

IEEE Guide for Control of Small Hydroelectric Power Plants

Sponsor
**Energy Development and Power Generation Committee
of the
IEEE Power Engineering Society**

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Foreword

(This Foreword is not a part of IEEE Std 1020-1988, IEEE Guide for Control of Small Hydroelectric Power Plants.)

Initially this document was planned to be a recommended guide strictly for the application of control systems to small hydroelectric power plants, one type of dispersed generation source. As work progressed, however, it was seen that such a guide would be lacking in depth if some treatment of the controlled electrical and mechanical systems and equipment were not made. For completeness, it was considered desirable to also mention salient civil features of small hydroelectric projects, and to offer discussion of equipment protection and operation.

The end result of this effort, although termed a guide to control of small hydroelectric power plants, is basically a tutorial document that presents descriptive information for use in planning the control system design and operation of small hydroelectric power plants. It is intended to provide a working knowledge of the terminology used in this field and an understanding of the principles of operation of hydroelectric generating units. It addresses the control requirements from an electrical standpoint. It does not discuss in any great detail the civil, hydraulic, and mechanical considerations that must also be taken into account when planning a hydroelectric project. It deliberately omits discussion of topics such as economics, environmental factors, financing, and licensing.

This document was prepared by a Task Force of the Working Group on Hydro Plant Controls of the Hydroelectric Power Subcommittee of the IEEE Energy Development and Power Generation Committee. Members of this Task Force represent a cross-section of the hydroelectric power industry, including power plant owners, designers, and equipment manufacturers. The persons listed below were members of the Task Force when the Guide was finalized and submitted for balloting.

E. T. Voelker, *Chair*
R. E. Howell, *Vice Chair*

S. R. Brockschink
H. Butz
H. E. Church, Jr.
H. R. Davis
C. R. Desrosiers
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J. H. Gurney

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R. F. Karlicek
D. L. Kornegay
J. E. LeClair
P. Micale
D. R. McCabe

W. R. Moon
G. D. Osburn
L. Pereira
B. J. Polk
J. Quinn
D. Seely
B. Zarlenga

The persons listed below also contributed to the preparation of this Guide.

R. W. Beckwith
C. G. Bickerdike
P. G. Brown
R. S. Coleman
Y. Cote

L. E. Felton
Y. Fukuda
G. Grinnell
J. A. Meuleman
W. O. Moll
W. I. Pentin

O. H. Smith
W. A. Stewart
J. Thomas
A. A. Tseng
E. C. Whitney

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

M. S. Baldwin
I. B. Berezowsky
L. D. Boydston
S. R. Brockschink
J. B. Cannon
R. W. Cantrell
R. L. Castleberry
E. F. Chelotti
R. E. Cotta
P. M. Davidson
D. Diamant

G. Engmann
D. I. Gordon
R. K. Gupta
J. H. Jones
C. E. Kneeburg
S. B. Kuznetsov
P. Landrieu
J. E. LeClair
P. A. Lewis
J. T. Madill
O. S. Mazzoni

D. R. McCabe
G. R. Meloy
M. W. Migliaro
R. E. Penn, III
C. R. Pope
R. J. Reiman
D. E. Roberts
E. P. Rothong
J. E. Stoner, Jr.
T. R. Whittemore
R. Zweigler

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Fletcher J. Buckley

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Thomas L. Hannan

Kenneth D. Hendrix

Theodore W. Hissey, Jr.

Jack M. Kinn

Frank D. Kirschner

Frank C. Kitzantides

Joseph L. Koepfinger*

Irving Kolodny

Edward Lohse

John E. May, Jr.

Lawrence V. McCall

L. Bruce McClung

Richard E. Mosher

L. John Rankine

Gary S. Robinson

Frank L. Rose

Helen M. Wood

Karl H. Zaininger

Donald W. Zipse

*Member Emeritus

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IEEE Guide for Control of Small Hydroelectric Power Plants

1. Scope

1.1 Purpose

This guide presents descriptive material intended to assist in the planning for design, development, and operation of small hydroelectric power plant control systems. It does not purport to cover every possible variation that may be encountered, but it should suffice to impart a working familiarity with the terminology and principles involved.

