小型水力發電廠之最佳管徑設計

Optimum Pipe Diameter Design for Small Hydropower Plants

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摘　要

臺灣位於亞熱帶氣候，一年四季雨量豐沛，所以水資源不虞匱乏，由於地勢陡峻，頗適合水力發電；以往著重於大型水力發電計劃，而忽略如何利用小型水力發電之研究。由於國內燃油及核燃料，均仰賴進口，往往受人為因素所控制，因此如何開發現有資源，為當前主要課題。

雖然石油去年年初大幅下降，但年末時又開始上升，所以，所以誰也不能擔保石油危機不會再發生，所以宜未雨而稠繆，勿臨渴而掘井，儘速規劃利用國全現有資源。

本報告針對小型水力發電廠之規劃，提出如何調查、規劃、計算及設計，並配合電腦作業，分析設計最佳管理，其中不僅顧及經濟效益，也關注生態均衡之發展。

由於本省許多渠道及山澗，均具有小落差發電功能，對於偏遠山區能提供一些自給自足的電力，祈冀能對本省現有水資源之開發利用有所幫助。

Abstract

Taiwan is located in the subtropical climate, with ample rainfalls all year round; the water resource is always sufficient. Taiwan is also pertinent to hydropower because of its unique geographics. However, the concering research have been focused on the large-scale hydropower plan, and neglected the mini hydropower one. In light of the facts that both our petroleum and nuclear fuel depends upon import and that the latter is often restrained from human factors, it is indeed very crucial to utilize our own energy resource.

This paper will center on how to plan small hydropower plants, how to survey, calculate and design, and how to integrate with computer computation, in order to bring forth the optimum pipe diameteı design. This research will thus take economic benefits into account and concern with the development of ecological balance.

Owing to the fact that Taiwan has many channels and creeks which have the generating ability of difference of small elevation, I venture to

give my own ideas about rural electricity development in order to contribute the present resource development in Taiwan.

Selectivity of the Geographic Location of Small Hydropower Plants

Discharge Observation

Discharge investigation is not only of great importance to any hydrology, but even more crucial to the design of small hydropower plants, because stream rate fluctuates greatly, which cannot offer sufficient quantity of water. This will naturally affect the efficiency of generation. Large-scale hydropower differs from small one in one point: the former is based on higher dam which converts potential energy into kinematic energy to generate; while the latter is based on the energy produced by both lower difference elevation and discharge to generate. From this we can realize that discharge observation is very important to small hydropower plant design. Methods of how to measure discharge are described in detail in many hydrologic books, so they will not be mentioned in this paper.

Investigation of Rural Electricity

The purpose of small hydropower is to provide the nearby rural populace with electricity without any beneficial-orientation. In mountain areas or remote places where electricity cable cannot reach, it is perhaps better to utilize the presently available resources. On the other hand, we have to include the amount of population and electricity utilities in our investigation. Since the pattern of electricity utilization is heavily related to people's routine schedule, we can use battery storage to adjust people's behavior of electricity use, in order not to make any unnecessary waste.

Will Small Hydropower Plants Influence Ecological Balance?

Generally speaking, higher dams shed a great deal of influence on ecological balance and usually cause irremediable damage. So, constructing a higher dam is always considered to be the first priority in ecological evaluation. Although mini hydropower has less water amount, there are still two ways to keep ecological balance:

1. To build a pond on a higher location by the river and use pipe system to induce the water current to downstream water turbine. The amount of water discharge should not exceed one-thirds of that of the original discharge.

2. To make a hydraulic structure, like lower dam or wier, in the middle of the river, and to set up fish ladder beside the structure in order to help the regression of fish. Since the structure is built directly in the river, the amount of water discharge should not exceed quarter of that of the original one.

The purpose of small hydropower is different that of large scale one: the purpose mini hydropower is to suffice itself; whereas the purpose of the large scale one is to gain profits. In order to be more applicable, we can adopt series generating electricity so that the same current can generate in a recycling way.

