AN ANALYSIS OF PERFORMANCE CHARACTERISTICS FOR SMALL HYDRO POWER PLANTS

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Abstract: A performance prediction model for Small Hydro Power(SHP) sites has been studied and developed. Twelve SHP sites were selected and the performance characteristics were analyzed by using the developed model. Also, primary design specifications such as design flowrate, plant capacity, operational rate were suggested and feasibility for small hydro power sites were estimated. It was found that the design flowrate is most important parameter to exploit SHP plant and the methodology developed in this study can be a useful tool to analyze the performance of SHP sites.

Key Words: Small Hydro Power, performance prediction model, design flowrate, performance characteristics

1. INTRODUCTION

Small Hydro Power(SHP) offers numerous advantages compared to other alternatives as an important source of renewable energy and it is brought to the more social, environmental and economic advantages compared to other alternatives as an important source of renewable energy.

First estimation of SHP resources was carried out by map survey to develop as an alternative energy after 1st oil crisis. Also, the design work was performed in 1975, and applying these results, the demonstration SHP plant was constructed at Anheung in Kangwon province. 2nd estimation of SHP resources was carried out through actual site survey after 2nd oil crisis(Park, 1975).

It is known as SHP is clean energy but need more initial investment per unit capacity comparing with other generation sources such as large hydropower, oil plant, nuclear power plant. The economics of SHP, however, can be improved by performing detailed analysis for geomorphological characteristics and capacity of SHP power sites. The capacity of SHP plant is determined by geomorphological conditions and flow duration characteristics of SHP sites.

This paper presents a concept of the performance prediction for SHP sites and its application. Based on the surveyed data of SHP sites, the performance characteristics were analyzed by using developed models.

Also, the optimum design flowrate, optimum capacity and primary design specification were presented.

2. RAINFALL DATA ANALYSIS AND FLOW DURATION CURVE

Hydrological data is not enough to decide flow duration characteristic of SHP sites because the most of sites locate upstream of rivers. The flow rate passing SHP sites can be calculated by analyzing the rainfall record measured by rain gauging station in drainage area concerning with sites.

Annual average flow rate of the river is related to the annual total amount of rainfall in the drainage area and estimated as follow.

$$Q_a = \frac{R_t \times 10^{-3} \times A \times 10^6 \times k}{365 \times 24 \times 60 \times 60} \qquad (1)$$

If the discharge coefficient, k does not vary during a year, the monthly average flow rate of the river can be described as follow.

$$Q_a = \frac{R_m \times 10^{-3} \times A \times 10^6 \times k}{30.42 \times 24 \times 60 \times 60} \qquad (2)$$

Monthly amount of rainfall measured at rain gauging station can be converted to monthly specific drainage per 1 km^2 of unit drainage area by using equation (2). Also, flow duration curve for unit drainage area can be determined by using monthly rainfall. Flow duration curve can be expressed to the type of cumulative probability distribution function because its concept is similar to probability density function. In this study, flow duration curve for unit drainage area is characterized by using the cumulative probability distribution function of Weibull distribution.

Probability density and cumulative probability distribution function of Weibull distribution is expressed as follows.

$$P(q) = (\alpha/\beta)(q/\beta)^{\alpha-1}\exp\{-(q/\beta)^{\alpha}\} \qquad (3)$$

$$F(q) = \int_0^q P(q)dq = 1 - \exp\{-(q/\beta)^{\alpha}\} \qquad (4)$$

Two constant, α and β in equation (2) and (3) can be found by using the regression analysis. If the both side of equation (4) take twice of natural logarithm, the equation is expressed to type of Y = aX + b as follow.

$$\ln[-\ln\{1 - F(q)] = \alpha \ln q - \ln\beta \qquad (5)$$

where,

$$\begin{aligned} Y &= \ln[-\ln\{1 - F(q)\}] \\ X &= \ln q \\ a &= \alpha \\ b &= -\alpha \ln\beta \end{aligned} \qquad (6)$$

In equation (6), a and b can be calculated by using (X, Y) data, i.e. data of cumulative probability distribution and monthly average flowrate.

$$\begin{aligned} a &= \frac{\sum XY - \sum X \sum Y/n}{\sum X^2 - (\sum X)^2/n} \\ b &= \sum Y/n - a\sum X/n \end{aligned} \qquad (7)$$

Flowrate and flow duration curve of SHP sites are decided by evaluating the data measured at several rain gauging stations because total drainage area always contains several rain gauging stations. If i_{th} rain gauging station exist in total drainage area as shown in Fig. 1.,

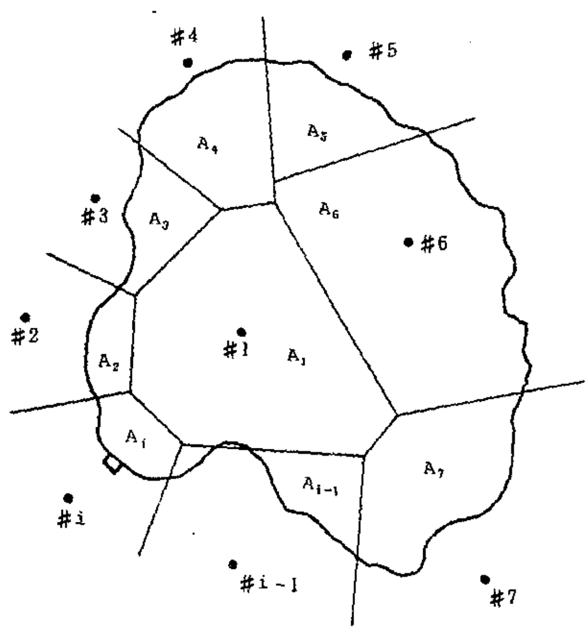

Fig. 1. Divided drainage area by Thiessen network

average rainfall of total drainage area can be expressed as follow by Thiessen network.

$$R = \sum W_i R_i, \quad W_i = A_i / A \tag{8}$$

Where A_i and R_i mean the small drainage area divided by i_{th} rain gauging station and the amount of rainfall measured at i_{th} station respectively.

