Renewable Energy Review Journal: Vol. 8, No. 1, June 1986

Research in Microhydropower – A New Zealand Viewpoint*

E.P. Giddens

Senior Lecturer in Civil Engineering, University of Canterbury,
Christchurch, New Zealand.

ABSTRACT

A definition of microhydropower is proposed that is not based solely on size but on other criteria that distinguish the extremely small hydropower installation, typically about 5 kW, from the conventional small hydropower scheme. A case is made for closer co-operation between the engineer and the social scientist in an attempt to reduce the significant number of cases where introduced appropriate technology founders through lack of maintenance. It is claimed that a unified direction for research in microhydropower that would lead to a code of trade practice can be justified. It would be concerned with minimising costs and, to that end, would seek to make the professional engineer redundant on the site. The feasibility of a code of trade practice is explored with reference to medium-head microhydropower. Reference is made to recent research, and directions for further research are outlined.

A DIRECTION FOR RESEARCH IN MICROHYDROPOWER

Microhydropower – a Definition.

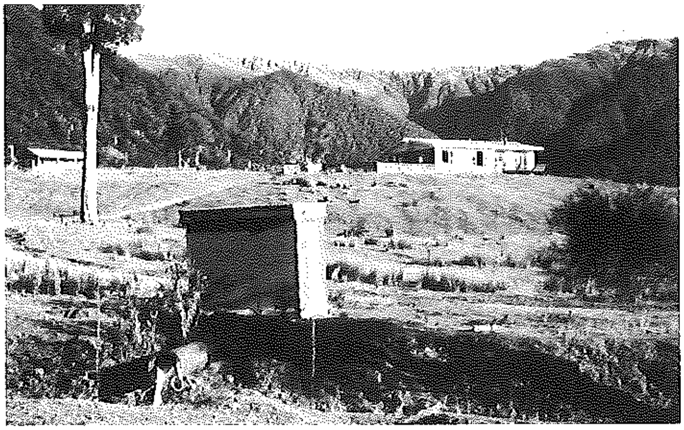
It is not sufficient simply to use submultiples of 10 to classify hydropower installations in terms of size. Widespread experience has shown that by simply scaling down in size that established practices of conventional hydropower, the unit costs increase to the extent that extremely small schemes become prohibitively expensive. In fact, a benchmark figure of 1 MW has, in the past, been suggested to represent the lower limit of viable conventional hydropower generation. The means for lowering such a limit have been explored as the major sites are increasingly exploited, and one such approach, by the larger equipment manufacturers, is to produce standardised turbogenerating sets.

However, if size reduction is considered down to such very small figures as 10 kW and less, which is the size required for isolated farms in developed countries or isolated villages in developing countries, a totally different approach is necessary if these very small schemes are to be viable on economic grounds.

These small schemes are in fact different in character from conventional schemes. They will be privately owned, which makes the capital cost and the return period of prime importance;

---

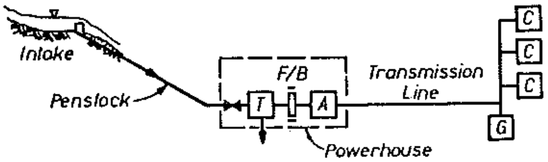
*This paper was prepared as a result of a seminar dealing with research in microhydropower, which took place at AIT on Tuesday 3rd December 1985.



A microhydropower installation in the Southern Alps of the South Island of New Zealand. The intake is in the mountain forest out of the picture to the left. The gross head is 92 m, the flow rate is 16 L/s the electrical output is 3.6 kW which is run by underground cable from the power-house in the foreground to the house on the hill and on to a further house out of sight.

they will be isolated from any electricity distribution system, which would otherwise determine the frequency – and yet they need to provide a supply of single phase, alternating current at 230 or 110 volts and 50 or 60 Hz in accordance with the standards of normal urban supply. The term "microhydropower" is taken to be restricted to these very small installations in which financial viability provides a singular challenge, but the risks are small and ingenious unconventional solutions are successfully being pursued.

