COST BASE

FOR SMALL HYDROPOWER PLANTS

(With a generating capacity of up to 10 000 kW)

Price level 1 January 2010

Norwegian Water Resources and Energy Directorate (NVE)

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Cost base for small hydropower plants

(up to 10 000 kW)

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Synopsis: This manual has been prepared as a tool for calculation of average foreseeable contractor costs (civil works) and supplier costs (mechanical and electrical equipment) for small hydroelectric power plants with an early phase generating capacity of up to 10 000 kW. These costs will depend on a number of conditions which may vary from plant to plant, and this requires that the user to have a sound technical knowledge. This applies in particular to the civil works associated with the hydropower plant. The manual is a supplement to our cost base for larger hydropower projects (Manual No. 2/2010).

Key terms: Average costs, small hydropower plants, civil works , mechanical and electro-technical equipment.

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COST BASE FOR SMALL HYDROPOWER PLANTS WITH A GENERATING CAPACITY OF UP TO 10 000 kW

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1 GENERAL

1.1 General information

1.1.1 Introduction

In 1982 a manual, "Cost basis for hydropower plants" was prepared as a tool for calculation of foreseeable construction costs. The report was subsequently revised in 1987, 1990, 1995, 2000 and 2005.

SWECO Norge AS has been assigned the task of revising the *Cost basis for small hydropower plants* by the Norwegian Water Resources and Energy Directorate (NVE) as of 1 January 2010.

Power plants with a generating capacity of 0-10 MW are often divided into:
Micro power plants which are power plants with a capacity of up to 100 kW
Mini power plants which are power plants with a capacity of between 100 kW and 1 MW
Small hydropower plants are power plants with a capacity of between 1 MW and 10 MW

1.1.2 Content and use of the report

The report has been divided into three main chapters:

1. Civil engineering works
2. Mechanical equipment
3. Electro-technical equipment

The report describes "normal" costs, and is intended to be used in the overall planning to quickly establish the rough cost level of a project.

Most costs are presented in the form of graphs with associated text.

1.1.3 Price level

The prices in the report are as of 1 January 2010. All prices are stated in Norwegian kroner, NOK.

1.2 Expected new technology

1.2.1 Strategy for small hydropower plants

In 2003, the Ministry of Petroleum and Energy presented its strategy as part of the Norwegian Government's objective to promote the establishment of small hydropower plants. One of the strategy measures is to grant financial support to research and development channelled through the NVE. Projects have been initiated relating to hydrology, the environment, resource identification, information and technological development.

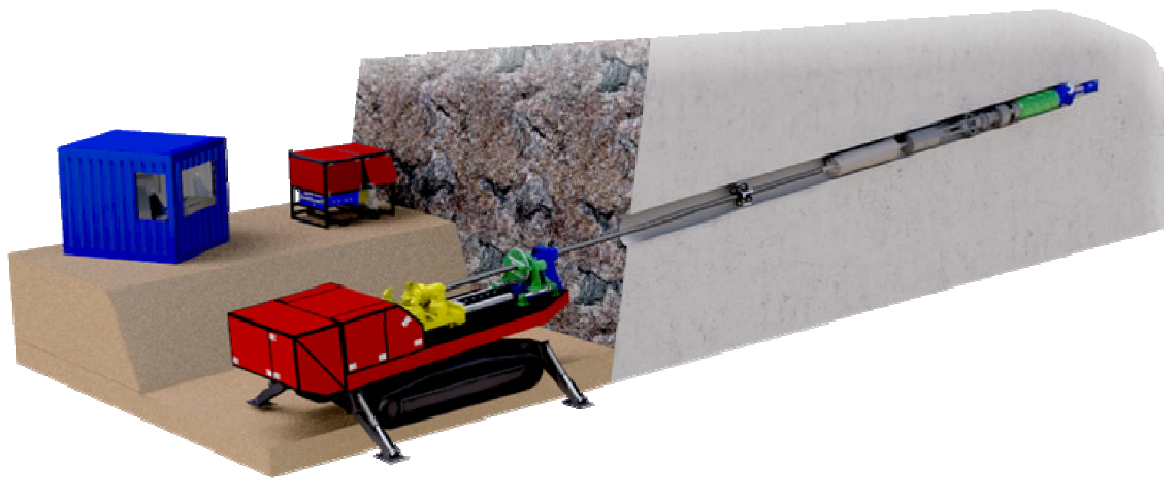
It is important to ensure that the technical equipment is of a high quality as major investments will be involved for the individual developer. This will provide equipment with a longer useful life and fewer instances of technical failure. New technology will ensure that the power stations utilise their potential to a greater extent, making developments more profitable.

1.2.2 Rock drilling

Based on land-based and petroleum-related drilling techniques are being developed which may be used to drill waterways in connection with construction of small hydropower plants. Equipment has been developed for drilling of 380 mm and 700 mm holes. The practical reach of equipment used to drill 700 mm holes is estimated at 1.5-2 km. However, this is being tested by gradually increasing the drilling length during project execution. Shafts with a diameter of 700 mm and a drilling length of approximately 700 m is now possible.

The drilling equipment for 700 mm holes is the first fully tipped drilling equipment suitable for directional drilling. The next development stage is to develop equipment for directional drilling with 380 mm holes. The equipment modules for this alternative must be light enough to be transported by helicopter. Moreover, there are plans to make equipment for reaming of 380 mm holes to approximately 2 m diameter.

When designing the drilling equipment it was important that the rig-up time of the equipment should be as short as possible, and that drilling should take place from the bottom up, thus avoiding transportation to the top. In addition, it has been important to achieve competitive drilling costs. Roughly estimated, the budgeted price for the ”700-drilling equipment” is in the region of 8000 – 12 000 NOK/m ready drilled tunnel. Lining costs will come in addition where necessary.



Picture 1: Illustration of drilling equipment for directional drilling

2 CIVIL WORKS

2.1 General information

2.1.1 Scope of delivery

The cost base includes costs as stated for the various construction elements.

In the *Cost base for small hydropower plants,* preparing and operating expenses are included in all construction cost components/elements. In general, there has been a relatively sharp increase in the cost level since the previous revision of the cost base in 2005. This is partially due to the general price trends during the period. However, it also appears that the cost of parts of the construction and engineering work had been set rather low in the previous revision.

Generally, preparing and running costs of **20% are included** in the unit prices obtained from diagrams and tables in the cost base.

The preparing and running cost may vary quite considerably. Costs for small hydropower plants are usually in the region of 10-30% of total costs of civil works, and in special cases even higher. This must be evaluated from project to project, and depends on the location and access to transport and communication. A greater distance to villages/towns increases the costs due to increased transport, travel and accommodation. In many cases the preparing and running costs will be 20-30%. Deviations from the costs of 20% must be corrected. However preparing and running costs also vary from contractor to contractor. Major contractors often have more expensive/ larger rigs, but are not necessarily more expensive in total.

The following costs have not been included, and must be evaluated for each project:

- Transport and temporary roads for construction purposes.
- Landscaping (forest clearing, routes, landfills, terrain work, revegetation)
- General costs: Represent additional costs of 10-15% and usually include the following:
  - Surveying and preparation of engineering basis (maps, profiles, etc.)
  - Stream gauging and hydrologic assessments
  - Environmental surveys
  - Impact assessments
  - Soil surveys
  - Planning and engineering. Depending on conditions by the dam, intake, penstock (incline), power station (depth to rock, etc.).
  - Administration, construction management, quality control
- Taxes and fees (value added tax, investment tax).
- Builders costs (land acquisition, valuation, compensation, financing expenses)
- Unforeseen costs. It is generally recommended to add 15-20% to all cost elements to cover any unforeseen costs.

2.1.2 Considerations relating to the value of developers' own efforts

General

"Own efforts" are the opportunity a developer has to make a personal contribution, performing parts of the project work and reducing the need for hired assistance, thus reducing the costs. There are many types of own efforts, usually performed in connection with preparatory and building-related work, whereas turbines and other equipment must usually be supplied by one or several suppliers.

The current situation in Norway does not allow for own efforts in public power plant projects. Nor will large private power plants be particularly suitable for personal own efforts as implementation requires substantial capacity and organisation over a period of time. It would then be difficult to coordinate the developer's own efforts with the work of the contractor. However, private landowners and unit holders may participate in the project in the normal commercial manner, such as contractor activities.

There is more opportunity for own efforts in smaller, private projects (mini and micro power plants). Such projects are often owned by one or a few landowners, and the power plant is often constructed with a great deal of idealism. Own efforts in smaller projects can significantly reduce some of the external costs, and may be necessary to implement the project.

Concept phase.

Landowners and owners of waterfall rights are often of the opinion that it should be possible to build a power plant at the site, and they want to develop the idea and assess the possibility. The first step is often to obtain written information about the procedure from the NVE and then to contact a neutral and experienced consultant on water resource management. It may also be a good idea to hire a consultant for a few hours for a professional evaluation of the project, particularly with regard to the potential size of the project and whether there are any special restrictions (e.g. environmental protection). The own effort may in this respect consist of procuring the relevant information, studying the procedures, and learning a little bit about others projects. Before proceeding, the rights for the entire development should be established.

Project Development

The landowner can do a fair bit of preparatory work; obtain maps, specify ownership, inform neighbours about the prospective project, register their thoughts and opinions, inform the municipal authorities about the concept and register the local authorities' viewpoints. If there are several landowners, it may be necessary to organise a landowner team. It may also be important to agree in advance to look into the opportunities, even if issues of ownership, etc. have not been fully resolved. These are time-consuming activities which the landowner(s) can do himself/themselves (and which they often do best). In this phase, it is often natural to contact external stakeholders, such as professional developers. This will often result in an independent evaluation of the project, and can result in inspections and meetings where the landowners participate and contribute. If the project is viable, the next phase will be to develop more specific plans and outline the project's main solutions.

Obtaining a design base

This is a phase in which the landowner can do some work, possibly in cooperation with a consultant. He can conduct surveys, establish and estimate ground conditions at the location of the potential dam, penstock and power station, and indicate the locations on a map. The landowner can obtain permits from the authorities and dig test pits or ditches to determine ground conditions.

