.
They never can deliver a reactive power to an autonomous and/or a public network that's why a decreasing of the sold energy value occurs (power factor too weak).
Their coupling to the network can be easily realised nearby at the same value of the synchronous speed.

However, when these machines are associated to the capacitive compensation, the overcost of these components must be considered as well as the functional constrains resulting from (capacitive self-excitation, dielectric rupture of capacitors, limited operating ranges...)

2.3. Synchronous generators:

This kind of machine having a rotoric excitation winding, allows the elimination of the asynchronous generator limitations concerning the reactive power.
It results that the thickness of the gap between rotor and stator is always sufficient to avoid the mechanical failures.
Besides, its efficiency is higher than the asynchronous generator, but its cost is higher because the rotor configuration is more complex (windings on salient poles, excitation rings or brushless excitation).
The rotoric excitation control (reactive power delivered to the network or absorbed by the machine) implies the use of a more complex regulating device so, more expensive.
To the rotoric excitation winding, permanent magnets can be replaced, but in this case, the adjustment capacity disappears; this solution has no practical interest except the use of such a machine associated to a frequency electronic converter in the variation speed domain.

2.4. Choice criteria:

The two types of generators have identical stators; only the complexity of their rotors is different which explains the different costs. But their functional performances are also different and the supplied network type (autonomous or public) is an important choice criterion.

3. SPEED VARIATION OF THE TURBINE-GENERATOR SET

It is well known that the adjustment of the turbine speed allows to maintain a maximum efficiency however will be the operation conditions (flow, head).
But because the electrical power must be delivered at constant voltage and frequency, an electronic frequency converter must be used.
This converter implies an investment overcost as well as complementary losses and the economical justification of such a solution must be very carefully studied function both of the turbine characteristics and of the plant hydraulic variability.

3.1. Asynchronous generator:

In this case the frequency converter is an autonomous voltage converter which supplies an autonomous and/or a public network.
A possible alternative consists of using a winded rotor for limitating the converter size, but this machine has a higher cost and its rotoric rings diminish its reliability and increase the maintenance effort. So, such a solution has no obvious interest in small hydro domain.

3.2. Synchronous generator:

In this case, the frequency converter is a self-inverted current converter associated both to the machine and to the public network; in case of an autonomous network, only the network converter must be replaced by an autonomous converter.

3.3. Choice criteria:

For the rated power and the voltage considered in a small hydro domain, the frequency converter cost is not very strongly related to their complexity.
It results that the choice of a cage asynchronous generator associated to an autonomous frequency converter using up-to-date semiconductor components of IGBT type (**I**nsulated **G**ate **B**ipolar **T**ransistor) is probably a good solution.
We must point out that the speed variation of a small hydro set leads necessarily to the modification of the classical voltage-frequency regulation but some advantages can result as for instance the stability of the hydro-electric process.

4. SOME THOUGHTS FOR R&D

Before beginning and orientating the discussions, I propose to tackle the following points; most of them results from the previous considerations and the others have a more specifically characteristics.

4.1. Mechanical integration v.s. standardized modules:

The design and construction of the small hydro plants come up against two difficulties: the weak rated power of the equipments and the diversity of the component assembly.

Could-it be possible to reduce the investment costs by using the mechanical integration concepts (turbine, generator, gear, cooling, converter...) and component modularity (size and standardized configurations) ?

4.2. Constant speed v.s. variable speed:

It is known that speed variation can increase the energetically efficiency of the turbine-generator set but a technical-economical study must be done for justifying this choice.
So, the cost of a frequency converter is an important factor depending on technical solutions not yet very well evaluated.

Could-it be possible to tackle the corresponding feasibility studies in order to define standardized solutions?

4.3. Control, Monitoring & Governing:

The device assembly where each one assures a distinctive function, is still a current approach in this field.
Today, the development of the computer systems give the possibility of increasing the performances and the functional complexity without increasing simultaneously the technological complexity; this tendency would allow to reduce the fixed costs of the plants, integrating most of the necessary functions.

Could it be possible, on one hand, to imagine the development of an adapted device for voltage-frequency regulation, compatible with different possibilities of connecting a small hydro plant to public and/or to autonomous networks ?

Could it be possible, on the other hand, to reconsider the connexion problem of a small hydro plant to a public and/or autonomous networks in today terms for simplifying the necessary devices (control, protections) and to foresee the functional reliability?

4.4. Direct connection and voltage level:

Considering the weak rated powers of the small hydro, the rated voltage of the generators is situated in the low voltage or medium voltage ranges (LV or MV).
Traditionally, a set-up transformer is inserted between the generator and the network.
Very recently, the direct connection of specific generator to the LV or MV network was proposed but some arguments presented on this occasion don't seem to be credible, particularly the aspect concerning the real advantage of the reactive power compensation.