One significant contribution in this category is the inexpensive electronic, load-diverting governor that controls the frequency by managing the electrical power consumption and diverting any unused power to waste – as opposed to the conventional governor which instead manages the input water power to the turbine for the same purpose. The electronic governor provides for operation of the generating equipment at constant load which enables the use of a simple turbine and eliminates the function of conserving water, for which a storage dam would be required. On the other hand, the design of such a system to meet peak load is difficult to justify and the consumers normally have to adapt to a base load supply of power. The general arrangement of a medium head microhydro scheme is shown in Fig. 1.



- SIMPLE INTAKE
- PENSTOCK
- SIMPLE TURBINE (T)
- FLYWHEEL AND BRAKE (F/B)
- GENERATOR (A)
- TRANSMISSION LINE
- ELECTRONIC GOVERNOR (G)
- CONSUMER RETICULATION (C)

Fig. 1 A typical medium head microhydro scheme
(no water storage; continuous full load operation).

Most of the terms in Fig. 1 are self explanatory. The brake is one method used, manually or automatically, to stop the turbogenerator set when required.

Appropriate Technology

Appropriate technology is taken to be that type of technology which, when introduced to a community for the first time, is so matched to the resources of that community that it can be accommodated successfully and become an enduring benefit. Technology that is not successfully accommodated, either initially or ultimately, is inappropriate and unfortunately there appears to be a significant number of cases where new technology fails because of initial rejection or, more generally, through a lack of maintenance. If microhydropower is to be a truly appropriate technology, it is of the utmost importance that the research philosophy should comprehend the need to establish practices that will lead to a benefit that can be sustained by the users.

If, in any particular instance, appropriate technology is to produce a change for the better it is inevitable that this change will, to some extent, require the community to adapt. This suggests the need for appropriate education to ensure that (a) the maximum benefit is obtained, (b) the necessary skills are available to operate the system, (c) there is the necessary awareness of any hazards of the new technology and (d) the resources are available to maintain it. The provision of a new single phase, alternating current power supply would represent a major technological step change to any community and the need for this adaptation would be an important consideration in designing the system.

The engineer, however, is not properly equipped to meet this demand. He is not trained in the social sciences and not competent to make the design decisions that involve the interfacing of the technology with the society for which it is intended. If he were, he would be able to devise systems that would invoke the necessary social attitudes to ensure proper maintenance. It is suggested that effective cooperation between the engineer and the social scientist would produce better solutions.

Experience indicates that schemes can founder in spite of maintenance training programmes. The understandable reaction of the engineer to this is to provide systems that require a minimum of maintenance. This is a common research aim in developing new methods. However, this is a solution that takes no account of the fundamental human reasons for the failure of maintenance and could, conceivably, be quite the wrong approach. The problem of interfacing technology with people is a social one and implies the need for the proper expertise. The social scientist may understand the human factors but it is necessary for the engineer to coöperate by clarifying the technological boundaries of the interface problem. A cooperative research programme suggests itself. The results would guide the research engineer and assist him in developing more appropriate technical systems.

Safety

The prime responsibility must be for the safety of the users. A secondary responsibility is the safety of the equipment. Safety considerations for both cases figure in the design and operation of a microhydro system. In developed countries, statutes or regulations will exist identifying the required practices and equipment to ensure a reasonable standard of safety of electrical work. These standards are maintained by a requirement that all permanent work has to be done by properly qualified people. A registered electrician is commonly specified.

The object of microhydropower in developing countries is to provide electricity to isolated villages at urban standards of supply. This enables the use of standard appliances but it calls for urban standards of safety. If such a policy were adopted, it would require the services of a properly qualified electrical tradesman to carry out the electrical installation and to be available for maintenance as required. It would also establish this as a prerequisite of the infrastructure of the community administration. The absence of such necessary community resources in the past could in some cases have contributed to appropriate technology failures.

Professional Costs

Professional consulting engineering fees would normally be involved in the site investigation, system design, supervision and commissioning. In the case of a microhydro scheme of about 5 kW capacity, this cost would be sufficient to render it totally uneconomic.