Furthermore, the landowner can photograph the river system at the assumed location of the dam and power station during different water flows; from the very driest conditions - to major flood conditions. The photographs should be taken at different seasons and specify the date when they were taken. (The photos should be digital and be taken from the same angle, preferably quite far away, at a distance of a few hundred metres, depending on the size of the project/river. It is important to take overview photos.)

Hydrological surveys, technical pre-engineering, environmental surveys, licence applications

These activities will usually be conducted by professional consultants. The landowner may prepare a draft for most of the work relating to very small mini and micro power plants, in accordance with NVE guidelines, and if necessary assisted by a hired consultant for inspection and supplementation.

Preparation of inquiries and budget prices of turbines and equipment is often at the top of a developer's to-do-list. However, the above-mentioned activities should be carried out before it is possible to obtain realistic data for actual quotes for the installation.

When a licence or an exception from the obligation to acquire a licence has been granted.

When a licence has been granted, implementation of the actual project will start. Detailed solutions for various parts of the installation are then prepared on the basis of the terms and conditions in the licence, surveys, etc., and tenders for equipment and civil works are prepared. After this, a plan for environment and landscape work and a detailed safety plan is prepared. The content of the detailed plans is to a large extent dictated by the licence. Moreover, the plans must be prepared in accordance with NVE guidelines. We recommend that this work is performed by a consultant with environmental, landscape and hydropower expertise. There are many consultants offering such services. Choosing a consultant with expertise in and experience from many different installations will provide optimal solutions, and predictable and safe implementation of the project both technically and financially.

After a licence has been granted, a common process for implementation of a small hydropower plant project might (>1MW) involve:

- Contracting consultants
- Preparation and submission of drawings and tender documents
- Preparation of a plan for environment and landscape work as well as a technical plan (calculations relating to dams, penstock, spillways etc). These should be submitted to the NVE. Note that the plans must be approved before construction can start. Processing time in the NVE is currently approx. 6 months.
- Contracting of contractors and suppliers
- Construction of power plants – civil works.
- Installation of electrical and mechanical equipment and commissioning.
- Trial period after commissioning 2-3 months.

Please note that construction of power plants on ground is difficult at many locations in Norway during the winter months. Developers should aim to carry out the most demanding construction work during the summer months. This applies in particular to work relating to dams, intakes and penstocks.

Funding

The developer or the landowner must provide the necessary funding.

Implementation and construction

For mini or small hydropower plants the landowner will be able to assist with preparatory work, ensuring accessibility for contractors and equipment by clearing the forest, constructing access roads, trenches, suitable sites for temporary accommodation modules and workshop containers, etc.
It will be necessary to ensure that the required permits are obtained, as well as follow-up of administrative issues vis-à-vis public authorities, connection to the public power grid, etc.

Operation

During the operating period it is often natural that the landowner should be responsible for daily supervision. This will primarily involve ensuring that the intake is clean, and possibly regulating the upstream dams to adjust the flow of water to the power plant in question.

Power sales

Power sales to the grid must be clarified through agreements and the amount of energy must be measured automatically. In some cases some of the energy may be used for one’s own consumption, and energy may be supplied by the grid during shutdown periods. Agreements for, and organisation of such conditions may be individual and may be contingent on the ownership and the size of the power plant.

2.2 Dams/head works

For typical dam designs, reference is made to the publications *Forskrift om sikkerhet ved vassdragsanlegg, NVE* (*damsikkerhetsforskriften*) (*Regulations governing the safety of watercourse structures - the Dam Safety Regulations*) and *Veileder for planlegging, bygging og vedlikehold av små dammer (Guidelines for planning, construction and maintenance of small dams, NVE).* Dams are classified according to their damage potential by failure. The design requirements for dams will reflect the dams' damage potential.

2.2.1 Small rock fill dams

The cost curves represent the price per consecutive metre of dam.
The given height of the dam is measured from the centre of the dam to the top. It has been assumed that the impervious core of the dam will be constructed using morainic material up to 1 metre below the top dam. Outside the impervious core it is assumed that there is a Geotextile cloth and a protective layer of blasted rock which is minimum 1 m. thick. The upstream inclination of the dam is 1:2.5 and the downstream inclination 1:2.

Varying depths have been given for the upstream seal trench, D= 1, 2 or 3.5 m with a bottom width of 0.5 (H+D), min. 3 m, where H = height of the impervious core in the centre dam. It is also assumed that there is an injection screen with a depth of 0.5 (H + D).

Downstream it is assumed that there is a depth D drainage trench with a bottom width of 2 m.

The width of the top of the dam has been stipulated to 5 m, including kerbstone and a gravel road.

The design flood water level should be set at least 2 m below the top dam.

The following main unit prices have been applied:

Cut off trench of local morainic material	156 NOK/m^3
Drainage trench	90 NOK/m^3
Injection screen	1 560 NOK/m^2
protective layer / slope protection	144 NOK/m^3
Geotextile cloth	19 NOK/m^2
Kerbstone and gravel road on top of the dam	264 NOK/m.
Preparing and running costs	20%

2.2.2 Concrete dams

For small concrete dams the following three types of dams have been described:
Gravity dam, flat slab deck dam and arch dam. All three types of dams have been designed for overtopping of water up to 0.8 m.

Concrete gravity dam

The cost curve shows the price per consecutive metre with a dam height of up to 6 m, concreted in sections of 6.1 m. It is assumed that the rock at the toe of the dam has been injected to a depth of 0.5 x H, where H equals the water depth at the highest regulated water level (HRWL). The inclination of the dam on the air side is 1:1. It is has been assumed that 1 m of uncompacted material is removed from the dam route.

The following main unit prices have been applied:

Digging, removal of uncompacted material	80 NOK/m^3
Injection screen	1 560 NOK/m^2
Foundation preparation (fine scaling)	120 NOK/m^2
Formwork	1000 NOK/m^2
Reinforcement	16 NOK/kg
Concrete	2500 NOK/m^3
Preparing and running costs	20%

Flat slab deck dam with inclined slab

A Flat slab deck dam of concrete may be more economical than a gravity dam above a certain height, especially in areas where it is expensive to have concrete delivered.

For the flat slab deck concrete dam, the cost curve shows the price per consecutive metre of dam in sections of 5 m. The injection screen goes down to a depth of 0.5 x H, where H represents the water depth at the highest regulated water level (HRWL). The inclination of the front slab is between 1:0.80-0.95, and the inclination of the supporting slab 1:0.25-1.0. The steepest inclinations are for the tallest dams. The slab concrete dam has not been insulated on the air side. It is assumed that uncompacted material is removed at 2 m width in the dam route, and depth to rock is 0-1m.

The following unit prices have been applied:

Digging, stripping of uncompacted material	80 NOK/m^3
Injection screen	1 560 NOK/m2
Scaling and sealing of rock surface toward slab	5000 NOK/m^2
Formwork	1000 NOK/m^2
Reinforcement	16 NOK/kg
Concrete	2500 NOK/m^3
Preparing and running costs	20%

Concrete arch dam

An arch dam might be the best solution for narrow locations. A concrete arch dam is characterised by a low mass volume compared to its height. Arch dams are therefore very practical at suitable dam locations.

In the cost curve the minimum thickness of an arch dam has been set at 0.6 m. The dam is uninsulated and functions as a spillway. Other associated costs have not been included, such as for discharge gates, pedestrian paths, larger abutments, etc. Rock that has been removed from the toe of the dam is replaced by concrete.

The following unit costs have been applied as a basis:

Injection screen	1 5 60 NOK/m2
Foundation preparation (scaling and concrete)	3500 NOK/m^2
Formwork	1 250 NOK/m^2
Reinforcement	16 NOK/kg
Concrete	2 500 NOK/m^3
Rigging costs	20%

2.2.3 Timber crib dams

At sites with easy access to rocks, timber and qualified manpower, timber crib dams are sometimes more economical than concrete dams and traditional riprap dams. Moreover, timber crib dams can be constructed with an overflow without major changes to the construction. This is an advantage compared to more traditional riprap dams. However, timber is a living building material with a fairly short lifespan.

For the timber crib dam the cost curve shows the price per consecutive metre of dam. The dam includes a seal trench and timber plank sealing on the water side.

The price of the timber crib dam does not include overflow. However the cost developments with timber plank overflow will be relatively similar. The curve is based on empirical figures with normal unit prices for the civil works. However, we would like to point out that the basis for determining the cost of a timber crib dam is very limited as relatively few dams of this type are constructed in Norway today. The costs will also to a large degree be determined by local conditions.

Preparing and running costs of 20% have been included.

2.3 Intake structures

For small plants, and in particular mini/micro power plants, it is important to reduce development costs as much as possible. It may therefore be appropriate to build intake structures that are significantly simpler and cheaper than for larger hydropower plants. In general, the choice and design of intake structures vary significantly and are highly dependent on local conditions.

An intake includes an intake reservoir, a thrashrack and a closing device. The reservoir/ intake structure should be designed to minimise problems relating to ice freeze-up/frazil ice, debris floating on the water surface and sediment transportation. This may also be diverted away from the intake whilst trying to maintain optimal inflow conditions. Typically, the top intake should be at least 2 m below the water level (and lower for large diameters). A small reservoir can be constructed by digging out/blasting out earth/rock mass in order to lower the bottom or by constructing a dam which dams up the water. For larger dams see Chapter 2.2. Generally speaking, an intake will increase in scope with the rate of flow to be handled and with better operational reliability in the structure. Dam costs are calculated separately.

For plants of up to 1 MW it is a fundamental question whether to construct an intake which will function for a long time without monitoring (proper submersion but well above the river bed, and the system will be self-cleaning), or whether to construct an intake which requires more frequent maintenance during operation (manual leaf/ice removal, etc.) The first alternative often gives an intake structure with a minimum height of 3.5-4 m. The latter gives a lower intake dam and thus much lower costs.

Intake structures are often integrated into the intake dam. The owner may find it economical to conduct major repairs/maintenance of the dam/ intake reservoir after each flooding, as long as the flood do not cause damage downstream of the intake. A very simple intake dam may for instance be constructed using local filling materials and a sealing cloth, or as a slab deck dam of wood, or a concrete flow sill, or by making use of a natural sill out of a scouring/pond.

