
**2007 Capital Budget Application
Electrical System Handbook
Hydroelectric Generation**

March 2006

Table of Contents

	Page
1.0 Introduction.....	1
2.0 Typical Small Hydroelectric Development	1
3.0 Civil Infrastructure.....	2
4.0 Mechanical Equipment	5
5.0 Electrical Equipment.....	6
6.0 Ancillary Systems	7
7.0 Newfoundland Power’s Hydroelectric Facilities	7

Appendix A: Glossary

1.0 Introduction

Newfoundland Power's annual capital budgets focus on a relatively large number of electrical system assets through which the Company delivers service to its customers. Accordingly, the material filed in support of annual capital budgets is necessarily technical in nature.

With its 2006 Capital Budget Application, Newfoundland Power filed a document referred to as the *Electrical System Handbook*. This handbook was provided to assist the reader in better understanding the electrical network and how Newfoundland Power's 2006 capital budget related to that network.

Accompanying the 2007 Capital Budget Application, this document, the *Electrical System Handbook Hydroelectric Generation*, focuses in more detail on the infrastructure and equipment that comprises a typical small hydroelectric plant. This version of the handbook is provided to assist the reader in better understanding the technical terminology used in the assessment of hydro plants. It is appropriate to present this material at this time as a considerable amount of information is being provided to justify the Rattling Brook Hydro Plant refurbishment.

2.0 Typical Small Hydroelectric Development

Hydroelectric generating plants capture the kinetic energy of falling water to generate electricity. A turbine converts the kinetic energy from the falling water to mechanical energy and the generator converts the mechanical energy into electrical energy. The turbine and generator are installed either in, or adjacent to, dams or use a penstock to carry the pressurized water to the powerhouse.

The power generating capacity of a hydroelectric plant is primarily a function of (i) the flow rate of the water and (ii) the hydraulic head which is the elevation difference through which the water falls. From an energy conversion perspective, hydro power is very energy efficient; more than double that of conventional thermal power plants.

The equipment associated with hydroelectric plants is well developed, relatively simple in design and very reliable. As very little heat is involved in the process to generate electricity in a hydroelectric plant, the equipment has a long life and malfunctions are rare. The service life of a hydroelectric plant is well in excess of 50 years at which time refurbishments can be carried out to extend the life even further.

A typical small hydroelectric development can be described in two parts, the civil infrastructure external to the plant and the electrical and mechanical equipment internal to the plant. Figure 1 shows a schematic of the civil infrastructure for a typical small hydroelectric development.

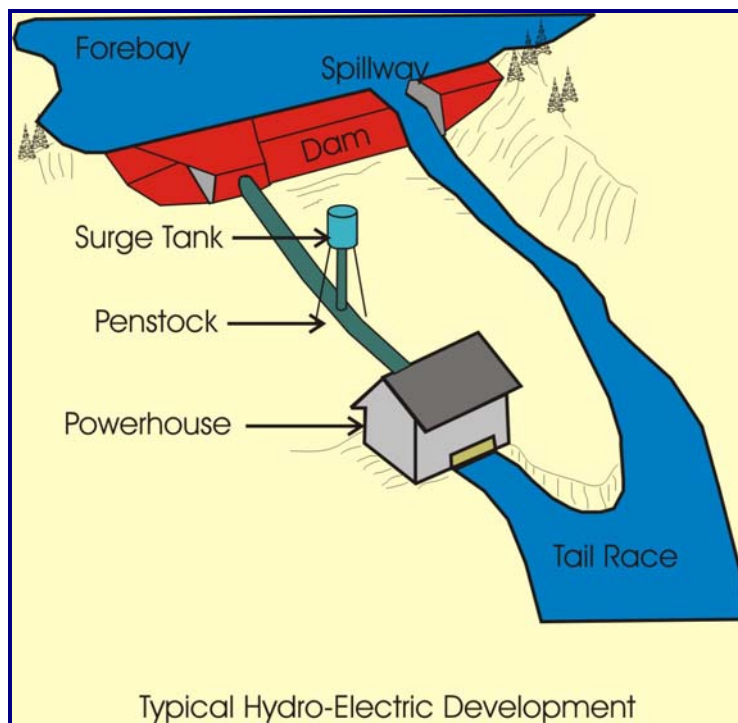


Figure 1

The civil infrastructure is comprised of dams, spillways, control structures, surge tanks and a penstock or canal to direct the flow of water to a powerhouse. Once at the powerhouse the water passes through the turbine spinning it with enough force to generate electricity. The water then exits the powerhouse and flows into a tailrace.