There is a growing need to make electricity available in the villages of developing countries. A few of these small schemes have so far been engineered with aid programme funds; but if microhydropower of this size is to become more widely available it will be necessary to reduce the professional fees component as far as possible.

If the minimum standard of skill necessary in the interests of safety is that of an electrical tradesman, it would be worthwhile to explore the possibility of upgrading this skill so as to make it sufficient for all technical purposes. Electrical trade training involves elementary circuit theory, hazards and protection processes, electric power reticulation equipment, and electrical machines. It includes elementary mathematics and involves a preparedness to confront problems. Such a background could provide an adequate basis for an extension into the remaining disciplines of a microhydropower installation if the necessary requirements were explicitly stated.

A Code of Practice

A statement of these requirements, comprehensible at the trade level, would comprise a code of practice for microhydropower. Most new technology, particularly of the consumer variety, eventually becomes sufficiently well understood and documented for it to be installed and serviced by tradesmen. Microhydropower has not arrived at this point yet. What is required is a set of straightforward procedures that will maximise the possibilities for an extremely small hydropower scheme to be serviced by technicians of the electrical tradesman level. In fact, such an approach is probably the only way in which these small schemes will even provide the benefit, where it is needed, that they are capable of contributing. There is a growing interest in research in these very small schemes, and a policy of evolving a code of trade practice would give direction to this work.

THE FEASIBILITY OF A CODE OF PRACTICE

Site Investigation

A site investigation is concerned with locating the water intake, the penstock route, the powerhouse site and the route for the transmission line. A variety of interrelated factors are involved but each one is straightforward in itself with the possible exception of the design flow rate.

Routine procedures exist for measurement of the head and stream flow and, with a typical value for overall system efficiency, the available power can be estimated. Information on the effects on run-off of topography, vegetation, geology and climate would be provided to aid in assessing the reliability of the water source but it is likely that the final decision on the design flow rate will be for a value greater than the anticipated safe minimum stream flow. This is likely to be a consequence of providing the necessary power while keeping the head to a minimum to reduce the length of the penstock pipes, which will be one of the major costs of the scheme.

The decision on the design discharge will most likely need to be based on the possibility of a period in the year when there will be insufficient stream flow. Then, standby provisions will need to be made, and the owner will need to be involved in the final decision on the design discharge, which will be a trade-off between cost and convenience.

A decision-making procedure needs to be evolved to deal with sites where there is insufficient hydrological data, and more convenient methods of stream gauging are required.

Intakes

Further research is necessary but it is expected that in due course it will be possible to offer standardised designs of maintenance-free intakes for small streams of all types. The appropriate intake would probably be decided on the basis of the site geometry, a sampling of the bed material, and the required extraction rate.

The operation of the scheme as a base load power supply obviates the need for water storage, and the intake will be a simple structure. The task of the intake is to separate water of sufficient cleanliness for the purpose and extract it from the natural stream bed. If the intake is to be maintenance-free, the energy required for the separation process must come from the head at the site. The intake will commonly have to be capable of intercepting the full flow of the stream at times of low stream flow. The design needs to cope with floating debris, suspended material and bed-load. The intake also needs to be located at a point along the course of the stream where the reduced stream flow downstream of the intake can still transport the full quantity of transported material approaching the intake.

A suitable intake has been developed for mountain streams that carry only a small gravel bedload, and the problem is mainly sticks and leaves. It has been operated without any form of maintenance for a number of seasons. The design, which was developed at the University of Canterbury, is illustrated in Fig. 2, and is described more fully in reference 1.