Some types of dams cannot be overtopped. Alternative flood diversion measures must then be implemented. Mini and small hydropower plants will need more robust and larger intakes to secure safe operation, and traditional dams as described in Chapter 2.2 will often form a part of the structure.

The simplest forms of intake might in some cases consist only of a strainer, whereas for larger plants with higher absorption capacity, it will be more appropriate to build an intake structure of concrete. Such an intake will often have a thrashrack and the possibility of installing a stop log/control gate, an intake cone, and a gate/valve to shut off the waterway. A gatehouse is often necessary to protect the gate system. It may also be necessary to provide a thachrack cleaner and install a self closing valve where stipulated in the regulations, instrumentation/surveillance, etc.

The cost curve for intake structures is related to the rate of flow, and applies to civil works. It has been assumed that the regulating elevation is minimal/low as the elevation will greatly affect costs.

Costs relating to thrashrack, gates, thrashrack cleaner etc. are not included in the cost of the civil work. These have been included in Chapter 3, Mechanical Equipment. However, costs for the intake cone and a simple superstructure are included. The cost curve is based on empirical figures with normal unit prices for the various civil works

2.4 Power station/power house

2.4.1 Power station on ground (powerhouse)

The costs of powerhouses are presented in a curve based on empirical figures. There are, however, great variations in the empirical figures. This is because the power plants are very different in terms of location, size and general standard. The costs also vary according to the choice made between crane rails/removable roof, vertical/horizontal-axis unit, the number of units, and foundation. In general, it is the type of turbine/elevation head which is most important and determines the design of the power station. Consequently, the costs have been presented as a function of the head and maximum turbine discharge.

For plants around 1 MW it is a fundamental question whether to construct a power station which will function without daily monitoring (typical power company) or a power station where the owner lives close by and is able to monitor the station on a daily basis. The prices in the enclosed curves are for stations with a generator capacity of > 1MW. For power stations with a capacity of less than 1 MW, a price of 34 000 NOK/m^2 can be used to estimate the cost.

Preparing and running costs of 20% are included in the given prices.

2.4.2 Underground power stations

Power plants with a capacity below 2-3 MW are normally not suitable for construction under ground. For small hydropower plants with a higher output the costs are determined on the basis of volume calculations from the cost base of larger power plants. Despite the substantial variations in volume, we have tried to express the space requirements in a simple formula with the net height of fall (head), total maximum water flow for the station and number of generators as parameters.

An indication of the blasted volume for underground power stations can be obtained by applying the following formula:

Blast volume $V = 78 \times H^{0.5} \times Q^{0.7} \times n^{0.1}$

V = blasted volume, m^3
H = net head, m.
Q = total maximum water flow, m^3/s
n = number of power units

Estimations obtained by applying this formula will only be approximate. We therefore recommend that an outline is drawn up for each installation and that this is used as a basis for calculating the blasted volume.

The total costs of civil works for underground power stations may be obtained by multiplying the estimated mountain volume by a unit price comprising the costs of blasting and construction of the power plant. Thus the unit price includes blasting, formwork, reinforcement, concreting, rock support, masonry, plastering, painting, etc. An evaluation of this, compared with empirical figures for construction of power stations in the open has concluded that the unit price as of January 2010 can be set at **2 250 NOK/m^3** blasted volume, including rigging costs of 20%.

Unforeseen costs have not been included, and it is important to be aware that power station prices vary significantly.

For underground power stations additional costs must be expected in connection with an access tunnel with cable culvert, separate exit tunnel if required, escape room, etc. These costs must be calculated separately, cf. *Cost base for large hydropower plants, NVE.*

2.5 Penstocks, channels

Pipes and closing devices are classified according to their damage potential in the event of a rupture. The design requirements will reflect the damage potential. Reference is made to the applicable regulations as well as to the NVE guidelines: *Retningslinjer for stenge- og tappeorganer, rør og tverrslagsporter (Guidelines relating to closing and drainage devices, pipes and vertical water gates)*

Relevant types of pipes comprise spirally welded steel pipes, glass-fibre reinforced pipes of unsaturated polyester (GRP), polyethylene pipes (PE) and ductile cast-iron pipes, of which GRP and cast-iron pipes are the most common.

In principle, the pipe foundations can either be buried or laid on foundation blocks. The various pipe types have different foundation requirements, due to e.g. the type of material, jointing method and how the impact forces are transferred. The most common combinations are listed in the table below.

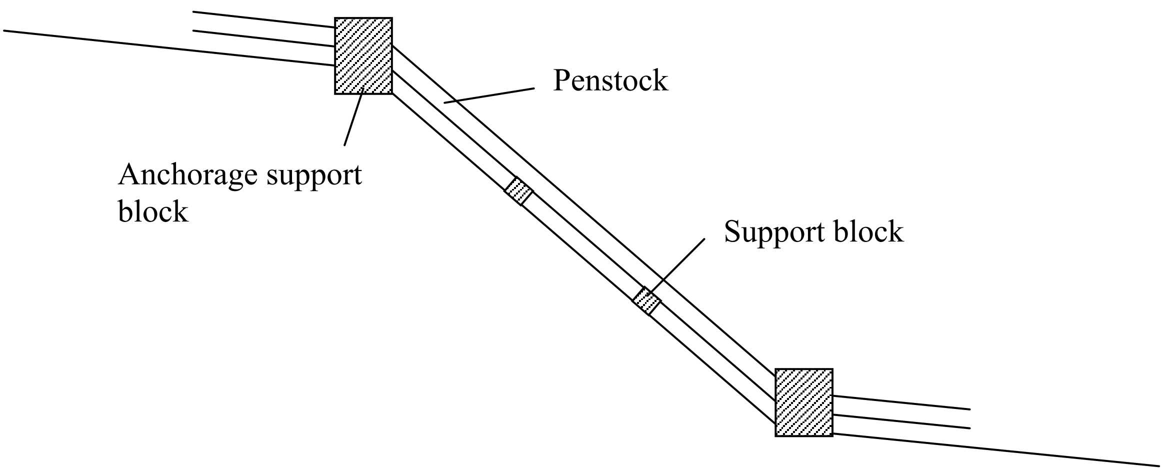
Type of pipe	Buried	On foundation
Steel pipes		X
GRP pipes	X	X
PE pipes	(X)	
Ductile cast-iron pipes	(x)	(x)

For mini and micro plants it may be appropriate to lay the pipe on the ground and clip it to the mountain. This is a simple construction method primarily used for small pipe diameter PE pipes and steel pipes.

2.5.1 Penstock foundations

Penstocks are buried or laid on foundations in the open.

Concrete foundations have different designs according to the forces they have to sustain, the type of pipes, whether there is a support bar or whether they absorb impact forces in an angular deflection in the penstock.



Costs for the different pipe types are presented in Chapter 3.6, Mechanical Equipment.
The design of pipe foundations will vary between the different types of pipes. In the following the mean cost has been calculated. The foundation design is available from the supplier's installation instructions. Experienced consultants / contractors will also be able to provide assistance.

In the following, the estimated cost of civil works for penstocks include foundations for an open penstock with the following assumptions:

Clearing the route, incl. rock removal/scaling	40 NOK/m^2
Digging, including loading and transport	80 NOK/m^3
Blasting	200 NOK/m^3
Foundation bolts	1000 NOK/each
Formwork (one-sided)	1 200 NOK/m^2
Reinforcement	16 NOK/kg
Concrete (minor concreting)	3500 NOK/m^3
Preparing and running costs	20%

In addition the following assumptions have been made:

Spacing between foundations:	9 m (steel) / 6 m (GRP)
Spacing between anchor logs:	60 m.

Average foundation height from the ground to the lower edge of the pipes: 1 m.
The cost curves have been prepared for moderate slopes and good ground conditions.

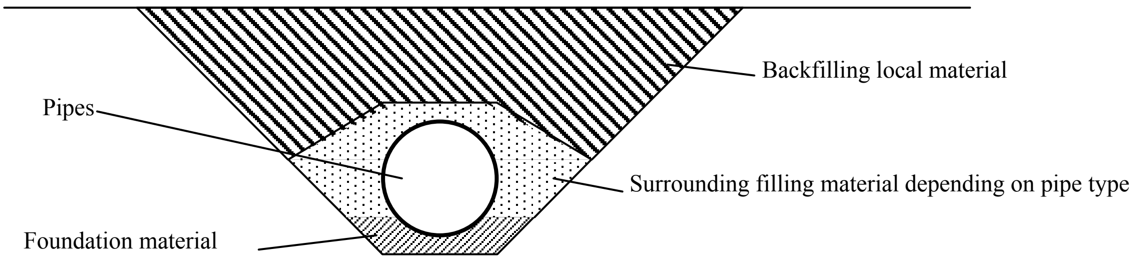
The costs of penstock foundations depend to a large extent on the size of the anchor logs, which must be dimensioned for water pressure in the pipe, change of directions and pipe diameter. Laying the anchor log at a horizontal bend in the rock cut/mountain trench will significantly reduce the volume of concrete.

2.5.2 Pipe trenches

Cost tables have been prepared for earth trenches and combined earth/rock trenches for use in cost assessments of embedded pipes. The tables apply to trenches in a relatively easy terrain.

GRP and cast iron pipes are most suitable for embedding. PE pipes may also be buried, but then at low pressures and in easy terrain.

The drawing below shows a typical trench section for buried pipes:



The inclination of trench slopes has been set at 1:1 for earth trenches and 5:1 for rock trenches. The bottom width of the trench is set as equal to the pipe diameter plus 1.0 m.

The costs in the tables include all contractor costs relating to digging, blasting and backfilling from 30 cm above the pipes. Costs for support in trenches have not been included.

Cost of refilling around the pipes is included. The prices are contingent on the use of local material. If local material is not available, approximately 150 NOK/m^3 must be added for delivery of the refilling material.

The prices include 20% preparing and running costs.

The price does not include construction of a temporary road to enable the digging of trenches and installation of pipes. This must be calculated separately. The road construction costs may be substantial, particularly if the terrain is steeper than 1:5.

The costs of rock trenches are assumed to be equal to the cost of combined earth/rock trenches.