The main electrical and mechanical equipment comprises the generator and turbine. Other equipment such as switchgear, governors and valves are required to operate and protect the generator and turbine.

3.0 Civil Infrastructure

Typically, small hydroelectric developments are run of the river type installations with very little storage. Newfoundland Power operates 23 small hydroelectric developments, some of which have small reservoirs for storing water. Dams, spillways and control structures comprise the reservoir civil infrastructure.

Dams and Spillways

Dams are used to create a reservoir to store water and to develop the necessary water pressure known as hydraulic head. There are a variety of different types of dams used in small hydroelectric developments. The most common types are earth fill dams, rock fill dams, and concrete gravity dams.

Spillways are required to ensure that water elevations inside the reservoir do not exceed safe levels. Spillways allow for the controlled release of water to regulate reservoir water elevations without damaging the down stream habitat. To avoid damage, the excess water must be safely discharged over the dam. Carefully designed overflow passages are incorporated into dams as part of the overall structure. These overflow passages are known as spillways.

An intake structure including trashracks and a gate provide the entrance for the water into the penstock. The trashracks ensure that large solid objects such as wood or ice do not enter the penstock. Trashracks are made up of one or more panels, fabricated from a series of evenly spaced parallel metal rods. The intake gates can be opened or closed to control water flow. Automatic closure of the intake gate may happen when a generator emergency stop is initiated. These gates are also used to seal off the penstock when it needs to be drained for inspections and maintenance. The intake is generally built of reinforced concrete and is an integral part of a dam structure.

Penstock and Surge Tank

The penstock carries the water from the intake structure downstream to the power house. Penstocks, which carry the water under pressure, can be made of steel, fibreglass, plastics, concrete or wood.

The water pressure in the penstock must be maintained at safe levels under all operating conditions. One of the most common ways to regulate penstock pressure is through the use of a surge tank. The surge tank must be elevated above the penstock such that it can support a column of water equal to the maximum design pressure for the penstock. If there is no surge tank, the turbine must be fitted with a large pressure relief valve to accomplish the same functionality.

Powerhouse

The powerhouse contains the turbine(s) and most of the electrical and mechanical equipment used to generate power. Figure 2 shows a schematic of a typical powerhouse.