Could-it be possible to obtain a realistic estimation of the investment profit brought by such a solution (transformer suppression) in the power range concerning the small hydro?

Among the functions assured by the set-up transformer (when it is well designed and realised...) we can point out the attenuation of the transient overvoltage generated by the network.

Could it be possible to guarantee the dielectric overvoltage strength of a generator directly connected to a high voltage network in order to obtain a sufficient reliability?

5. R&D STRATEGY PROPOSAL IN SMALL HYDRO

5.1 Preliminary remarks:

It is not easy, a-priori, to elaborate a R&D best strategy concerning the electro-mechanical domain. Indeed, in a small hydro project, all the concerned disciplines are interactive: technical and/or technological progress can engender both marginal economical gains (but quantifiable) and significant indirect gains (but, a-priori, more difficult to estimate).
The following strategy proposal must be considered as an expert advice and it has no pretention of being the only one possible.
After that, one limitates to justify its objectives and formulate R&D proposals within a coherent manner.
For complementary precisions, please contact the author:

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5.2 Actual irreductibility of investment costs:

The techno-economical improvement limits of the small hydro are well known for a long time. The designer has at his disposal a catalogue of components available or specifically workable and he tries to combine them in order to obtain the specifical performances for a minimum investment cost.
Unfortunately, the physic laws of component dimensioning penalize intrinsically the considered weak powers and the very large diversity of natural sites counterbalances a rational standardizing of the components.
Moreover, a lot of functions translates by fixed costs independently from their size (governor, switchgear panel, protection equipment, automatic control, power station auxiliary equipment...) and the part of the budget destined to the project study is always limited.
So that it is necessary to find an adequate strategy allowing to avoid these difficulties.

5.3 New strategic orientations:

Even if significant gains could be obtained by using punctual technical and/or technological innovations, this design methodology has its limits. Parallel, the actions which hold diverse demonstration projects should be analysed of a more critical point of view. The underlying idea consists of verifying, by a concrete realisation, that a certain concept is technically valid and, eventually, economically acceptable.
In fact, this approach, except its incitating role, is globally expensive end less efficient because the transposition of the experiments and their generalisation are not economically compatible with the number and the cases to be considered.
That’s why I propose to orientate the R&D efforts to the following aspects:

- to reduce the diversity of projects by choosing a power domain and a type of small-hydro plants having both common features and a sufficient energetical potential;
- to introduce right away and simultaneously all the technical and technological innovations accessible in short and average term in hydro-electrical conversion domain (turbine, generator, network, governing...);
- to integrate all the functions in only one set, having a good energetical performances, a sufficient adaptation flexibility related to hydraulic and electric variability, a high operating reliability and a weak impact on the environment.

This concept of integration and modularity constitutes an innovative response to the technical standardization needs.

Such a standardization should have to allow the economical compensation of the intrinsic disadvantage of the size effect by the the advantage of the series effect.

5.4 The major lines of a R&D program:

Starting from the above proposed orientations, the R&D program can be condensed in four major headings;

- choice of the hydraulic site type, so the turbine nature and the project size;
- general specifications of the project in terms of reliability, technical performances, standardization and specific cost;
- brief description of the notion of integrated hydro-electric group, of its functions and components;
- complementary studies allowing to valuate the R&D project.

5.4.1 Domain choice and general characteristics:

The energetical potential of low head is important but slightly exploited in the world. *According to UNIDO definition, it's about micro-hydro plant ranges (inferior to 100 kW) and small hydro plants (between 100 and 1000 kW) corresponding to low heads (inferior to 3 m).*
A low voltage prototype group (triphase AC 230/400 V) of 30 kW (between 10 and 100kW) corresponding to an easily accessible site (adequate location for an efficient and economical coordination of the R&D program) would be a good compromise between the project cost and its validity into the range1 up to1000 kW.
From this choice, practically results the type and the assembling of the low speed turbines: Kaplan, propeller and cross-flow, outdoor integral intakes siphon units or bulb unit submerged in the flow.

5.4.2 General specifications:

The group must be able to operate at a good energetic efficiency considering both the flow and low head variabilities.
It also must be able to deliver easily the electric energy by automatic coupling to a public and/or autonomous network.
Besides the basic function related to hydro-electrical conversion, the group must be able to integrate more complementary functions (governor, protection...).
Its modularity and compact configuration must allow an easy installation by means of limited handlings.
Lastly, the choice of technical and technological solutions concerning its internal components should consider not only their performances and reliability, but also the constrains related to a possible industrialisation and to the corresponding series effect.