A terrain profile is required in order to be able to calculate the costs of pipe trenches, as well as a thorough assessment of the local conditions. An uneven and/or steep terrain and difficult access will have a great impact on the total costs.

Uncertainty in the cost estimations for relatively easy terrains is ± 30%.

The following unit prices have been used:

- Clearing of vegetation 40 NOK/ m^2
- Digging 50 NOK/m^3
- Rock removal/scaling 60 NOK/m^2
- Blasting 500 NOK/m^3
- Refilling material (handling of local material) 150 NOK/m^3
- Backfilling 110 NOK/m^3

Trench costs (NOK/lm). Trench width 1.5 m at the bottom.

Total trench depth:	1.5 m	2.0 m	3.0 m	4.0 m
Earth trench *(NOK/lm*	1350	1790	2030	2600
Rock trench or combined earth/rock trenches *(NOK/lm*	2000	2610	3760	5220

The prices include a 20% surcharge for Preparing and running of the construction site

Trench costs (NOK/lm). Trench width 2.5 m at the bottom

Total trench depth:	1.5 m	2.0 m	3.0 m	4.0 m
Earth trench *(NOK/lm*	1890	2520	2920	3500
Rock trench or combined earth/rock trenches *(NOK/lm*	2910	3880	5800	8220

The prices include a 20% surcharge for preparing and running of the construction site.

2.5.3 Canals

Where conditions allow, canals can be a good alternative to for example pipes. It has been assumed that the material/masses are impervious and that coating/erosion protection is unnecessary.

The estimated cost curves are based on work in an easy/ moderate terrain with the following unit prices.

Clearing	40 NOK/m^2
Digging	100 NOK/m^3
Blasting	300 NOK/m^3
Preparing and running costs	20%

Unforeseen costs are not included.

2.6 Under ground works

Under ground work is sometimes necessary for small hydropower plants. Consequently, costs have been estimated for the so-called "minimum cross-section", i.e. the most inexpensive tunnel cross-section related to tunnel length.

Costs relating to large-hole drilling have also been estimated.

The cost of underground work depends to a large extent on the quality of the rock and the geological conditions, which may vary considerably within a small area. Compared with good rock conditions, the cost of underground work can easily triple or quadruple if rock conditions are difficult, and might in some places be even higher. In Norway rock conditions are generally good. However, faults and cracks appearing as recessions in the terrain are often of a poorer quality and one should avoid constructing tunnels or bore holes that run in the same direction as these. See also Chapter 1.2.

2.6.1 Tunnel minimum cross-section

Tunnel costs for small hydropower plants are generally lower than for large projects. The reason for this is that there are a number of minor players on the market for small hydropower plants. Costs are estimated for cross-sections from 10-22 m^2, run as conventional tunnel operations.

A 20% rock support is included in the tunnel costs. This is normal for good rock conditions. For small hydropower plants poor rock quality may exclude the tunnel option as an alternative.

Preparing and running costs of 20% have been included.

2.6.2 Large-hole drilling

There are three cost curves for large-hole drilling, showing good, medium and poor drillability. The costs apply to drilling of pilot holes which are expanded (reamed) when the drill bit is retracted.

Rock protection costs have not been included in the cost curves. Rock protection is not normally conducted where rock conditions are good. However, this should be considered in each case.

Preparing and running expenses of 20% are included, but these may vary from 15% to 30%. The drilling costs per metre are higher for a long hole than for a short one. Consequently, the costs should be corrected by a factor linearly increasing from 1.0 to 1.25 for drilling lengths starting at approximately 200 m up to 500 m.

Due to the uncertainty relating to the direction of the pilot hole, it is uncommon to drill more than 500 m using this method. The maximum drilling length is currently up to 3500 m. However, much progress is being made in this field and such lengths require directional steering of the drill bit, ref. Item. 1.2.2.

2.7 Transport facilities

2.7.1 Temporary roads for construction purposes

Empirical figures from various hydropower plants have been used as a basis for calculating the costs of temporary roads.

The costs will vary significantly with the topography and accessibility of the material, as well as the standard of the temporary roads.

We have assumed that the temporary roads maintain a standard corresponding to (a Norwegian) forest road category 3.

The costs comprise a fully prepared road including planning, staking out, digging, blasting, culverts, placing of base courses and gravelling. The scope of each operation such as blasting and transport of material will have a significant impact on the price.

Costs for a fully prepared temporary road:

- Temporary road in easy to moderate terrain: 500-1000 NOK/consecutive metre of road.
- Temporary road in moderate to difficult terrain: 1000-2000 NOK/ consecutive metre of road.

Maintenance of temporary roads in the construction period is assumed to constitute approximately 10% of the temporary road costs.

For small and simple bridge constructions costs are estimated at approximately 20 000 NOK/m^2 roadway (decking).

2.7.2 Helicopter transport

2.7.2.1 General

Expenses relating to helicopter transport will vary according to a number of different conditions and the use of helicopters must be carefully considered in connection with small hydropower plants.

In the following both average costs and key information have been provided, enabling calculation on a common basis in cases where there is detailed information about the construction conditions.

The costs stated are total extra costs incurred due to helicopter transport.

Table 2.7.2 A. Transport of concrete with helicopter. Average transport capacity

Distance in km (one way)	Transport volume, m^3 concrete/ hour	
	Helicopter with a load capacity of approx. 3 tonnes	Helicopter with a load capacity of approx. 1 tonne
1	12	6.5
5	7.5	3.1
10	4.0	1.7
15	3.0	1.3

Table 2.7.2 B. Helicopter flight times

Return trip during normal transport conditions

Distance in km (one way)	Normal load (min.)	Concrete transport (min.)	Ground transport (min.)
1	3	4	6
5	7	8	10

For longer distances the flight time will increase by 1 min/ km.

A height difference of up to 15% of the distance has been included in the table. For greater height differences the flight time can be calculated by adding 0.5 km to the distance per extra 100 m. height.

2.7.2.2 Helicopter transport prices

Helicopter transport is used to transport both materials and personnel. The price of a transport assignment appears as the sum total of a return flight from the helicopter base to the assignment base, plus flights within the construction area. The long distance speed without load can be set at 200 km/h. The flight speed with a concrete load has been set at 60 km/h.

The price has been given in NOK per hour effective flight time and is in principle the same for flights to and within the construction area. Discounts are often available for flights to the construction area.

Normally the helicopter used has a load capacity of approximately 1 to 3 tonnes. The different companies offer different helicopters from different bases. Other types of helicopters are also available with a load capacity between those specified here. The price per tonne is generally more or less the same regardless of the choice of helicopter.

Work carried out with the use of a helicopter transport will normally be considerably more expensive. Remote locations necessitating helicopter transport of both manpower and materials will give high unit prices. The prices will normally be significantly higher than those quoted by the helicopter company.

We suggest that the following unit prices are used for such work:

- Formwork 2000 NOK/m^3
- Reinforcement 20 NOK/kg
- Concrete 8000-10000 NOK/m^3
- Preparing and running cost 30% in addition for quantity items

Prices for helicopter transport only as quoted by the helicopter company and without contractor surcharges are given in the table below.

Table 2.7.2.C. Helicopter hire costs

Type	Hire costs: NOK/hour of operation	Load capacity: tonne
Small helicopter	13000	approx. 1.0
Large helicopter	48 000	approx. 3.0

3 MECHANICAL EQUIPMENT

3.1 General

3.1.1 Scope of delivery

Delivery of mechanical equipment generally includes equipment being installed and ready for operation, if not otherwise specified in the comments to each individual cost curve.

However, the delivery does not include:

- Civil works
- Ventilation, installation of lighting and heating at the power plant
- Spare parts
- Value-added tax
- Builder expenses
- Unforeseen costs

3.1.2 Price estimate

The prices are based on installations constructed in the last five years, and, whenever there is sufficient basis to do so, on installations constructed in the last couple of years. The prices have been adjusted for inflation to 2010 levels.

Since the last cost base update in 2005 there has been significant variations in the cost increase for the different components.

In general, the price of turbines has increased significantly, by about 30%. Turbine prices fell during the period 2000 - 2005 due to a strained market. During the same period, several suppliers developed more customised and cost-efficient solutions for small hydropower plants. This resulted in particularly low prices in 2005, and explains some of the increase we have experienced during the period 2005 to 2010. Turbine components are produced in a number of countries, and are therefore influenced by international price trends. In particular, the price of stainless steel has increased significantly in the last five years. In addition, the economic situation was generally good after 2005 resulting in a somewhat strained market.

There has been a relatively high increase in the cost of certain components such as steel pipes and gates, but the highest increase has been in connection with extended use of stainless steel. Correspondingly, GRP pipes have seen an average price increase of approximately 45%.

Budget prices from suppliers have varied a great deal. Generally speaking, one should be careful with budget prices obtained in an early phase of a project. We recommend comparing these with the price curves in this document.

3.2 Turbines

Turbine prices are given as NOK/kW nominal effect, and as the function of maximum absorption capacity and effective head.

Price curves have been prepared for each of the most common turbine types on the market for turbines with a power range of between 500 – 10 000 kW. For turbines with a power range of up to 500 kW, see Chapter 5.3, Micro and mini power units.

The rotational speed has been included in the price curves for turbines with a power range of between 500 and 10 000 kW. If the rotational speed is low, gears are often used for turbines with a power range below 2 – 3 MW.

The head graphs indicated in the price diagrams correspond to a common range for small turbines of the Pelton, Francis and Kaplan type, respectively. The top graphs do not in any way represent an upper limit for the use of turbines of this type.

The rotational speed graphs are only indicative, corresponding to a specific forced rate (submersion/suction head). If a turbine is chosen with another rotational speed than the one specified in the relevant flow diagram, the head curve can still be used to define the price per. kW.

The rotational speed can be taken into account in the following manner:

If one chooses a turbine with a lower rotational speed than the one shown in the diagram over the given rate of flow and head, the turbine price will generally be somewhat higher than indicated in the diagram based on the value of the rate of flow and the head graph, and vice versa if a higher rotational speed is chosen than the one shown in the diagram.

The given price level for turbines reflects what can be referred to as a normal price level. There are turbines on the market that are both significantly cheaper and more expensive than indicated in the price curves.