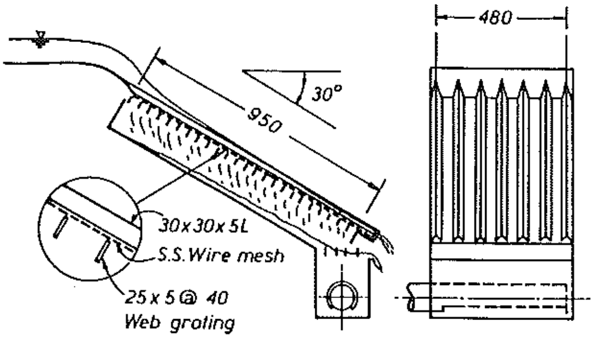


Fig. 2 A self-cleaning intake for mountain streams
(Extracting 12 L/s with a maximum particle size of 1 mm.).

A further study is proposed for the purpose of extending this concept to streams with a strong bedload movement of heavy gravels. It will use a naturally renewable filter bed of the largest size of bed material, held in place by a fixed matrix and kept clear by the same mechanism that produces armouring of gravel river beds. It will be set on a sufficient slope to scrub off the fines and prevent blocking of the interstices between the stones of the single-stone filter layer. The proposal is illustrated in Fig. 3.

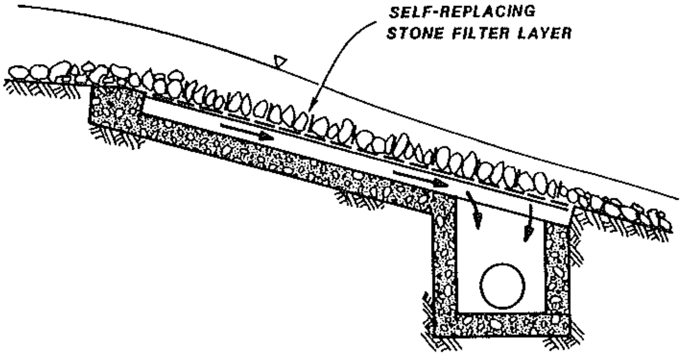


Fig. 3 A proposed maintenance-free intake for gravel streams (The need for secondary sand separation is anticipated).

It has been observed that immediately behind a wall built across a gravel-bearing river, the gravel deposit will remain undisturbed under all conditions of flood flow. A further study is proposed to explore the feasibility of a filter intake permanently buried in this location, as illustrated in Fig. 4. It is proposed to use automatic periodic back-flushing, similar to that described in reference 2.

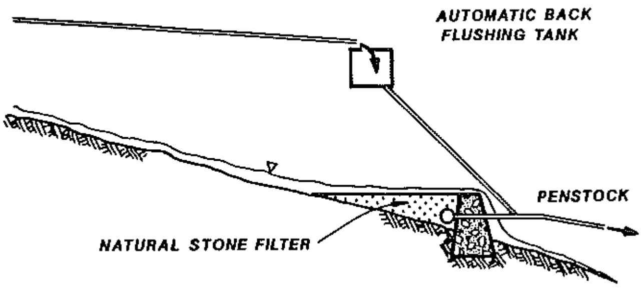


Fig. 4 A proposed self-cleaning filter intake.

Grit Separation

Some designs of intake will admit grit with the extracted water, and it may be necessary to remove it. The mountain stream intake, referred to above, was fitted with a woven stainless steel mesh that would pass particles no larger than 1 mm which were not considered dangerous for either the pipeline or the water turbine. Under other circumstances it may be necessary to remove grit from the separated water, and the usual method is sedimentation. This, however, requires either periodic cleaning or a complicated means of automatic flushing. Simpler means of automatic flushing are required or other methods of maintenance-free grit separation.

A maintenance-free grit separator has been developed for a small intake and is shown in Fig. 5. It takes the form of a centrifugal separator operating at atmospheric pressure, and is intended for use close to the intake. To minimise the head loss, which is characteristic of centrifugal separators, a recuperator was fitted. The "vortex finder" took the form of an orifice plate.

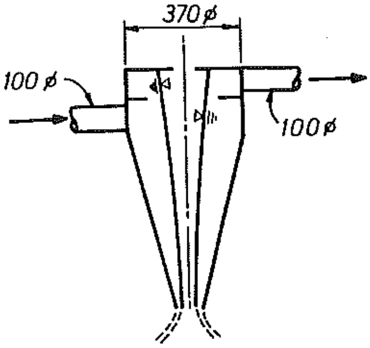


Fig. 5 A maintenance-free grit separator
(Outflow 12 L/s; bottom flow 1 L/s; head loss 1 m).