5.4.3 Concept of integrated variable speed group:

It's about a modular component associating a turbine, a generator, a frequency electronic convertor and a corresponding system of voltage-frequency regulation.
Because of the low rotation speed, it is necessary, if we want to avoid the installation of a mechanical gear, to use a permanent magnet synchronous generator.
Indeed, this type of electrical machine is practically that one which allow to obtain both a good efficiency and an acceptable diameter compatible with that one of the turbine. (Other possible variants are not presented here: machine type, structures...).
Concerning the power electronic convertor, the present available components on the market (IGBT, especially) give the possibility to realize a compact and reliable interface between the turbine and the electric network, eventually transformer free.
The assembly, including the electronic of control-regulation, which can be efficiently cooled by water, has a natural overload capacity in order that a standardized unit could be efficiently adapted to the variations of the hydraulic and electrical conditions.

5.4.4 Project complementary studies:

Besides the preliminary studies concerning the definition of the program, its logistic coordination, the site choice, project evaluation, etc., the following points must be specifically studied:
- evaluation of the available low head hydraulic potential: energetical characteristics, location and the nature of electrical consumption (public and/or autonomous network);
- objective evaluation of coupling criteria to the electrical networks concerning the small hydro-plants automatically operating, in order to reduce some economical and technical constraints;
- evaluation of the concept indirect advantages on the other parts of the installation (civil engineering, network coupling...).

5.5 Conclusions:

This innovating project would be the first step in a global strategy whose aim is the use of a global methodology, giving the possibility of improving, in the average term, the small hydro profitability and its insertion in the environment.

III Lists of proposals for R&D works in Small Hydro field.

I° Due to the numerous ecological errors made in the past for large and small hydro projects, the hydro-power media image must imperatively be improved and independently of any economic analysis, it is essential to prove to leaders and population that the small hydro power can have an important economic, sociological and environmental impact.
In parallel to political and quality regulation actions, new solution and demonstrators must be proposed to improve small hydro impact on rivers (see Part I .4) :

- fish friendly turbines
- water quality improvement plants (air or anti polluting products injection, ...)
- transport of sediment control
- improvement of watery life near small hydro plants
- ...

II° Global integrated design tools to define the best turbine characteristics in accordance with the hydrology and electrical demand.
Such kind of codes exist or are in development and are used to define some equipments in a power plant for different topics, Hydrology, Civil engineering, ... To optimize precisely all components it is necessary to have access to a code taking in account all the plant elements, from the civil engineering part to the grid connection with a precise modeling for each parts, in particular the turbine in order to be able to simulate hourly output of the plant if corresponding hydrological data are available or simulate. With such kind of tool, a non linear optimization techniques can be applied to define the optimal equipments available in the data bank for a specific plant. With this code, a small hydro designer could optimize the hydro plants using its proper data base with its own technical elements and prices.
Broadly on the whole of the small hydro community, this type of code would make it possible to improve in a significant manner the global profitability of new and refurbishing projects.
The development of this kind of code must be a shared project between specialists of each parts of the power plant.

III° In order to design easily with low engineer time costs specific design, the adaptation to small hydro machines of advanced design techniques used for large hydro industry and introduction of these techniques to SMEs will be a key point to lower costs and to improve quality and performances of small hydro plants. The proposed numerical tools can be implemented on NT platforms witch are typically the computer available now in SMEs companies and the actual performances of these machines permit to implement design techniques, CFD and structural analysis codes and automatic analysis procedure to permit to engineer with a minimal training to develop high quality turbine design.

IV° Low head turbines

In small hydro, it has been seen in Part I that the potential of growth is especially dependent to low head power plants. For these machines, the cost of electromechanical elements is important and if a reduction of 20% of the cost is required, important research efforts has to be to provide. The improvements will be obtain not only by optimizing the turbine, generator and all electotechnical and control devices but also by researching a global integrated optimal power plant (see II).
For the turbine, lower costs can be reached, while developing adapted design to the plant. By developing new specific turbines, using optimal design codes and CNC techniques adapted to

these machines, by using well grounded tools and developing *rationalization* of all elements, development times, study and manufacturing costs can be reduced in a significant manner. New materials (plastic, glass fiber,...) can also be research to replace more expensive materials.
Specific electrical generators must be developed to permit better operating of low head turbines. For instance compact generators with permanent magnet cooled by water can be developed with specific power electronic to connect to the grid. Such kind of generator, working with high flux and current density, rotates at sufficiently low speed (~300 rpm) to drive the turbine without step-up gear. Some part of electrical protection and filters can be directly integrated in the power electronics, so high quality of current can be guaranteed with in standard proposal, connection to isolated or connected grid. The power electronic device permits also easier start-up of machine, what makes it possible in some project to remove the control by the downstream vane and to simplify the control process. By standardization of some specific generator in the range from 10 to 50 kW, it will be possible to significantly reduce prices of such kind of generators.