We have prepared price curves for the following turbine types:

- Pelton
- Francis
- Kaplan/bulb turbine

The following has been included in the individual curves:

<u>Turbines with a capacity of 1 – 500 kW</u>

See Chapter 5, Micro and mini power units.

Turbines with a capacity of 500 – 10 000 kW

The given price curve is for the turbine + turbine control + inlet valve (not on Kaplan turbines).

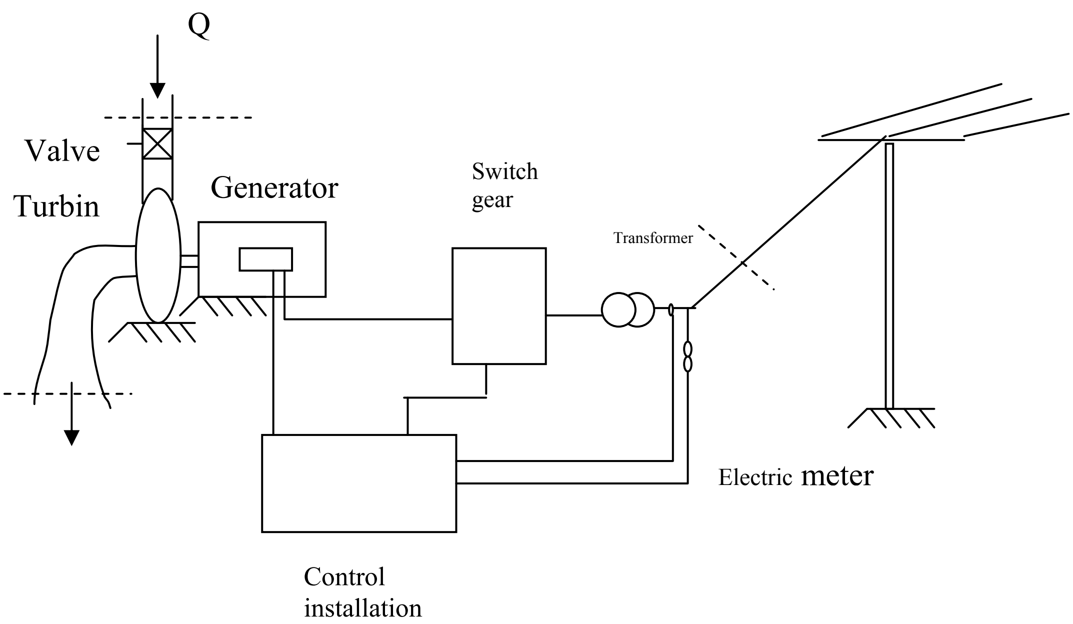
For prices of electrical equipment for plants with a capacity above 500 kW, see the price curves in Chapter 4, Electro-technical work.

General advice on the choice of turbine supplier

In addition to the price, the following should be considered when selecting a turbine supplier:

- References. Contact other developers who have used the same supplier.
- Power plant automation. Important with regard to how much work is required for daily operations.
- The turbine's catchment area, such as maximum and minimum rate of flow for continuous operation. Important for making maximum use of the flow.
- Efficiency. Be critical of turbine efficiencies that are not supported by reliable documentation.
- Operational reliability can be just as important as high efficiency.
- Does the delivery (price) include everything? Check whether the quote includes all necessary equipment/work.

Schematic diagram:



3.2.1 Pelton turbines

Range of application

For larger installations Pelton turbines are used for high heads. However, for smaller installations, Pelton turbines may also be used at relatively low heads. The operation range for Pelton turbines overlaps with the range for Francis turbines.

Advantages and disadvantages of Pelton versus Francis turbines

Advantages:

- A large operation range from approximately 10% of maximum discharge. Francis from approximately 40% of the maximum discharge.

- Flat efficiency curve, though with a lower top than the best efficiency point than a Francis turbine.

- No pressure surge problems in the penstock when the turbine is shut down.

Disadvantages:

- The turbine runner must be located at a certain distance above the highest tailwater level, which means some of the head is lost.

- Pelton turbines have traditionally been more expensive than Francis turbines.

The large operation range is often a reason for choosing a Pelton turbine; this makes it possible to handle major water flow variations with just one power unit.

Different technical solutions for Pelton turbines.

- Number of /jets. Using several jets gives a larger operation range, whilst at the same time enabling the use of higher rotational speeds and consequently smaller dimension turbines. Therefore, the use of several jets allows for the use of Pelton turbines at higher rates of flow and effect in relation to the head.

- The most common solution for small Pelton turbines has been an arrangement consisting of a horizontal shaft and one or two jets. A vertical shaft with several jets is used for large installations. Most suppliers now offer small vertically arranged Pelton turbines at a price that is often competitive with that of traditional horizontal units.

- Most smaller Pelton units are constructed with the turbine runner mounted directly on the generator shaft.

3.2.2 Francis turbines

3.2.3 Range of application

The Francis turbine is the most commonly used turbine in Norway, with an extensive area of use between the Pelton and Kaplan turbines.

Advantages and disadvantages of the Francis versus the Kaplan turbine

Advantages.

- The Francis turbine has higher top efficiency, whereas the Kaplan turbine has a lower, but more even efficiency curve.

- A Francis turbine is less expensive than a Kaplan turbine.

Disadvantages.

- A Francis turbine has a smaller operation range than a double regulated Kaplan turbine.

- A Kaplan turbine generally requires more submersion than a Francis turbine.

For a comparison with the Pelton turbine, see comments under Pelton turbines.

Technical solutions for Francis turbines

- Horizontal/vertical rotation axis.
  A horizontal setup is used for most Francis turbines of this effect range. This is because construction is much simpler and less expensive for horizontal arrangements. In addition maintenance is easier for horizontal arrangements.

- Conventional spiral casings represent the most common solution for small Francis turbines. Cylinder casing solutions are not very relevant today except for the smallest turbines. A vertical unit with a case turbine may be suitable for very low heads.

- Most small Francis units are constructed with the turbine runner mounted directly on the generator shaft. Solutions with gears may be economical if the rotational speed is very low.

- To avoid cavitation the turbine runner must be installed in such a way that it has a certain minimum pressure, either by limiting the suction head, or by submerging the runner below the tailwater level. A ”forced” turbine will a have higher rotational speed and smaller dimensions, but will allow for less suction head and require more submersion than a less “forced” turbine. Smaller installations are often constructed with the turbine hall floor and generator above the highest tailwater level to avoid the risk of the station flooding. In practice this means that the runner centre must be located two to three metres above the regular tailwater level. The rotational speed graphs shown in the price diagram have been prepared for a degree of "forcing" corresponding to this suction head.

3.2.4 Kaplan/Bulb turbines

3.2.5 Range of application

Whereas large Kaplan turbines can be used for heads of up to 60 m, small Kaplan turbines are rarely used above 25 m. The lower head limit is often determined by the NOK/kWh costs.

Calculated in NOK/kW, Kaplan turbines are relatively expensive. This is because they are used for high rates of flow and small heads, resulting in a turbine of large dimensions in proportion to its effect.

Advantages and disadvantages of the Kaplan turbine.

See the section on Francis turbines.

Technical solutions

- Horizontal/vertical rotation axis.
  Turbines with Kaplan runners come with a number of different arrangements, with both vertical and horizontal rotation axes. Vertical Kaplan turbines have been relatively common in Norway. However, one advantage of a horizontal setup with axial flow is that the width of the power station is reduced, which in general will reduce the cost of construction.

  Bulb turbines have a horizontal or tilted arrangement. An S-turbine is a variant of the bulb turbine, the main difference being that the generator is located outside the waterway, whereas for bulb turbines it is located in the waterway.

- Double and single regulated Kaplan/Bulb/S-turbines.

  There are three main ways of regulating these turbines.

  1. Double-regulated turbine where it is possible to regulate both runner blades and guide vanes. This is the most expensive solution, but gives an even and wide efficiency curve over a wide operation range.

  2. Single-regulated turbine with adjustable runner blades only. This is a less expensive solution with a more pointed efficiency curve. This unit does not have an adjustable guide vane operating system. Start-up, synchronisation and shutdown take place by means of the inlet gate.

  3. Single-regulated turbine where only the guide vanes are adjustable and the runner blades are fixed (also called propeller turbine). This will generally give the cheapest solution. However, the efficiency curve is very pointed.

- The low rotational speed of Kaplan turbines may necessitate gear transmission between the turbine and the generator. Another less used alternative for low effects is belt drive transmission. Both gear and belt drive transmissions must be correctly dimensioned to ensure problem-free operation. Even with correct dimensioning, both gear and belt drive transmissions represent wear elements with a shorter lifespan than other main components in a hydroelectric power station. It is not uncommon that the gear or the gear mechanism needs replacing after ten years of operation. The lifespan of a belt may be even shorter (However, the price will normally be significant lower). Other aspects that should be considered as regards gears are noise and loss of effect (approx. 2-3%). Gears are rarely used for turbines with an effect above 2-3 MW.

Comments to the cost curves

The cost curves apply to double-regulated turbines. A single-regulated turbine will give a lower price. Normally there will only be insignificant variations in the price of machine costs of vertical and tilted/horizontal turbines. However, construction costs may vary significantly depending on the choice of turbine setup.

3.2.6 Other solutions and turbines

The turbines and solutions described above are the most common types of turbines in Norway today.

There are, however, a number of other turbines and solutions less commonly used. These were more common previously, or they may be common in other countries.
Some typical examples are described below.

«Double» turbines

A double turbine has two turbines for the same generator.
One solution is to install a complete turbine on each side of the generator. This solution has been used for both Francis and Pelton turbines.

Another solution is to have a double turbine on one side of the generator. Previously, this solution was often used for Francis turbines, either with a common intake, a double turbine runner and two separate draft tubes, or with two guide vane operating mechanisms in a common drum or case, and a common draft tube.
The advantage of a double turbine is primarily that it makes it possible to increase the rotational speed of the turbine (by a square root of two) compared with a single turbine, without having to increase the forced rate or submersion. The use of gears has resulted in this solution rarely being used today.