1.2 Basic Definition

The term “small hydroelectric power plants” does not lend itself to rigorous definition since small physical size is not necessarily synonymous with small (low) unit output ratings. For example, low head installations require physically much larger turbine equipment to develop the same output as would be the case for high head installations. Small hydro (hydroelectric) power plants, for the purposes of this guide, have the following general attributes:

1.2.1 Unit Ratings

Output ratings are considered to range from 100 kW to approximately 5 000 kW, and generated voltages from 480 V to 13 800 V. “Mini” or “micro” units, as those with outputs less than 100 kW are often called, generally have fewer control requirements. Units with outputs greater than 5 000 kW frequently require or justify more extensive control and protection than is discussed in this guide.

1.2.2 Unit Type

Small hydro turbines may be of any of the types commercially available, including pumps operated as turbines, but excluding reversible pump-turbines. Almost exclusively, small hydro generators are of the alternating current type and may be either synchronous or induction type. Usually, small hydro units are expected to require a minimum amount of field assembly and installation work, so this would tend to rule out very slow-speed, large-diameter units such as those with split generator stators that require final winding assembly in the field.

1.2.3 Application

Small hydro units are commonly applied in situations where associated civil construction work and costs are minimal. These applications include installations at existing dams, pipelines, canals, or at new impoundment structures that can be inexpensively built.

1.2.4 Operation and Control

Almost universally, small hydro units are provided with equipment and circuitry to enable unattended operation.

1.2.5 Interconnection

Small hydro units are generally connected to the local power company system, and are connected either directly or through a main transformer, frequently at a distribution substation, or tapped into a distribution circuit. The unit may supply a portion, or all, of its output to a local private load, and any surplus may be marketed to the power company. Special interconnection requirements are set by each power company to protect its equipment, system, and personnel. Privately owned generator installations are required to meet ANSI/NFPA 70-1987, National Electrical Code, Article 705, "Interconnected Electric Power Production Sources" [1].¹

2. Definitions

Definitions provided here reflect industry common usage as related to small hydroelectric power plants, and may not in all instances be in accordance with ANSI/IEEE Std 100-1988, Dictionary of Electrical and Electronics Terms [2] or other standards. For more rigorous definitions, or for definitions not covered herein, the reader is referred to the IEEE Dictionary and appropriate standards.

accumulator: Container that stores hydraulic oil under pressure as a source of fluid energy.

axial flow: Used to describe any turbine, such as a propeller type with an inlet that directs the water axially toward the runner, as contrasted with radial entry to the runner.

brushless exciter: Direct-connected ac generator with shaft-mounted rotating rectifiers and without a commutator and brushes.

bulb unit: Propeller turbine and generator, with the generator in a bulbous enclosure in the water passageway.

NOTE — The term "bulb turbine" has no meaning.

bus: A conductor or group of electrical conductors serving as common connections between circuits, generally in the form of insulated cable, rigid rectangular or round bars, or stranded overhead cables held under tension.

bypass: A means to pass the flow of water around a turbine to the same discharge outlet.

capacity: Maximum output of a turbine generator unit.

cavitation: With respect to an operating hydraulic turbine, cavitation is the formation of vapor-filled bubbles in high velocity, low pressure regions of the water passage—for example, around the turbine runner. The rapid collapse of the bubbles as they are propelled out of the low pressure region produces a pressure wave, which can erode nearby material.

circuit breaker: Fast-acting switching device used to close and open an electric circuit and capable of interruption of fault currents.

contactor: A device used for repetitive opening and closing operation of an electric circuit, and which has load current interrupting capability. It has no fault-current interrupting capability.

¹The numbers in brackets correspond to the numbers in the Bibliography in Sec 9.

discharge: Water flow, exiting from a turbine. It is generally measured in cubic feet per second or cubic meters per second.

drawout circuit breaker: Circuit breaker equipped with slides or rollers and quick disconnect means to facilitate removal and replacement.

excitation: A source of direct current for the synchronous generator field.

field flashing: Short-time application of an external direct current source to the field of a synchronous generator to enable it to build up its voltage and become self-excited.

flow: Water movement in a stream or conduit. It is generally measured in cubic feet per second or cubic meters per second.

flow-duration curve: Graphical representation that shows how stream flow has varied historically.