The Estimation of Generating Capacity of Small Hydropower Plants

Because .the aim of the small hydropower plant is to serve the rural farmer, the peak use period often occurs during cooking hours and between 7 and 9 PM. This is totally different from urban peak use pattern. Thus, the amount of battery storage depands on estimation of peak use:

Choose N samples, measure every half hour for 2 to 4 weeks incessantly, and take average to analyze the demand in every half hour(D)

Total demand electricity per day(TD) = Sum of (D)* 0.5 hr. . . . . (1)

Average demand electricity per day(AD) = (TD)/24. . . . . (2)

If (D)>(AD), we need battery to supply

If (D)<(AD), we can use battery to storage electricity

To Estimate of Demand Head

The power of the small hydropower plant is

P=Q*H*e/C=A*V*H*e/C . . . . (3)

where, P: power (KW)
Q: discharge (CFS)
e: the efficiency of generating power (%)
A: average cross-section area (square feet)
V: velocity (FPS)
C: constant = 11.8 = 737.56/62.4 (1 kw = 737.56 1b-ft/sec, r = 62.4 1b/cu ft)

The demand head can be calculated by

H=C*P/(Q*e) . . . . (4)

Optimum Pipe Diameter Design

To Calculate the Head Loss

According to Darcy's formula can get head loss

H=f*L*V*V/(D*2*g) . . . . (5)

where, H: head loss
f: friction coefficient
L: characterstic length
V: velocity
D: Diameter
g: gravity

The head loss of the pipe can be found from Table. 1, and the equivalent lengths of fittings as shown as Table. 2

Computer Analysis

The analytical operation of this paper is based on Lotus-123, which is very convenient for table calculation work. Once the appropriate pipe and discharge are choosen, we can calculate the pipe friction loss and dynamic loss in order to aviod some complicated calculation.

This paper deals with the analysis work in two ways:

(1) If the battery storage system is not taken into consideration, the generating design will be based on peak power demand analysis (Figure 1.)

(2) If the battery storage system is taken into account, then the generating design will be based on average power demand analysis (Figure 2.)

How to Choose the Optimum Pipe Diameter

Table 1. and Table 2. tell us that different pipe and different discharge

Table 1. Head Loss per 100 Feet of Schedule 40 PVC Pipe

Pipe size	Flow Rate(GPM) 50	100	150	200	250	300	400	500	750	1000	2000	3000	4000
2"	5.79	20.9											
2.5"	2.42	8.72	18.5										
3"	0.81	2.93	6.20	10.6									
4"	0.21	0.76	1.61	2.75	4.16	5.83	9.93						
5"	0.07	0.24	0.52	0.88	1.34	1.87	3.19	4.82					
6"	0.03	0.10	0.22	0.37	0.56	0.78	1.33	2.00	4.25	7.23			
8"	0.00	0.00	0.05	0.09	0.14	0.20	0.34	0.51	1.08	1.84			
10"	0.00	0.00	0.00	0.04	0.05	0.07	0.11	0.17	0.36	0.61	2.19		
12"	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.15	0.26	0.94	1.99	3.41

Table 2. Equivalent Lengths of Fittings; In Feet of Pipe

Fitting	Pipe Diameter 2"	2.5"	3"	4"	6"	8"	10"	12"
Glove value, fully open	58.6	70.0	86.9	114.1	171.8	226.1	283.9	338.2
Angle valve	25.0	29.8	37.1	48.6	73.3	96.4	121.1	144.3
Gate valve, fully open	2.2	2.7	3.3	4.4	6.6	8.6	10.9	12.9
3/4 open	6.0	7.2	8.9	11.7	17.7	23.3	29.2	34.8
1/2 open	27.6	32.9	40.9	53.7	80.9	106.4	133.6	159.2
1/4 open	155.0	185.2	320.1	302.0	454.9	598.6	751.5	895.4
90° Elbow	5.5	6.2	7.7	10.1	15.2	20.0	25.1	29.8
45° Elbow	2.8	3.3	4.1	5.4	8.1	10.6	13.4	15.9
90° long radius	4.3	5.1	6.3	8.3	12.5	16.5	20.7	24.7

bring forth different energy loss. When discharge is in a stationary condition, the smaller the pipe, the greater the energy loss. On the other hand, in the same pipe diameter, the smaller the discharge, the smaller the energy loss. According to different discharge and pipe diameter, we draw Figure 1. and 2. But before we draw them, we have to analyze with computer in order to calculate the pipe friction loss (PLF), the dynamic loss (DL) as well as the total power loss (TPL). The result is shown in Table 6. If we substract the TPL from the total energy head, we can get the effective head. Then we can draw several groups of curves according to the effective head, different discharge, and different pipe. From Figure 1. and 2 we can see that the general small diameter pipe are only proper for some discharge; on the other hand, the larger the pipe diameter, the less the economic benefit.