Cross-flow turbines

The range of use for the cross-flow turbine overlaps that of the Kaplan, Francis and Pelton turbine. In most practical cases it is used within the same range as the Francis turbine.

Cross-flow-turbines have been used successfully for small, simple installations in developing countries.

The turbine runner resembles a water wheel; the water passes across the wheel transversely and goes through the runner twice, first on its way in to the turbine runner, and again on its way out. Cross-flow turbines are often constructed with a shared intake providing a large catchment area.

The efficiency is however, lower than for conventional turbines, and it has often proved difficult to document its efficiency.

The price varies somewhat between different suppliers. Comparisons conducted for specific installations have shown that the cost savings that one would expect compared to a Francis turbine are often insignificant when all elements are considered.

Turgo turbines

A Turgo turbine is a partial turbine like the Pelton turbine. It is particularly suitable for medium pressure ranges from 100 to 300 m. It is particularly good if sand abrasion is a problem. It has a high specific speed, allowing for higher rotational speed and a more compact turbine than the similar Pelton turbine. Consequently, the generator costs are reduced. The efficiency is approximately 85%.

3.3 Gates

The gate prices are given in NOK million, and as the function of the gate size. The height of the shaft and gate and the design pressure have been set at a constant value for each price curve and type of gate.

Price curves have been prepared for the type of gates that are most relevant for small hydropower plants:

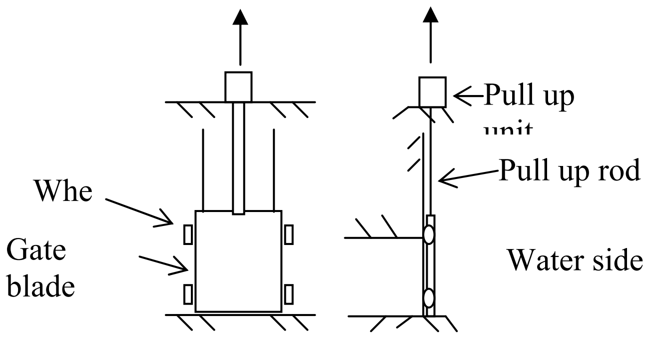
- Roller gate
- Slide gate
- Tilting gate
- Rubber gate

<u>Dam gates</u>
Dam gates are gates which are connected to the dam. Spillway gates and bottom sluices are often used for large dams. The names of the gates derive from their function or the location of the gate in question.

<u>Inlet gates</u>
Inlet gates are gates placed in the intake in the waterway to the turbine.

3.3.1 Roller gate

Schematic diagram:



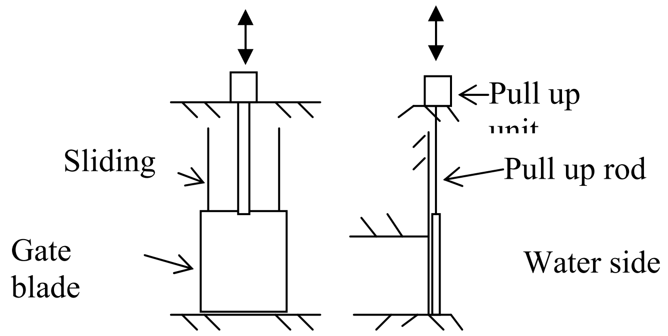
<u>Area of use</u>
Roller gates are most often used as inlet gates.

<u>Retraction (pull up)</u>
Retraction consists of a single-acting hydraulic cylinder, i.e. the gate is self-closing. When using a self-closing gate there will only be tensile forces in the pull up rod.

<u>Gate blade</u>
The gate blade is made from a massive steel plate for small dimensions and low water pressures. For larger dams/water pressures the gate blade is made up of a front panel reinforced with ribs.

3.3.2 Slide gate

Schematic diagram



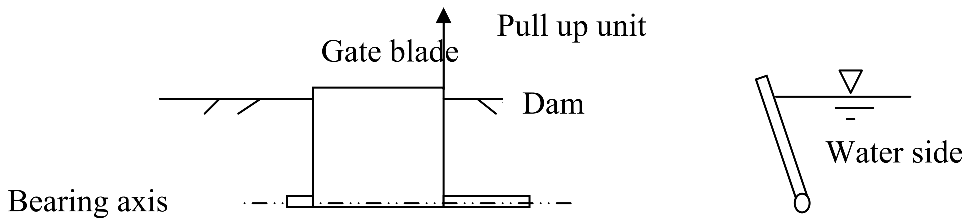
Area of use
Slide gates are used as discharge gates, spillway gates, draft tube gates, inspection gates and inlet gates.

Pull up
Pull up often consists of a double-acting hydraulic cylinder or a mechanical nucleus of screw. The opening and closing forces are larger for a slide gate than for the roller gate.

Gate blade
Operation of the gate blade is the same as for the rolling gate.

3.3.3 Tilting gates

Schematic diagram



Area of use
Tilting gates are mainly used in the same way as spillway gates and flush gates. Tilting gates are not often used in small dams.

Pull up
Closing takes place by using a single-acting hydraulic cylinder attached either to the top of the gate or a bearing axis. Tilting gates are self-opening with water pressure.

3.3.4 Rubber gates

Area of use

Rubber gates are often used to replace dams in smaller plants. At larger plants, parts of the dam may consist of a rubber gate. In a flood situation, air/water will be released out of the gate and the water will flow over the dam (rubber gate).

Adjustment/retraction

Rubber gates are adjusted by either air or water.

3.4 Thrashrack

The cost of thrashracks is given in NOK as a function of the thrashrack area. Water pressure, the height of the thrashrack and the centre distance between the thrashrack bars have been set at a fixed value.

Usage
The thrashrack is used to prevent debris from entering the turbine waterway.

Dimension criteria
The maximum water speed through the screen should not exceed approx. 1 m/s, and should be even lower if there is a risk of icing. The screen should be dimensioned for boarding during inspection work.

Different screen materials
Traditionally, thrashrack have been made of black steel which has been hot dip galvanised and then painted. Alternatively, the thrashrack can be made of stainless steel or a synthetic material.

Advantages/disadvantages of thrashrack made of stainless steel and synthetic materials

Stainless steel:
Advantages

- Well-tested solution, buckling resistant and non-corrosive, wear resistant, greater distance between supports (support bars).

Disadvantages

- High price.

Synthetic materials:
Advantages

- No icing, non-corrosive, reduces loss of head provided that the bars are not too thick, price.

Disadvantages

- Not extensively tested on the Norwegian market, they buckle significantly, short distance between supports (support bars).

3.5 Lifting equipment

3.5.1 Travelling crane

Travelling cranes cover a large area and are almost always used for larger hydropower plants where there are strict lifting equipment requirements.

The cost curves for travelling cranes are in NOK 1000 as a function of the lifting force. Span, lifting height and lifting capacity are fixed values in the price curve.

3.5.2 Electric hoist with electric traverse carriage

The service area of electric hoists is limited to the area along the crane beam. Electric hoists are available with chains or wires. Chain hoists are suitable for low lifting heights and lifting forces. The length of the crane beam and the lifting height are fixed values in the price curve.

3.5.3 Alternative lifting equipment

For the smallest power stations it may be an option to use a manually operated chain hoist, either fixed or with a travelling hoist. Price curves have not been prepared for chain hoists.

3.5.4 Mobile cranes

Mobile cranes may be an alternative to permanent lifting equipment at the power plant. If a mobile crane is used there must be sufficient road access and a power station building with, for instance, a removable roof. Cost curves have not been prepared for mobile cranes.

3.6 Thrashrack cleaner

Usage

A thrashrack cleaner is used to clear the thrashrack and to reduce head loss. The thrashrack cleaner can be operated manually or automatically (unattended). Start-up is initiated via a start signal from a time switch or from head loss measuring equipment above the thrashrack. The price of thrashrack cleaner varies significantly according to their mode of operation and the thrashrack service area.

The price of a small thrashrack cleaner with an area of $< 15\ m^2$ is in the region of NOK 150 000 - 600 000.

3.7 Pipes

Cost curves have been prepared for each of the most relevant pipe types.

- PE pipes
- GRP pipes
- Spirally welded steel pipes
- Ductile cast-iron pipes

The cost curves indicate the cost per metre of pipes. Installation costs have been given as a percentage of the pipe costs. Installation costs for some pipe types have not been included in the cost curves. Where this is the case, installation costs can be estimated as 20-30% of the pipe costs.

Installation costs may vary significantly in accordance with terrain conditions and transportation along the penstock.

The cost curves are based on penstocks that are minimum 150 metres long. The unit prices will change for shorter or longer penstocks.

The cost of the various pipe types may vary considerably between different suppliers.

The pressure ratings and dimensions of each pipe type specified in this document are not always permitted for use in all hydropower plants. This depends on the pressure/diameter ratio and the rupture consequence category of the power plant in question. The NVE has prepared guidelines for when each pipe type can be used.

It may be profitable to use stainless steel for steel pipes with a diameter of less than 400 mm. This is because maintenance is difficult and expensive for small dimensions.

Wooden pipes and concrete pipes have not been included in this revision of the cost base. This is because these types of pipes are used infrequently in the construction of small hydropower plants. Thus the price estimate is considered insufficient.

3.7.1 PE pipes

Pressure ratings and dimensions

PE pipes are usually held in stock for the following pressure ratings and dimensions:

Pressure rating	Available dimensions [mm]
PN 4, PN6, PN10, PN16	from Ø 110 – Ø 630
PN25	from Ø 110 – Ø 315
on order PN4	Up to Ø 1200

When ordering, PE tubes are described in outer diameters. To find the inner diameter the material thickness must be deducted. The material thickness varies between 4 – 60 mm depending on the pressure rating and pipe diameter.

In the cost estimate, inner diameters have been used as a parameter.

Properties
Advantages:

- The material is able to withstand rough handling on the site, particularly in cold weather. The pipes are laid in all-welded pipe sections with 100% protection against permeability, no coating necessary, long lifespan, and few problems with icing.

Disadvantages:

- Low strength and rigid material, during welding an inner edge is often formed at each pipe joint which causes increased loss of head in penstock.