The device is simple, has a relatively small head loss, separates all unwanted particle sizes and operates without maintenance. The bottom hole is large to avoid blocking, and the wasted bottom flow was only 10% of the useful outflow. Standard designs of this separator could be developed.

Penstocks

The penstock pipes are likely to be the major expense of a microhydro scheme, and consequently sites are unlikely to be chosen where the penstock is long or large in diameter. The schemes most likely to be viable are medium-head schemes set in relatively steep country. To minimise penstock length, a headrace might be used.

Unlike the penstocks of conventional schemes, the microhydro penstock will not be carefully aligned, but will follow the existing surface topography. It may be run in a shallow trench for protection.

Such alignment suggests problems of air venting and blow-back, particularly in view of the possibility of the system being operated at less than full discharge at times of low stream flow. The diameters of the penstocks of microhydro schemes are small – from 100 to 300 mm – and, to avoid excessive head losses, the velocities are relatively low at 1 to 2 m/s. Further study is needed but it is expected that standard practices will be evolved to overcome the problems of venting and blow-back in these small pipe sizes.

A study at the University of Canterbury has produced a solution that provides for the continuous venting of trapped air from a small penstock during operation at less than full flow. It is illustrated in Fig. 6 and described in reference 3.

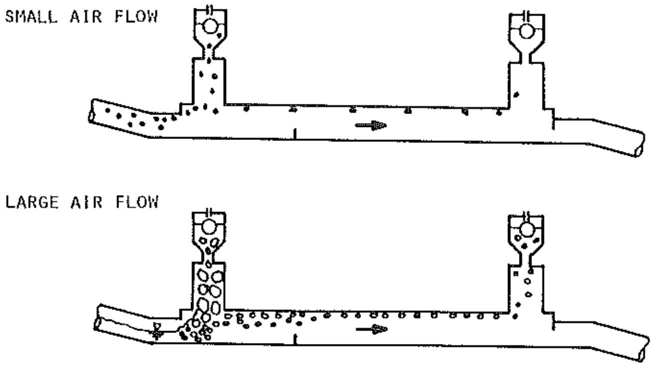


Fig. 6 Air separator with vents (100 mm penstock; water flow 12 L/s; pressure 100 kPa; maximum air venting rate 1 L/s of free air).

Emergency relief of the penstock is a method that has been used for overspeed protection on load rejection. This, or penstock failure, can result in very large flows discharging from the penstock. If the penstock is fed by a headrace, these very large flows could persist. Such excessive flows can be prevented by the provision of a choke at the penstock inlet in the form of a critical flow control section. Standard designs could be prepared.

A study of valving could lead to practices that would safeguard against the dangers of water hammer. Standard geared butterfly valves are expected to be the basis of a solution for medium – head schemes.

There appears to be a need for a commercially available valve in the smaller size range, with a non-linear connection between the operating mechanism and the flow control surfaces, designed to reduce the risk of water hammer. Such a valve would also have wide application in urban water supply work.

Turbine Selection

Current practice in microhydropower is to adopt a base load approach, using run-of-the-stream flow, generating at constant output and diverting the instantaneously unused electric power to waste. This approach avoids the use of the conventional speed control governor that manipulates control surfaces within the turbine to maintain constant speed and frequency. Constant frequency is retained by the inexpensive load governor and further economy results from the use of a simple, fixed geometry turbine.