Francis turbine: Reaction type turbine in which the water enters radially and leaves axially.

governor: A system which controls speed and power output of a turbine.

grid: Network, usually of a power company, for transmitting and distributing electric power.

ground: Connection to earth or to a common conducting body that serves in place of the earth.

hardwired: Wired interconnections of relays and other control devices.

head: The difference in hydraulic energy between two points, which includes the elevation head, pressure head, and velocity head.

headwater: Source of energy for a hydraulic turbine.

headloss: Loss of potential energy mainly due to hydraulic friction. This loss is usually expressed in feet or meters of head.

impulse turbine: A turbine that uses nozzles to convert water pressure into kinetic energy at atmospheric pressure to develop power.

induction generator: A generator that produces power with rotor speeds slightly higher than synchronous speed. It does not have the rotor field excitation requirement of synchronous generators.

interlock: Device that permits equipment or controls to operate only after other conditions have been fulfilled.

inverter: Equipment that converts direct current to alternating current.

isolating switch: Device used to isolate plant electrical equipment from the rest of the circuit.

load controller: Auxiliary control device that adjusts turbine flow in response to plant output requirements.

lock-out relay: An electrically or manually reset auxiliary relay whose function is to hold associated devices inoperative until the relay is reset.

logic: (Control or relay logic.) Predetermined sequence of operation of relays and other control devices.

motoring: An induction or synchronous generator operating as a motor and drawing power from the grid.

neutral: Common point of a star-connected generator or transformer winding.

overspeed: Any speed in excess of rated speed.

power factor: Ratio of real to total apparent power (kW/kVA) expressed as a decimal or percent.

power factor correction capacitor: Device that provides a capacitive load to offset the demand for lagging reactive power.

programmable controller: Solid state control system with programming capability that performs functions similar to a relay logic system.

propeller turbine: A reaction turbine with fixed or variable pitch propeller-type blades.

reaction turbine: A turbine that uses the velocity and pressure of the water flowing through the runner to develop power.

reactive power: Power that is in quadrature with real power, such as used by capacitive or inductive loads, expressed in kvar.

runaway speed: The maximum speed obtained when a turbine-generator is operated unloaded with wicket gates fully open at maximum head.

runner: The rotating element of a turbine, which converts hydraulic energy into mechanical energy.

run-of-river plant: One utilizing stream flow as it occurs and with little or no storage at the project site.

servomotor: An actuating device used to position turbine wicket gates, runner blades, deflectors, or other turbine control devices.

shear pin: Replaceable protective device that fails by shearing when an obstruction prevents a wicket gate from closing.

sluice: Open water trough, also used to describe operation of a turbine when operated under free discharge conditions to release flood flows.

spillway: Section of dam, or structure near dam, for flow of excess water.

static exciter: Nonrotating source of directcurrent for the synchronous generator field, utilizing controlled rectifiers.

switchgear: An assembly of equipment used to switch and control electrical power.

synchronizing: Process of paralleling and connecting a synchronous generator to another source.

synchronous generator: A generator that produces power with rotor speed exactly proportional to the frequency of the system. The generator has field poles excited by direct current.

tailrace: The exit channel of water from the powerhouse.

tailwater: The water in the tailrace.

wicket gates: Series of overlapping adjustable guide vanes that regulate the amount of water flowing through a reaction turbine.

3. Introduction

3.1 General

Prospective applications for small hydro projects occur wherever water or other liquid flow and head exist. The majority of sites will utilize the head developed by fresh water. The head developed by other fluids, such as salt water or treated sewage outflows, can be utilized under appropriate conditions.

The generating unit may have its shaft vertical, horizontal, or inclined, with the type selected to suit the site's physical conditions. A typical vertical shaft Francis turbine generating unit is shown in Fig 1, and a horizontal shaft propeller turbine unit in Fig 2. Other possible configurations include horizontal Francis turbine units and vertical propeller turbine units. The figures illustrate the interrelationships between the equipment and control systems. The equipment required for a specific installation will depend upon the operational requirements of the project. Major auxiliary equipment descriptions are included in later sections of this guide. In general, there are no major differences in the type of control equipment required for vertical versus horizontal units.