3.7.2 GRP pipes

Glass-fibre reinforced unsaturated polyester

Pressure ratings and dimensions

GRP pipes are usually held in stock for the following pressure ratings and dimensions:

Pressure rating	Available in dimensions [mm]
PN 6 and PN 10	from Ø 300 – Ø 2.000
PN 16	from Ø 300 – Ø 1.600
PN 25 and PN 32	from Ø 300 – Ø 1.400

Properties:
Advantages:

- Low weight, few problems with icing, suitable for trenching, little or no maintenance, no extra coating necessary, low head loss, chemical resistant, long lifespan.

Disadvantages:

- Require good foundations and anchoring to avoid problems with the pipe joints, poor impact-resistance, can easily be damaged by rocks falling on to the penstock, etc.

3.7.3 Spirally welded steel pipes

Pressure ratings and dimensions.
Spirally welded or longitudinally seam welded steel pipes usually come in dimensions from Ø 200 – Ø 1.400 mm, whereas longitudinally seam welded pipes are used for diameters below 500/600 mm. Pipes produced according to the DIN 2458/1626 standard are pressure tested to 50 bar = 500 m water column. When choosing material thickness a rust allowance must be added for each side of the pipe.

Properties
Advantages:
- Very strong, require less anchorage than GRP tubes.

Disadvantages:
- Require maintenance (coating), high weight, welded joints require much work, particularly for large wall thicknesses.

3.7.4 Seamless steel pipes

Seamless steel pipes have not been included in this price review as this type of pipe is rarely used in penstocks for hydropower plants. This is because of its high price, which is approximately five times higher than for spirally welded steel pipes.

3.7.5 Ductile cast-iron pipes

Dimensions and pressure ratings
Available in diameters of up to Ø1.800 mm, and for a pressure up to approx. 600m, standard pipe length 8 metres.

Properties
Advantages:
- Low installation costs and high corrosion resistance when trenched, simple and high quality pipe joints.

Disadvantages:
- High weight.

The costs of ductile cast iron pipes are given according to pressure ratings K9-K12. The correlation between the given pressure ratings and bar pressure follows from the table below. 1 bar = 10 mVS.

Table 1: Pressure rating ductile cast iron pipes

DN [mm]	K9 [bar]	K10 [bar]	K11 [bar]	K12 [bar]
400	42	48	55	61
500	38	43	49	55
600	36	41	46	51
700	34	38	43	48
800	32	37	41	46
900	31	35	39	44
1000	30	34	38	43
1100	29	33	37	42
1200	29	33	37	41
1400	28	31	-	-
1500	28	31	-	-
1600	27	30	-	-
1800	26	29	-	-
2000	26	29	-	-

4 ELECTRO-TECHNICAL EQUIPMENT

4.1 General

The cost basis provides an overview of electro-technical installations in power plants, and reflects the cost level for a normal scope of delivery and equipment. The enclosed cost curves reflect electrical equipment for generators larger than 500 kW. For generators with a capacity lower than 500 kW the electrical equipment is usually part of the turbine delivery, and are therefore included in the turbine cost curves.

For small hydropower plants it is important that the electrical equipment is as simple as possible, but still practical and reliable. The cost basis assumes a control system based on the rest current principle, as well as an asynchronous generator for generators with a capacity below 1000 kVA. We further assume that the power plant will deliver electricity to a 22 kV distribution grid.

The cost basis is generally based on prices obtained from Norwegian installations constructed in the last five years, and, whenever there is sufficient basis to do so, on installations constructed in the last couple of years.
On several previous occasions we have obtained budget cost from different suppliers. However, there are such great variations in these prices that we have chosen not to use them in this cost basis. This price variation may partly be explained by some suppliers factoring in potential additional costs, thus proposing a solution that is overly expensive, whereas others may give a price for solutions that are incomplete and which will then appear overly cheap. Moreover, budget cost may not sufficiently reflect the engineering, installation and commissioning costs that will incur.

As for machines, though to an even greater extent, the costs of electro-technical components are governed by the international economic situation. The market was relatively weak from 2000 – 2005, which resulted in a very modest price increase during this period. However, in the last five years the market has been characterised by high activity both domestically and internationally, and this has resulted in a fairly high price increase for certain components.

The price increase for generators is in the region of 35 - 40%. For power transformers there has been an increase of 50 - 60%, depending on the size of the transformer. Control system and switching station approximately 30%, but with substantial variations in the obtained cost basis.

The following main components are presented:

- Generators
- Transformer
- Control system incl. auxiliary supply
- Switchgear
- Power transmission line

4.1.1 Power factor (cosΦ)

The output for electro-technical components such as generators, transformers and appliances is indicated in kVA. In the chapters describing construction-technical and mechanical installations kW is used to measure output. In keeping with the other chapters KW is also used for electro-technical material. We have assumed a fixed power factor (cosΦ) of 0.90. This entails that the electrical output in kVA is 11% higher than when given in kW.

4.2 Generators

Scope
The price estimate applies to air-cooled generators with an output of 500-2000 kVA, and water-cooled generators with an output of 2000-10000 kVA. Units with an output below 500 kVA are usually sold as part of a package along with the turbine and other equipment.

The majority of installations in plants of this size use horizontal machinery. In the cost estimate it is assumed that there is a support which can carry the turbine on a free axle. Furthermore, a natural moment of inertia has been assumed, without flywheels. The prices are further based on machines with a rotational speed between 1500 and 375 rpm (synchronous rotational speed). Slow-moving generators are only to a limited extent standardised and are therefore somewhat more expensive.

Units with a rotational speed of 333 rpm or lower have not been included in the price review. In such cases it will often be profitable to consider using gears between the turbine and the generator to increase the rotational speed of the generator.

Ventilation
The power plant's ventilation system must be designed to remove waste heat from the generator. With an air-cooled generator the typical waste heat is 2-3% of the nominal effect. In the winter some of this heat can be used to heat the machine hall. Ventilation inlets for incoming air should have a suitable air filter.

Price level
The prices are based on information obtained about implemented projects and on tenders from relevant producers and suppliers in Norway.

Below follows an overview of foreseeable price variations for various relevant changes/supplements beyond the scope outlined as a basis for the given prices:

- Supplement for vertical arrangement: +10 %
- Deduction for asynchronous generator: -5 %
  (usually not relevant for generators larger than approximately 1000 kVA)

The generator voltage of machines with a performance below 1500 kVA is often 400 V. Generators above 2500 kVA are often high voltage, whereas 690 V is often used for medium capacity generators.

A voltage regulator is supplied as a standard component of the generator.

4.3 Transformers

Power transformers
The cost basis consists of transformers for supply of power to a 22 kV distribution grid.

Transformers with a capacity of 1600 kVA and below are usually standard oil-filled distribution transformers. In many cases it has also become more common to use dry-insulated transformers for these capacities even though they are 0-5% more expensive. Larger transformers have not been standardised in the same way and are therefore relatively more expensive.

The transformer voltage can usually be adjusted in five steps by using a tap changer designed for coupling in voltage-free conditions. On-load tap changers which can adjust the voltage during operations are very expensive and not relevant for this type of installation.

Cooling
Most transformers for power stations of this category (small hydropower plants) can be constructed outdoors or in well-ventilated rooms, and are air-cooled naturally.

Price level
The cost are based on implemented projects and tenders obtained for relevant projects.

Complicated control equipment is not required for transformers for small hydropower plants. Usually it is sufficient to have a temperature controller to protect against overload. A sudden pressure relay may, however, be necessary for the largest ones.

Station transformer
Power stations with a generator voltage higher than 400 V must have a separate station transformer for supply of auxiliary current to the installation. These are small transformers and are often dry-insulated. They are only intended to supply pump motors, fan motors, battery chargers and other support equipment. Typical station transformer prices are approximately NOK 25 000 to 50 000 for outputs between 25 and 50 kVA.

4.4 Control system

The control system normally consists of:

- Power unit control
- Generator protection
- Other protection for the switchgear and, if necessary, power transformer protection
- Switchgear control functions
- Water level regulation
- Remote control (SCADA)
- Battery with charging rectifier

Small and medium sized facilities are usually not designed to supply to their own local grids, so-called island operation. Consequently, it is common to apply ratio control measures. The grid owner can demand that larger installations must be able to supply the local grid, if, for instance, there is a fault in the overlying grid. This entails rotational speed control which is a somewhat more expensive solution. Both ratio control and speed control can be integrated in the power unit control, but are often delivered as separate units for larger power units.

The power unit control comprises start and stop functions of units and auxiliary functions. Equipment for automatic synchronisation and water level regulation is usually integrated in the control system. Operation of the power plant should be automated as far as possible. The extent of automation is determined by the type of watercourse and operating philosophy.

Remote control will be an option for most small hydropower plants, perhaps with the exception of very small ones. This can be supplied as simple systems suitable for small installations, designed to transfer just a few signals over an ordinary telephone line or other communication networks. Power plants which supply power to the interconnected transmission grid are required to have an hour registering counter which the grid owner is able to read remotely.

As a minimum, the generator protection contains:

- Overcurrent/short circuit protection
- Reverse power protection
- Earth-fault protection relay

and, if necessary:

- Over/under voltage protection (only for synchronous machines)
- Differential protection (common on machines larger than approximately 2000 kVA)
- Etc.

Other protection can consist of:

- Overcurrent/short circuit protection for outgoing lines
- Earth-fault protection relay for outgoing lines
- etc.

The price basis has been limited, as control equipment and switchgears are often delivered as a package from the supplier. The price curve indicates that large price variations must be expected depending on quality and complexity. The function and setup of the control system is not necessarily proportionate to the size of the unit, but is to a large extent determined by the instrumentation, the extent of automation, type of remote control, etc.

4.5 Switchgear

Switchgear for power stations below 10 000 kVA are usually simple.

The prices are based on supplied and tendered installations, as well as budget prices from suppliers of the relevant equipment in the last 1-2 years.

Below follows graphical overviews of the price level for switching stations for installations with one power unit. We have not provided price estimates for installations with two or more units. However, one can generally assume that the price for a power plant with two units is nearly double.

It is assumed that the delivery is terminated by the station wall, i.e. including HV switchgear, but excluding cable connections to high voltage power lines.