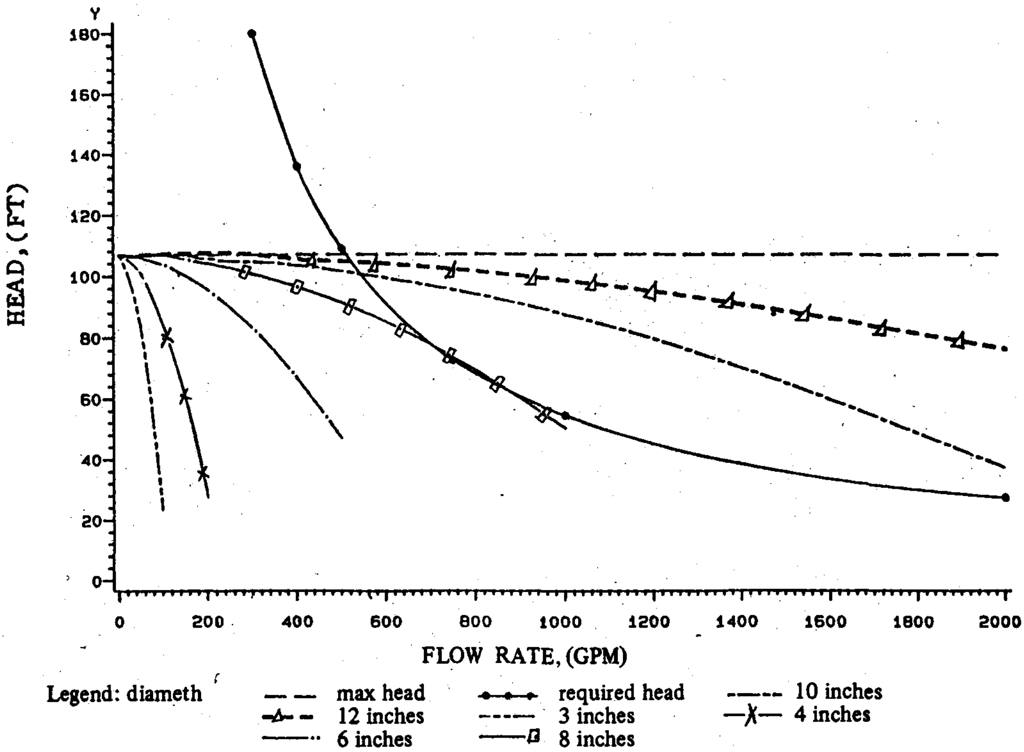

Figure 1. Optimum pipe design for small hydropower plants
(Peak power demand)