Because of the simplicity of manufacture, the Pelton wheel for high heads and the Cross-flow turbine for medium heads are commonly used. However, being impulse turbines, they run relatively slowly and are likely to need speed-increasing mechanical transmission systems. Increasingly the rotodynamic pump, usually the centrifugal pump, is being used in the reverse mode for the turbine duty. Tests have shown that centrifugal pumps can be just as efficient in the turbining mode as in the pumping mode, and furthermore are widely distributed in a variety of sizes, come complete with bearings, seals, etc., ready for installation, and the cost is not excessive. If reputable makes are used there is likely to be a continued availability of spares. Since the specific speed of pumps higher than that of impulse turbines, and there is a wide variety of pumps available, a suitable pump is likely to be available that can be directly coupled to a synchronous generator and thereby reduce the mechanical transmission costs.

Operated in the reverse mode at the same speed, the power output at the turbining best efficiency point will be the same as the power input to the pump at the pumping best efficiency point. The turbining head and flow will be greater than for the corresponding pump case, with higher water velocities through the machine. If the axial thrust is not balanced, it will be greater in the turbining mode because of the higher head, and it is recommended that the shaft nut be secured properly on account of the reverse direction of rotation. Mechanical seals are to be preferred to packed glands as a clean supply of gland sealing water is unlikely to be available.

The main problem is the absence of any means of selecting the right pump for the purpose. What is needed is a translation statement that will enable the turbine performance to be obtained from the manufacturer's pump performance data without further testing. Stepanoff[4] offers a guiding statement which relates the performance between the two best efficiency points only. A suitable translation statement would make the selection of pumps as turbines a straightforward task.

Numerous designs have been published for the manufacture of cross-flow turbines, and local manufacture of an appropriate impulse turbine might be considered. However, any region with the technical resources to install and properly maintain a microhydro scheme is likely to have access to a supply of centrifugal pumps.

Generators

The generator is most likely to be a standard synchronous alternating current machine preferably of the brushless type.

There are some potential advantages in using the induction motor in the reverse mode as an isolated induction generator. The induction motor is cheap and rugged – and, as an induction generator, it is well suited to starting electric motors; but it has problems of excitation and voltage control. Studies to resolve these problems are currently under way at the University of Auckland, New Zealand, with the aim of producing a design for a standard controller that could be marketed as a packaged unit.

Tests have successfully been conducted to operate a complete submersible pump in the reverse mode as a turbo-generator set. The arrangement is illustrated in Fig. 7 and described in reference 7. It has the advantage of a very appropriate enclosure for any environment, including high tailwater levels; but as a generating option it still needs a solution to its excitation and voltage regulation problems. It also poses a particular problem for overspeed protection.

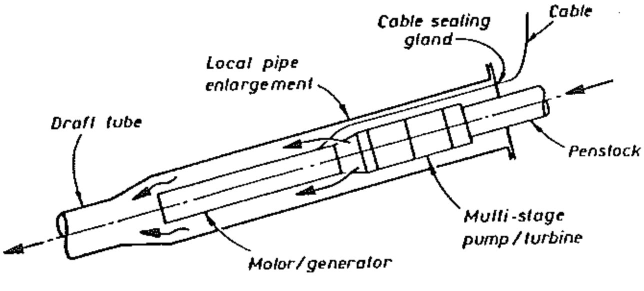


Fig. 7 Reversed submersible pump set.

Overspeed Protection

Load rejection can occur as a result of failure of the electrical system at any point up to and including the electrical load governor. It can occur within the generator from such simple causes as loss of a control process or dirty brushes. When this open circuit happens, in the absence of any automatic control of the water flow, the machines will accelerate very rapidly to the runaway speed which is likely to be high enough to put the generator at risk. The response to this situation has to be so fast that it prohibits the closing of the water supply because of the water hammer danger to the penstock. Alternatives that suggest themselves are a brake to stall the turbogenerating set and diversion of the water supply to waste. Of the two, a dead-weight or spring-operated, drum or disc brake is the simpler solution and has been used to good effect. As an emergency system, it is also operated for normal starting and stopping of the plant. When stopped with the brake, water continues to flow through the stalled turbine with no significant pipeline transients, keeping the intake and pipeline flushed.

In conventional hydropower, a relief value is used in conjunction with the guide vanes to unload the turbine rapidly without endangerous the penstock. In a microhydro system using a fixed geometry turbine, there will be no guide vanes, and for a relief valve to be effective by itself there has to be a permanent impedance in the system to reduce the energy of the flow to the turbine when the relief valve is opened, as shown in Fig. 8.