The grid owners will require a connection fee to cover their investment costs. They will be the owner of the high-voltage installation and have operational and maintenance liability for the installation if the developer does not conform with regulatory requirements. This cost should be included in the total cost of the power plant.

<u>Condenser battery</u>
The grid owner may request that condenser battery should be installed for phase compensation purposes at power plants with asynchronous machines. In that case, it may reduce the price advantage of asynchronous installations versus synchronous installations.

4.6 Power line

One of the first things to look into when planning a power plant is how to transfer the electricity to the local or regional electricity grid. A promising project can easily become unprofitable if it is contingent on construction of a relatively long, new power line or if an existing power line has to be upgraded.

The cost of power lines (constructed either as a cable or overhead line) varies significantly depending on the ground and climate conditions. It is therefore important to obtain advice as well as a price estimate from a line contractor, consultant or the local grid owner at an early stage of the preliminary studies.

5 COMPLETE ELECTROMECHANICAL DELIVERIES

5.1 General

5.1.1 Scope of delivery

Delivery of complete electromechanical equipment generally comprises all necessary electromechanical equipment at the power plant, installed and ready for operation, if not otherwise specified in the comments to each price curve.

A complete electromechanical delivery normally includes the following:

- Turbine
- Turbine control
- Intake valve
- Generator
- Control system
- Switchgear
- Transformer 22 kV (see separate note below under micro and mini power units)
- All internal cabling at the station.
- Transport, assuming a passable road
- Engineering, installation and commissioning

However, the delivery does not include:

- Building and construction work
- Ventilation, installation of light and heating at the power plant
- Spares
- Value-added tax
- Builder expenses
- Unforeseen costs

5.2 Complete small hydropower plant unit from 500 – 10 000 kW

5.2.1 Cost estimate

Cost curves have not previously been prepared for complete electromechanical deliveries for installations with a capacity above 500 kW. Thus there are no previous cost bases to compare with.

The cost estimate is generally based on costs obtained from Norwegian installations constructed in the last five years, and, whenever there is sufficient basis to do so, on installations constructed in the last couple of years.
The prices have been adjusted for price inflation to 2010 levels.

The cost estimate provides an overview of electromechanical installations in power stations, and reflects the price level for a normal scope of delivery and quality of equipment.

For small hydropower plants it is important that the electrical equipment is as simple as possible, but still practical and reliable. The price estimate assumes a control system based on the rest current principle, as well as a synchronous generator for generators with a capacity above 1000 kVA We further assume that the power plant will deliver electricity to a 22 kV distribution grid.

Budget prices from suppliers have varied a great deal. Moreover, budget prices may not sufficiently reflect the engineering, installation and commissioning costs that will be incurred. Generally speaking, one should be cautious with budget prices obtained in an early phase of a project. We recommend comparing these with the price curves in this document.

5.2.2 Small hydropower plant generators

The costs are given as NOK/kW nominal effect, and as the function of the absorption capacity and maximum efficient head.

Cost curves have been prepared for each of the most common turbine types on the market with a power range of between 500 – 10 000 kW. The head graphs indicated in the cost diagrams correspond to a common range for small turbines of the Pelton, Francis and Kaplan type, respectively. The top graphs do not in any way represent an upper limit for the use of turbines of this type.

As regards the choice of turbine type, generator and transformer, etc., please see Chapter 3 ”Mechanical engineering” and Chapter 4 ”Electro-technical work” for more information and detailed explanations for the respective disciplines.

5.3 Micro and mini power units with a capacity of up to 500 kW

5.3.1 Price estimate

The prices are based on installations constructed in the last five years, and, whenever there is sufficient basis to do so, on installations constructed in the last couple of years.

During the period 2000-2005, the general price increase was very low due to a strained market with relatively little activity. However, during the period 2005 to 2010 there was a great deal of activity, both in Norway and internationally, both with regard to turbines and electrical equipment in particular. This led to a price increase on complete electromechanical deliveries of between 30 and 40%.

The price increase has been particularly high for micro turbines with a capacity of less than 5 kW. This has not been sufficiently reflected in the price curves for turbines with a capacity from 0 to 500 kW. For turbines < 5kW the prices are above 30 000 NOK/kW. The kW price in this segment varies from 30 000 to 100 000 NOK/kW.

5.3.2 Micro and mini power units

The costs are given as NOK/kW nominal effect, and as the function of the absorption capacity and maximum efficient head.

Cost curves have been prepared for each of the most common turbine types on the market with a power range of up to 500 kW. For turbines below 10 kW the prices in NOK/kW can be very high. The curves for Pelton turbines have been drawn at the bottom as vertical multi-jet Peltons are commonly used for micro turbines.

The rotational speed has not been included in the price curves for turbines with a power range of between 1 and 500 kW. Gears are often used for turbines at low rotational speeds, and sometimes belt drive transmission.

The head graphs indicated in the price diagrams correspond to a common range for small turbines of the Pelton, Francis and Kaplan type, respectively. The top graphs do not in any way represent an upper limit for the use of turbines of this type.

It should also be mentioned that the given price level for micro units reflects what can be called a normal price level. There are turbines on the market that are both cheaper and more expensive than indicated in the price curves.

We have prepared price curves for the following turbine models:

- Pelton
- Francis
- Kaplan/bulb turbine

Other relevant turbine types include Crossflow and Turgo turbines.

The following has been included in the individual curves

Turbines up to 500 kW

The given cost curve is for a complete electromechanical setup, i.e.
turbine + turbine control + intake valve (not for Kaplan-turbines) + generator + control system + switching station + transformer, if relevant.

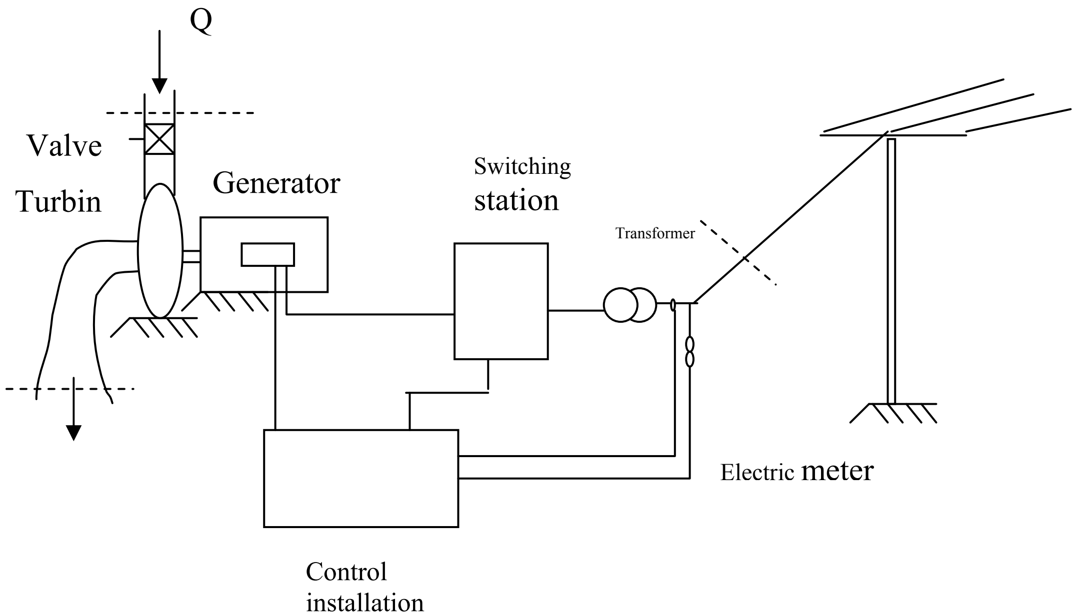
Transformers are not necessary for installations that are directly connected to the low-voltage grid (240/400V). This usually applies to installations with an output of less than approximately 100 KW.

General advice on the choice of micro unit supplier

In addition to the price, the following should be considered when selecting a turbine supplier:

- References. Contact other developers who have used the same supplier.
- Power plant automation. Important with regard to how much work is required for daily operations.
- Turbine catchment area, such as maximum and minimum rate of water flow for continuous operation. Important for making maximum use of the flow.
- Efficiency. Be critical of alleged turbine efficiencies that are not supported by reliable documentation.
- Operational reliability can be just as important as high efficiency.
- Does the delivery (price) include everything? Check whether the quote includes all necessary equipment/work.

Schematic diagram:



5.3.3 Pelton turbines

Area of use

Pelton turbines are used for high heads. However, for smaller installations, Pelton turbines may also be used at relatively low heads. The area of use for Pelton turbines overlaps with the area for Francis turbines. Pelton turbines with 1 to 6jets are often used for the lowest rates of flow and effects.

The large catchment area is often a reason for choosing a Pelton turbine, as it can handle large water flow variations with only one unit.

Small Pelton units do not usually have a traditional ring main, and are often installed vertically. The simplest Pelton units may be equipped with a needle valve on one injector and a globe valve upstream the remaining nozzles/injectors. Mini turbines can have plastic wheels if the pressure is below 100 m.

5.3.4 Francis turbines

Area of use

The Francis turbine is the most commonly used turbine in Norway, with an extensive area of use between the Pelton and Kaplan turbine. Francis units are not usually used for very low outputs, as a multi-nozzle Pelton unit is more practical. A Francis unit may be more suitable than a Pelton unit for low heads, i.e. heads < 50 m. However, this depends on the head/rate of flow ratio.

5.3.5 Kaplan

Area of use

Small Kaplan turbines are seldom used above 25 m. The lower head limit is often determined by the NOK/kWh costs.

Calculated in NOK/kW, Kaplan turbines are relatively expensive. This is because they are used for high rates of flow and small heads, resulting in a turbine of large dimensions in proportion to its effect.

5.3.6 Other types of turbines

Crossflow and Turgo turbines are described in Chapter 3. These types of turbines are also relevant as micro and mini power units, and are available on the international market down to the lowest effects. These types of turbines are not produced in Norway. The advantage of a Turgo turbine is that it is more compact than a Pelton turbine. It is also more suitable than a Pelton turbine if there is a risk of sand abrasion. The advantage of a Crossflow turbine is that it is relatively easy to maintain and inexpensive to purchase.