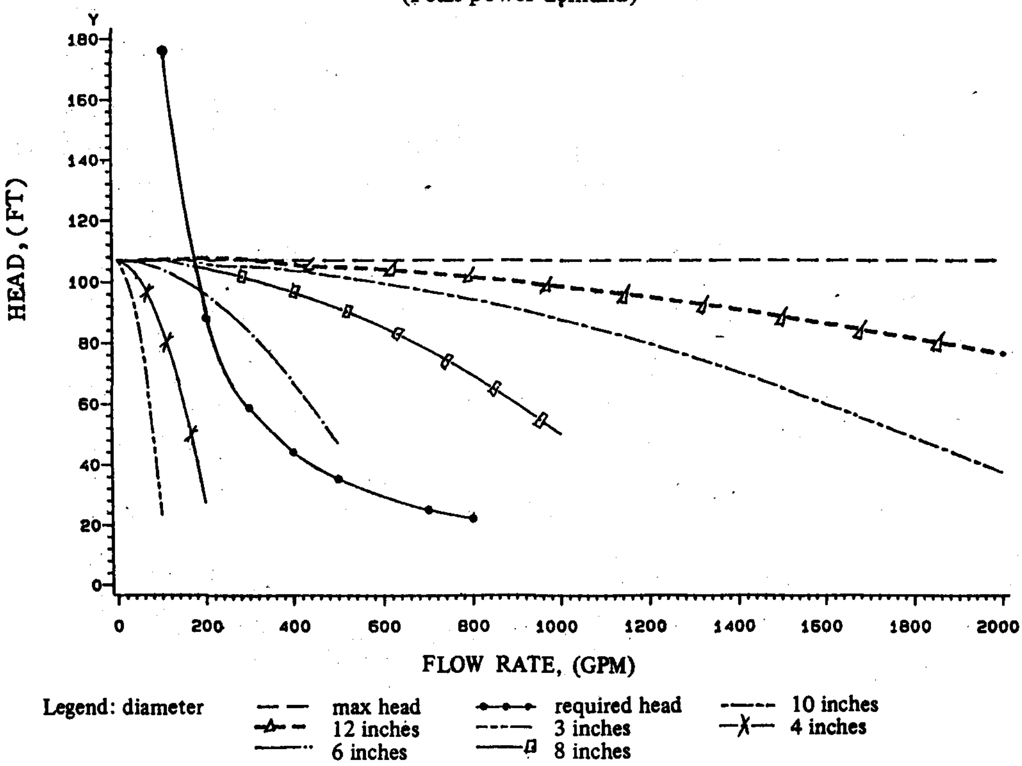

Figure 2. Optimum pipe design for small hydropower plants
(Average power demand)

If we combine those curves with the demanding head curves in Figure 1. and 2, we find several intersections. It is these intersections which are worth taken into consideration. In Figure 1, the 3-inch, 4-inch, and 6-inch pipes are not considerable, because they cannot provide the energy of demanding head. However, although the 8-inch, 10-inch, and 12-inch pipes can all provide enough energy. Only the 8-inch pipe is of the greatest economic benefits. Similarly, in Figure 2. the 6-inch pipe is the optimum one.

Design Example

Suppose we want to build a small hydropower plant on a lower difference elevation creek. We get the effective head of 107 feet and 4.88 CFS discharge after our investigation. But in order not to influence ecological environment, we use only a quarter of total discharge. Based on the calculation of former's electricity usage, we get the average daily demand as shown in flollowing Table 3.

The pipe system adopts PVC pipe, which is 2700 feet in length. During the design process, we decide to use the following accessories: twelve 90-degree elbow pipes, four 45-degree elbow pipes, and one half- open gate valve. Now we try to get the optimum design which the best fits.

(1) To calculate the average power demend
From formula (1), we can calculate
Total Power Demand (TD) = 59.875 KHW
Average Power Demand(AD) = 59.875/ 24 = 2.5 KW

(2) To calculate the peak power demand
From Table 3. find the Maximum value P = 7.7 KW

Table 3. An example of the average daily demand

Time	Demand, (KW)	Time	Demand, (KW)	Time	Demand, (KW)
0:00	0.7	8:00	2.5	16:00	3.4
0:30	0.7	8:30	1.9	16:30	4.4
1:00	0.6	99:00	1.9	17:00	6.5
1:30	0.6	9:30	2.1	17:30	7.7
2:00	0.6	10:00	2.0	18:00	6.6
2:30	0.7	10:30	1.8	18:30	5.9
3:00	0.4	11:00	2.7	19:00	5.6
3:30	0.4	11:30	2.8	19:30	6.4
4:00	0.3	12:00	4.3	20:00	4.3
4:30	0.4	12:30	2.6	20:30	4.3
5:00	0.6	13:00	2.2	21:00	4.2
5:30	0.6	13:30	2.1	21:30	3.1
6:00	0.8	14:00	3.0	22:00	2.6
6:30	1.0	14:30	2.5	22:30	2.2
7:00	0.9	15:00	2.6	23:00	1.9
7:30	2.3	15:30	1.9	23:30	1.0

(3) To calculate the electricity supply

The discharge of the river is measured, (Q= 4.88 CFS). If the hydrualic structure is considered in order not to influence ecological balance, the amount of water discharge should not exceed a quarter of that; thus, the available discharge is 1.22 CFS.

(a) To generate according to the peak power demand rather than battery storage.

(b) To generate according to the average power demand and to store electricity with battery.

(4) To generate according to the peak power demand and to calculate the height of head demanded by different discharge. We can use formula (4) to calculate different discharge (Q). The effective power e= 75%. Then, use peak power demand P = 7.7 KW to get the demanding curve of the height of head as shown in Figure 1. and Table 4.