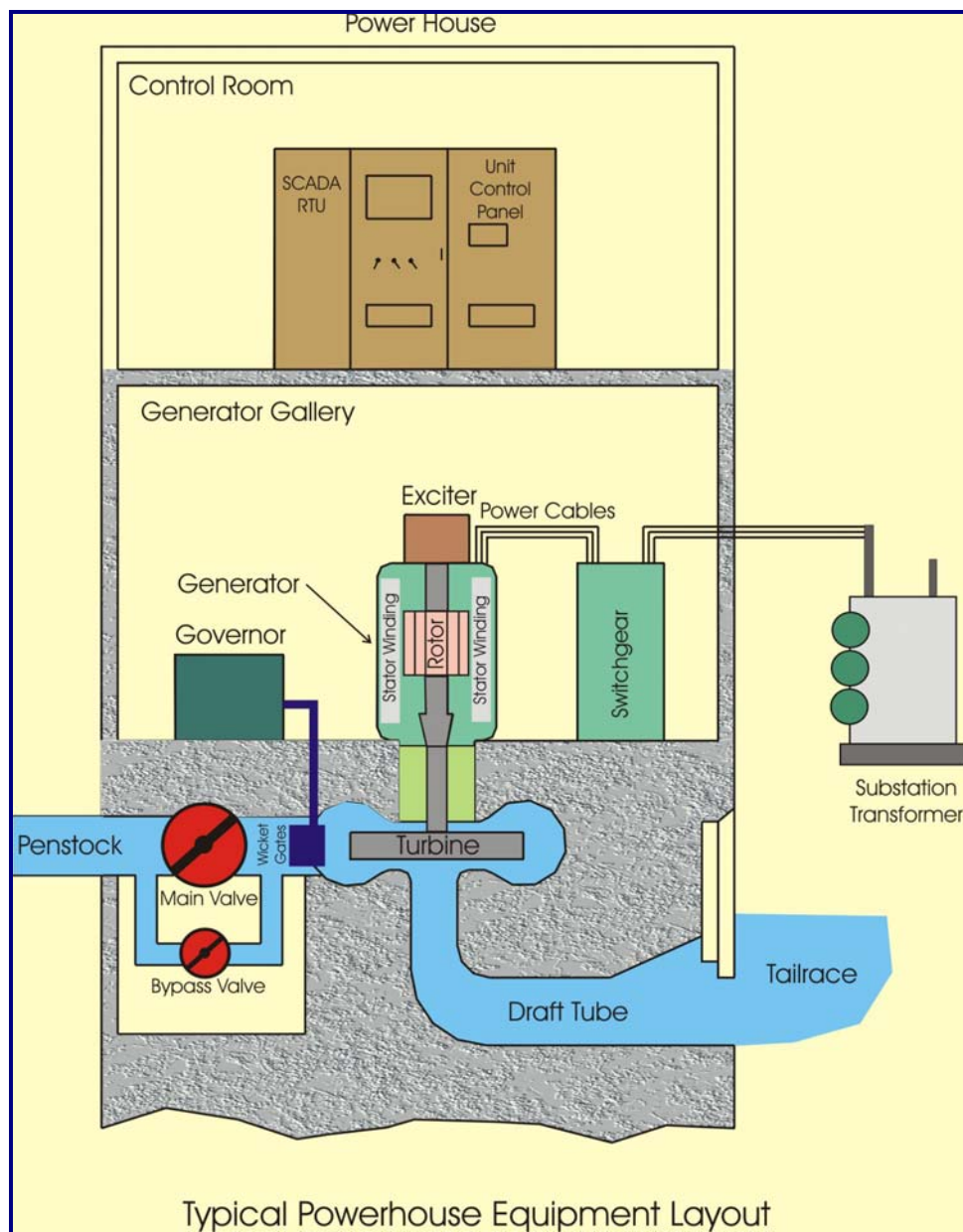


Figure 2

4.0 Mechanical Equipment

The primary mechanical components of a small hydroelectric plant are the main valve, draft tube, turbine and runner. In some locations the energy from the water can support more than one generator. In this case the powerhouse may have more than one operating generator.

In addition to the primary mechanical components identified above, other mechanical equipment consists of valves, pneumatic and hydraulic power components, governors, lubrication and cooling water systems.

Valves

The penstock is attached to a main valve at the entrance to the powerhouse. This valve is necessary to stop the flow of water when the plant is shutdown or when maintenance of the turbine is being performed. Typically the main valve has a large diameter similar to the penstock. In a small hydroelectric plant the valve diameter is typically between one and two metres in diameter.

The main valve is normally accompanied by a bypass valve and occasionally a drain valve. The bypass valve's function is to divert water past the main valve prior to opening, thereby equalizing pressure on both sides of the main valve to reduce the strain associated with opening such a large valve. The drain valve is normally a manual valve that is used to drain the penstock for maintenance.

Governor

The governor can be a powerful piece of hydraulic or electric equipment controlled by a speed feedback from the generator. The governor's function is to keep the water flow to the turbine under control by adjusting the position of the wicket gates. Wicket gates regulate the water flow by adjusting the amount of force the water places on the turbine. If the generator starts to slow down, the governor opens the gates to create a greater force on the turbine. If the generator starts to speed up the governor closes the gates to reduce the force on the turbine. The regulation of the gates is intended to maintain an electrical frequency of 60.0 cycles per second.