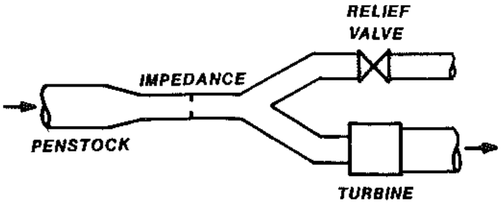


Fig. 8 Relief valve with upstream impedance.

An alternative that is being studied is the use of a parallel dummy impedance and two valves, so ganged together that they can be operated rapidly or slowly for either starting or stopping the turbine – in such a way that there is no change in the flow through the penstock and consequently no risk of water hammer. The proposed arrangement is shown in Fig. 9. This method of overspeed protection would be suitable for close-coupled pump sets operated in reverse as turbogenerating sets, including the submersible pump.

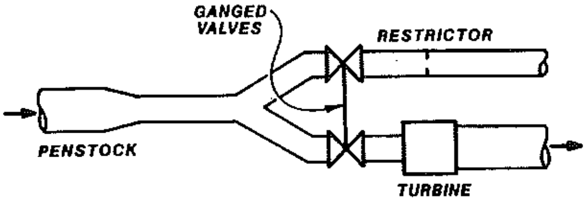


Fig. 9 Relief valves with parallel impedance.

System Operation and Control

The use of the electronic load-diverting governor provides for the generating set to run at constant speed by continuously monitoring the electrical output and making appropriate adjustments to the total electrical load by dumping surplus power to waste as necessary. The governor can be located at any point in the electrical reticulation but is most likely to be situated close to the consumers so that use can be made of the dumped energy.

With a constant supply of power to the turbine, any variations in total electrical load would produce variations in current, voltage and frequency and, on the face of it, any one of these could be used by the governor as a reference signal to control the load.

It would be usual to use a synchronous generator with its own in-built voltage regulator which produces an essentially constant voltage and this would discourage the use of voltage as a load sensing signal. If the water supply falls below the necessary minimum, the system may continue to operate usefully at reduced load. In fact, stable operation down to 35% of full load has been accomplished, with proper precautions to deal with entrained air, as shown in Fig. 10.

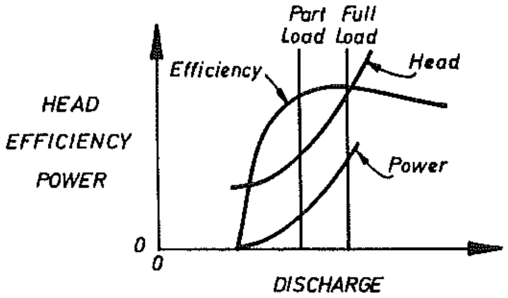


Fig. 10 Performance at reduced discharge (Lower limit of reduced discharge: – 75% of design discharge, 50% of design head, 35% of design power output).

Steady performance at such a reduced current would preclude the use of a constant current as a reference signal. The most convenient signal is considered to be frequency, and a maintenance-free, electronic governor which adjusts the diverted load in 15 steps from no-load to full-load on the basis of a frequency range of 49.3 to 50.7 Hz has been developed at the University of Auckland, New Zealand (see reference 8). It can be used for any load up to 11 kW, and for greater loads can be used in multiples. The unit is commercially available at a very modest cost. Other electronic load-diverting governors are available from various sources around the world.

One difficulty was experienced in starting up a small conventional synchronous generator connected to a frequency sensing governor, together with its dump loads, when the electrical system was otherwise open-circuited. The governor determined the frequency by measuring the half-cycle period and the open circuit wave form of the generator was so dominated by harmonics that the governor was measuring spurious periods and failed to control the speed correctly. The problem was resolved by ensuring some resistive load connected across the generator before starting.