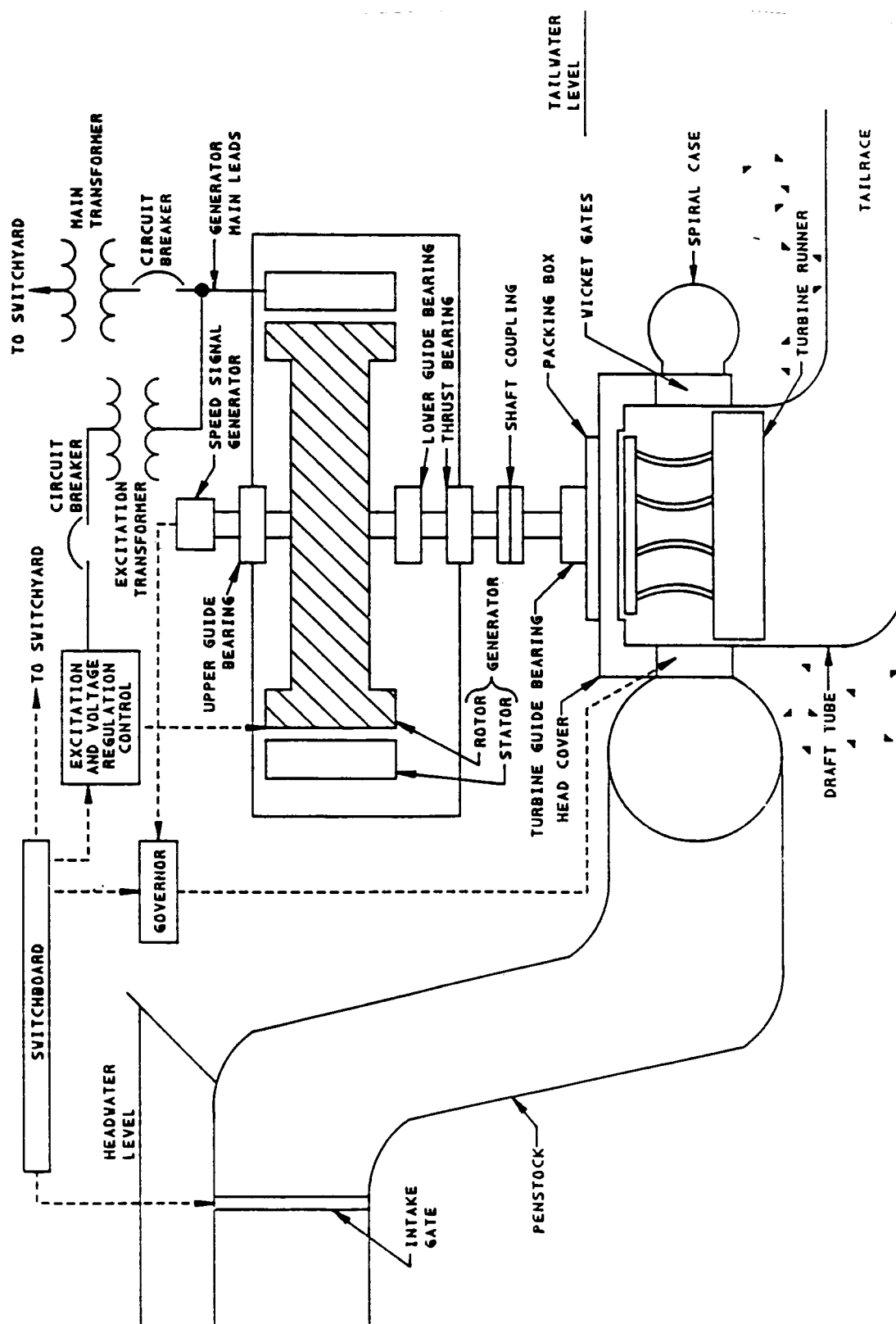


Figure 1 — Vertical Francis Unit Arrangement

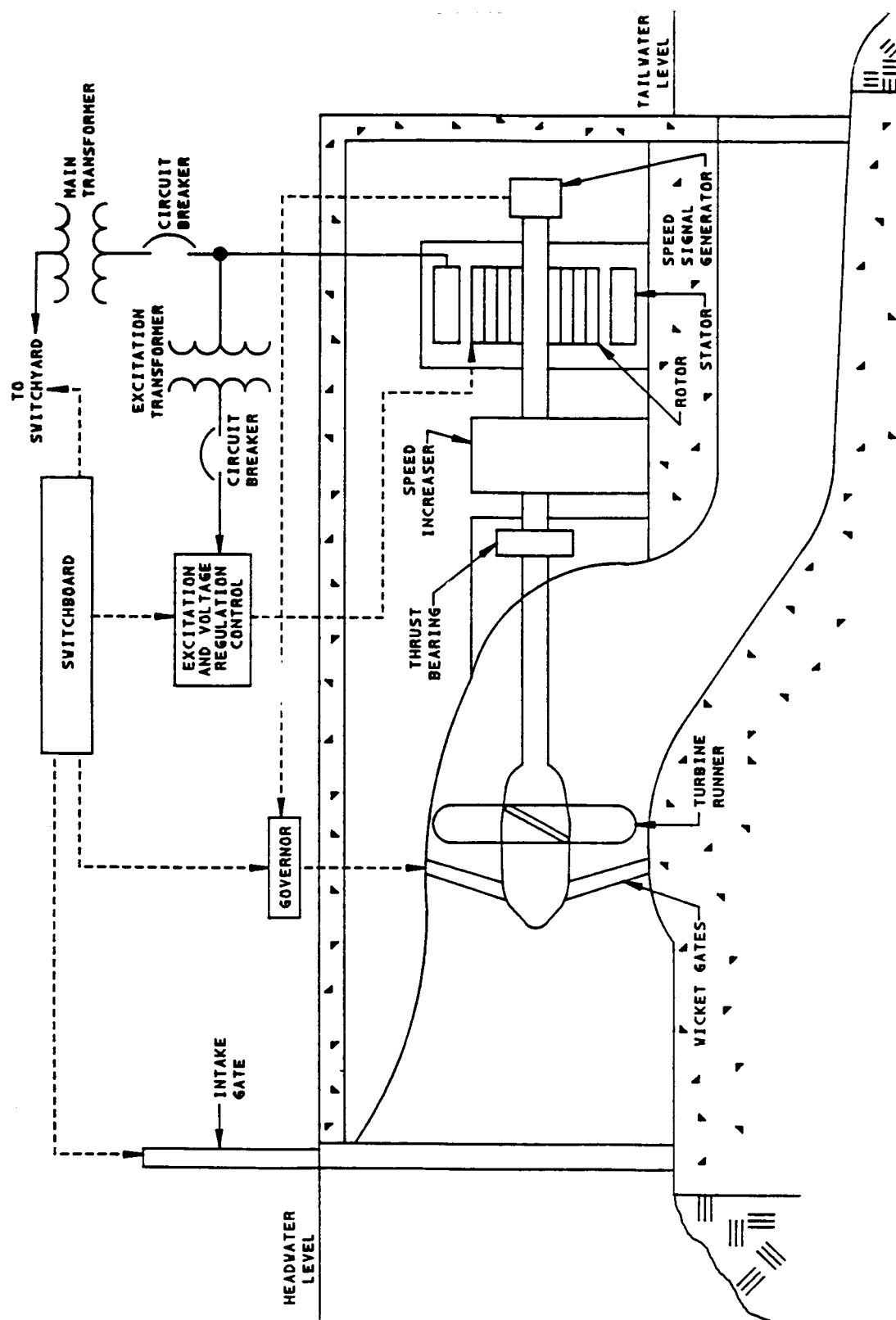


Figure 2—Horizontal Axial-Flow Unit Arrangement

3.2 Project Evaluation

Various data pertaining to the project being considered must be obtained to determine its feasibility. Items to be considered when evaluating project feasibility include physical site characteristics, head and flow data, size, quantity, and type of units.

3.2.1 Site Characteristics

Site characteristics fall into these broad categories: (1) new sites, (2) developed sites, and (3) working sites.

New sites are those that do not have any existing facilities for addition, modification or rehabilitation. A new site will require extensive civil construction for a dam, water conduits, spillway, powerhouse and other facilities.

Developed sites already have significant structures that can be added to or reworked to accommodate installation of generating equipment. Developed sites could include abandoned powerhouses, existing dams, and waterways associated with irrigation, flood control, recreation, water supply, or sewage outflows.

Working sites have functional generating units in place, and may or may not have provisions for conventional installation of additional small units.

3.2.2 Flow Data

Available flow and head will determine the power and energy that can be obtained from the proposed installation. Available flow and head may be influenced by external requirements to also meet irrigation needs, maintain minimum downstream releases, or to cause minimal impact on a water supply system. Historical water head and flow data on the drainage area upstream of the site can often be obtained from appropriate government agencies. Daily flow variations as well as seasonal variations need to be studied. Historical and projected maximum (flood) and minimum (drought) flows will impact not only on generation capabilities, but also on design of the dam and spillway structures. From the raw flow data, flow duration curves similar to the one in Fig 3 are plotted. These curves will indicate the percentage of time, over the long term, that a specified flow will be equalled or exceeded. By using this curve together with the head and proposed pondage (the working storage over days or weeks) available at the sites, an estimation can be made of available energy on an annual basis. The variations in head that occur with varying flow need to be considered in making this estimation.