Turbine

The turbine is a rotary engine that converts the energy from the water that is forced through the wicket gates to rotational motion. The turbine is then coupled to the generator through a series of shafts. The generator rotor converts the rotational motion into a rotating electric field. The generator stator windings convert the rotating electric field into electricity.

When the water leaves the turbine it passes through the draft tube on the way to the tailrace. The tailrace carries the water from the powerhouse back to the river system or ocean.

Bearings

With these large generators rotating at 600 revolutions per minute (rpm), there are a number of bearings employed to keep the unit stable. These bearings require lubrication and water cooling to overcome the heat from friction on the bearing surfaces.

5.0 Electrical Equipment

There are typically three large pieces of electrical equipment in each small hydroelectric plant; a power transformer, generator and the switchgear.

Power Transformer

The power transformer is normally located in a substation adjacent to the hydro plant. It transforms the generator output voltage from low levels such as 6,900 volts up to transmission line voltages of tens and hundreds of thousands of volts for transmission to large load centers that require the power.

Generator

Generators consist of two parts - the rotor and the stator windings. The rotor is coupled to the turbine and rotates when water is flowing through the turbine. An electromagnetic field is placed on the rotor through slip rings and brushes. As the electromagnetic field rotates, its lines of flux cross the stator windings creating an electric current.

Switchgear

The switchgear includes a generator breaker for switching power from the generator onto the grid. It also includes the potential and current transformers for metering and protection. Depending upon the equipment design the switchgear may also include the station service transformer, generator protection relays and generator field breaker.

Protection and Control

Modern small hydroelectric generators are controlled using programmable logic controllers (PLC) that are assembled into unit control panels. These unit control panels also house the synchronizer, voltage regulator and operator interface. Some designs will include all unit protection and metering in the unit control panel. The PLC monitors all feedback from the generator and turbine, accepts input from the operator interface, checks for trip conditions from instrumentation and protection devices, and in some designs determines the appropriate load for the generator.

6.0 Ancillary Systems

In addition to the main electrical and mechanical equipment there are ancillary systems that are required to carry out various critical functions. These ancillary systems ensure that the equipment operates safely and provides reliable service over its life. These ancillary systems include cooling water, lubrication, ventilation, heating, station service and DC power.

7.0 Newfoundland Power's Hydroelectric Facilities

Newfoundland Power operates 23 hydroelectric facilities across the province with 32 individual generators. These generators range in size from the largest - Mobile at 12 MW and the smallest - Port Union at 0.26 MW. Typically these plants predate the time in the 1960s when the provincial electrical grid was established. These plants were constructed to operate on small isolated electrical systems serving the communities in the immediate vicinity of the facility. As a result most are synchronous generators with black start capability.

In all cases penstocks are used to connect the plant to the water supply. Pre-1960s, woodstave construction was the most cost effective solution for providing the penstock requirements.

Today these plants are well maintained and remotely monitored and controlled by the Newfoundland Power System Control Center. Most employ water management schemes to ensure that the plants are operated at the most efficient load setting determined in consultation with hydrology consultant SGE Acres Limited. The plants have relatively low operating cost thereby allowing them to be highly efficient and low cost providers of electricity to the provincial grid.

Appendix A

Glossary

Glossary

This glossary does not aim to be exhaustive, but gives a few definitions of terms that frequently are used in the technical assessments provided in the Capital Budget Application.

Black Start

Black starting a generator is a term that is used when a generator is started without the presence of an established power grid. On an isolated system the first generator coming on line is black started, while all subsequent generators are synchronized to the first generator's voltage and frequency.

Dam

Civil engineering work (earth, concrete, rocks) that is constructed to provide a barrier to the flow of water to redirect that water to the intake of a hydroelectric installation. Storage dams store water for a future electricity demand.

Draft Tube

Low pressure part of reaction turbines (Kaplan, Francis) situated downstream of the runner. The draft tube is meant to reduce the speed of water at the turbine outlet, so as to recover a part of the kinetic energy. A water conduit, which can be straight or curved depending upon the turbine installation, that maintains a column of water from the turbine outlet and the downstream water level.