The stepwise nature of the governor operation imposes small transients on the generating system. The effects are imperceptible to the consumer, but a minimum inertia is necessary in the rotating parts for stability. Simple rules are available for sizing flywheels but for the case of close-coupled pump sets run in reverse this is not a suitable solution, and further studies remain to be done on the stability of these systems.

The urban consumer is supplied with power in any quantity up to the fused limit of his installation. The peak consumption could be 10 or 15 times the average consumption. With a microhydro scheme, designed to give a base load supply, it would be unreasonable to provide for the possible peak demand, and the usual arrangement would be to provide a base load supply of about 3 times the equivalent urban average demand. This restricted supply requires some adaptation by the consumer, but on the other hand offers more energy than would normally be consumed.

This restricted supply means that the consumers will frequently be trying to use it to its full capacity, and overloading is inevitable. This has been effectively controlled with the use of a warning signal to the consumer that provides a pre-set time for load to be reduced before the consumer is otherwise isolated.

Normal malfunction equipment would be installed at the generator to detect out-of-range frequency, current and voltage, and which would open-circuit the generator and automatically operate the stalling brake and stop the plant. Consumer protection is particularly important in the case of geographically isolated installations – even more so in developing countries where the users may be less familiar with the technology. Malfunction procedures suitable for these small isolated systems have been described in reference 9.

CONCLUSIONS

If microhydropower, in sizes of about 5 kW, is to become a viable widespread benefit, particularly in developing countries, all means possible will have to be used to reduce the capital cost, while still maintaining proper standards of supply and of safety. Professional fees would, of themselves, be sufficient to render these small schemes uneconomic and there is a need to reduce them to a minimum. With care, most aspects of a microhydro scheme could be so devised that they could be undertaken by people with only trade skills, and this represents a worthy aim of research in the subject. A trade level of skills is necessary if the proper level of human protection is to be provided, and the object should also be, as far as possible, to make it sufficient for the purpose.

The technical aspects of research in microhydropower do not present overwhelming challenges to the engineer, but the engineer should consider whether he has the resources to deal with the human problems that present themselves, with particular reference to maintenance by the users in developing countries. If in doubt he should enlist the aid of the appropriate experts who are probably to be found in the social sciences.

ACKNOWLEDGEMENTS

The research work undertaken at the University of Canterbury and described above was done with the aid of funds from the New Zealand University Grants Committee.

REFERENCES

1. Giddens, E.P. (1984), A self-cleaning intake for mountain streams, *Proc. Hydraulics in Civil Engineering Conference,* Adelaide, Australia, Institution of Engineers Australia, National Conference Pubn. No. 84/7, pp. 44-48.
2. Williams, H.C. (1967), Gisborne waterworks intake, *New Zealand Engineering,* Vol. 22, No. 12, Dec. 1967, pp. 502-505.
3. Giddens, E.P. (1983), An air separator, *Proc. Eighth Australasian Fluid Mechanics Conference,* Newcastle, Australia, University of Newcastle, 1983, Vol. 1, pp. 2C1-3.
4. Stepanoff, A.J. (1957), *Centrifugal and axial flow pumps,* Wiley and Sons, New York, 2nd edn., pp. 276-277.
5. Haimerl, L.A. (1960), The cross-flow turbine, *Water Power,* Vol. 12, No. 1, Jan. 1960, pp. 5-13.
6. Clemens, Adam (1974), *B.Y.S. cross-flow turbine,* Swiss Assoc. for Technical Assistance, Zurich.
7. Giddens, E.P., W. Spittal, and D.B. Watson (1982), Small hydro from a submersible pump, *International Water Power and Dam Construction,* Vol. 34, No. 12, Dec. 1982, pp. 33-35.
8. Woodward, J.L. and J.T. Boys (1984), A low cost electronic load governor for load management, *Proc. First International Conference on Small Hydro,* Singapore, Feb. 1984.
9. Bryce, P. and E.P. Giddens (1985), Malfunction protection for electrical equipment used in microhydro plants, *Micro Hydro Supplement, International Water Power and Dam Construction,* Nov. 1985.