Table 4. The demanding head with different discharge
Peak Power Demand, (P = 7.7KW)

Discharge, Q(GPM)	400	500	750	1000	2000
Demand head (FT)	135.9	108.7	72.5	54.4	27.2

(5) To calculate demaning height of head demanded by different discharge according to average power demand. We still use formula (4), but P= 2.5 KW, as drawn in Figure 2. (also see Table 5).

Table 5. The demanding head with different discharge
Average Power Demand, (P = 2.5KW)

Discharge, Q(GPM)	100	200	300	400	500	750	800
Demand head(FT)	176.5	88.31	58.8	44.1	35.3	23.5	22.1

To use Lotus-123 to analyze the total energy loss.

Total Pressure Losses= Pipe Friction Loss + Dynamic Loss

The Effective Head = Max. Head – Total Pressure Losses

And to draw Table 6. according to total pressure losses, pipe friction loss, and dynamic loss.

(7) To draw discharge and head curve

To calculate the effective head according to the relationship among Table 4, 5, and 6, and to draw several groups of curves to show the relationship between discharge and head of different diameter.

(8) To decide the optimum pipe diameter

To use our design to find out the intersection of several points where head curve and head energy curve of different size pipe meet. For example, in Figure 1, the optimum pipe size pipe meet. For example, in Figure 1, the optimum pipe size is 8-inch one; while in Figure 2, it is the 6-inch one.

Table 6. The Energy Losses with Different Pipe and Discharge
(Using Lotus-123 to analyze)

Discharge (GPM) / Losses		100	150	200	250	300	400	500	750	1000	2000
4"	PFL	79	167	286							
	DL	4	9	15							
	TPL	83	176	301							
5"	PFL	20	43	74	112	157					
	DL	2	3	5	8	11					
	TPL	22	46	79	120	168					
6"	PFL	3	6	10	15	21	36	54			
	DL	0.3	0.6	1	2	3	4	6			
	TPL	3.3	6.6	11	17	24	40	60			
8"	PFL		1.3	2.4	3.7	5.4	9	14	29	50	
	DL		0.2	0.3	0.5	0.8	1	2	4	7	
	TPL		1.5	2.7	4.2	6.2	10	16	33	57	
10"	PFL			1.1	1.4	1.9	2.9	4.6	9	16	59
	DL			0.2	0.3	0.4	0.5	0.8	1	3	11
	TPL			1.3	1.7	2.3	3.4	5.4	10	19	70
12"	PFL						1.4	1.9	4.1	7	25
	DL						0.3	0.4	0.9	2	5
	TPL						1.7	2.3	5.0	9	30

Discussion

(1) This paper aims at the research analysis of optimum pipe diameter design, which is based on some viewpoints of fluid mechanics. However, in real practice, we have to make a research analysis in other accessories, like water turbine, surge tank, and electricity storge plant, etc.

(2) Generally speaking, in building a small hydropower plant, we have to consider the continuity of water resource, especially in drought season. The more applicable ways will be to utilize existing water resources such as channels and streams. In the case of foreign countries, this kind of utilization is largely applied to rural area, which electricity cable is hard to reach.

(3) The cost of investment for a small hydropower plant needs merely initial investment of the plant construction. Its maintenance cost is also a lot less than both firepower plant which consumes

petroleum and nuclear power plant which uses nuclear fuels. However, we have to be aware of the impact on ecological environmental, in order not to be detrimental to ecological balance.

(4) According to Auslam's (1983) analysis, the average life of 10-150 KW diesel generator is around 10 years; while the average life of the small hydropower turbine is about 30 years. So, small hropower plant is indeed more economic in terms of the cost of investment.

(5) Boyd (1985) once emphasized in his energy management system must be based upon reasonable initial investment and reliability and must be expanded and accepted by people easily. During the energy crisis period, all the oil-consuming countries encounted greater impact. That is also the reason why the more explicit picture about energy saving.

(6) According to NRECA (1983) (National Rural Electric Cooperative Association) and AID (U.S. Agency for International Development), there are four criteria for setting up small hydropower plants: (a) priority for area development; (b) sites which have favorable benefit to cost ratio; (c) priority for productive use; (d) replacement of existing diesel generating set.

Conclusion

The premise of whether or not to set up the small hydropower plant is based on area development. Generally speaking, the generating power of small hydropower plant cannot be compared to that of the large scale one. However, the small hydropower plant is much more applicable for remote areas.

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