Efficiency

Value that expresses the transformation degree of one form of energy into another. For instance, a mechanical turbine efficiency of 90% means that 90% of the energy from the water is transformed into mechanical energy.

Freeboard

Vertical distance between the water surface elevation and the lowest elevation of the top of the containment structure.

Fly-Wheel

Massive metallic disc coupled with the turbine shaft to limit the rotational acceleration and deceleration of the turbine. It is used in a small isolated network to improve the regulation precision of a very responsive generator.

Forebay

Used to impound water immediately upstream from a dam or hydroelectric plant intake structure.

Francis Turbine

Type of turbine that has a submerged fixed blade design. The water flow to the turbine is varied by controlling the wicket gates.

Generator

Machine that converts mechanical energy into electrical energy

Governor

A piece of mechanical equipment attached to a turbine intended to regulate generator speed by manipulating flow rates into the turbine. Feedback is provided for generator speed to a control section of the governor, which in turn provides control signals to the power section of the governor.

Head Losses

Energy losses due to stream directions changes, frictions on the penstock walls, obstacles (for instance the grids or valves), etc.

High Head

Power plants that operate with a high difference in elevation from the turbine to the intake that can reach several hundreds of meters.

Hydroelectricity

Electricity generated by transforming the hydraulic energy of a river or body of water into mechanical energy and then into electrical energy by a turbine and a generator. It is a renewable and non-polluting energy with high energy efficiency.

Intake

The entry point of water into a penstock for delivery to a hydroelectric plant turbine.

Kaplan

Type of turbines that has a submerged variable pitch blade propeller design. The water flow to the turbine is varied by controlling the pitch of the propeller blades.

Low Head

Power plants that operate with a lesser difference in elevation from the turbine to the intake that can reach only several meters.

Pelton

Turbines used in high head installations are of the impulse type design, the most common of which is the Pelton wheel turbine. The runner of the impulse turbine spins in air and is driven by a high speed water jet.

Penstock

A pressurized pipe that transports water from the forebay intake gate to the hydroelectric power plant.

Trashrack

A steel grill placed across the entrance of the intake to remove any floating object from entering the penstock and damaging either the pipe or turbine runner.

Reservoir

A body of water which is impounded by one or more dams, inclusive of its banks and shores.

Runner

The rotating part of the turbine that converts the energy of falling water into mechanical energy.

Run-Of-River Power Plant

Hydroelectric power plant that uses the natural discharges of the river without any possibility of water storage.

Scroll Case

A spiral-shaped steel intake guiding the flow into the wicket gates located just prior to the turbine.

Small Hydroelectric Plant

The classification of a small hydroelectric plant is regionally based; generally they are installations with a rated output power less than 10 MW are considered within this classification.

Speed No Load Condition

The generator must rotate at synchronous speed with voltages that match in amplitude, phase and frequency those on the power grid before it is safe to connect the energized generator.

Springline

An imaginary horizontal reference line located at mid-height, or halfway point, of a circular conduit, penstock, or tunnel. In the case of a penstock it is located at the maximum horizontal dimension of the pipe.

Spillway

Weir, channel, conduit, tunnel, gate or other structure designed to permit water discharge from the reservoir.

Synchronous Generator

A synchronous generator comes equipped with an integral excitation system that is powered by the plant DC system. A synchronous generator can be black started and operated isolated from the main power grid.

Surge Tank

A structure attached to a penstock in the vicinity of the power house whose purpose is to regulate pressure in the penstock, and to prevent water hammer due to abrupt changes to flow.

Tailrace

A channel that allows the return of the turbinized water to the river or ocean.

Turbine

Hydraulic machine which transforms hydraulic energy into rotational mechanical energy.

Transformer

Electrical device meant to modify voltage (such as 230, 400, 6,000 Volts) in order to make it compatible with the network to which it is connected (for example 66,000 Volts).

Wicket Gates

Adjustable gates that control the flow of water to the turbine passage.