Flowrate at SHP site can be expressed as follow.

$$Q = A \sum W_i q_i , \tag{9}$$

The cumulative probability distribution function and probability density function are expressed as follows.

$$F(Q) = A \sum W_i [1 - \exp\{-(q_i / \beta_i)^{\alpha - 1}\}] \tag{10}$$

$$P(Q) = A \sum W_i (\alpha_i / \beta_i)(q_i / \beta_i) \exp\{-(q_i / \beta_i)^{\alpha - 1}\} \tag{11}$$

Also, flow duration function at SHP site which can indicate flow duration characteristic is obtained as follow(Lee, 1989).

$$D(Q) = A \sum W_i \exp\{-(q_i / \beta_i)^{\alpha - 1}\} \tag{12}$$

3. ANALYSIS OF PERFORMANCE CHARACTERISTICS OF SHP PLANTS

Energy extracted from SHP plant is affected from flowrate and head. Ideal hydro energy can be calculated as follow.

$$P_i = \rho g Q H \tag{13}$$

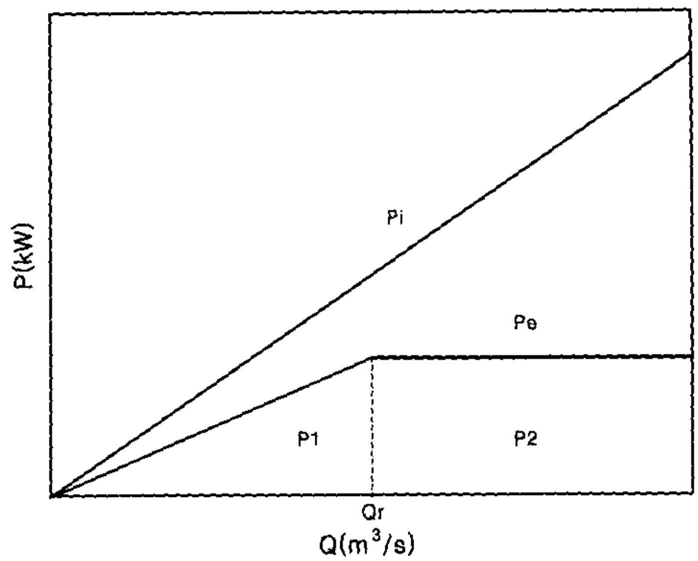

Fig. 2. Power characteristics of SHP

Power extracted from SHP plant with unit head is shown in Fig. 2. Power from the plant is differed from ideal hydro energy, because of design flowrate and efficiency of hydro turbine-generator. Up to design flowrate, the power is varied linearly with flowrate, however, it is always less than the ideal hydro energy. From design flowrate, the power is maintained constant because the exceeding flowrate is discharged over diversion dam.

Electricity produced from SHP plant per unit time is obtained as follow(Lee et al., 1992).

$$P_e = \rho g H_e \eta \int_0^{Q_r} P(Q)dQ + \rho g H_e \eta Q_r \int_{Q_r}^{\infty} P(Q)dQ \quad (14)$$

Equation (14) can expressed as follow, assuming plant efficiency has constant value during operation.

$$\begin{aligned} P_e &= \rho g H_e \eta \left\{ \int_0^{Q_r} P(Q)dQ + Q_r \int_{Q_r}^{\infty} P(Q)dQ \right\} \\ &= \rho g H_e \eta (S_1 + S_2) \\ &= P_1 + P_2 \end{aligned} \quad (15)$$

Where $S_1 = \int_0^{Q_r} P(Q)dQ$ and $S_2 = \int_{Q_r}^{\infty} P(Q)dQ$

The capacity of SHP plant, operational rate and annual electricity production can be calculated as follows.

$$C = \rho g H_e Q_r \quad (16)$$

$$L_f = (S_1 + S_2)/Q_r \quad (17)$$

$$E_a = 8{,}760 C L_f \quad (18)$$

4. Results and discussions

Twelve SHP sites were selected and ana-

Table 1. The characteristics of SHP sites

sites	drainage area (A, ㎢)	natural head (m)	dam height (m)	Remarks
Daeki	215.0	25.8	5.0	Tunnel-type
Duckchon	2,025.0	14.1	5.0	Tunnel-type
Kujul	233.0	21.6	6.0	Tunnel-type
Dodon	733.0	8.1	5.0	Tunnel-type
Misan	349.0	12.1	6.0	Tunnel-type
Kikok	277.9	20.3	4.0	Tunnel-type
Hwoiryong	955.8	12.2	5.0	Tunnel-type
Daiya	170.8	22.0	5.0	Tunnel-type
Yangchon	1,096.6	5.9	4.0	Tunnel-type
Keowoon	2,294.0	0.0	14.0	Dam-type
Woonchon	4,208.8	0.0	4.5	Dam-type
Sasuk	1,801.4	0.0	7.0	Dam-type

lyzed. The geomorphological data of each site are summarized in Table 1. Natural head and river width if selected sites were determined by actual site survey and dam heights were restricted to avoid submerging of the residential areas upstream(Park et al., 1997).

Out of twelve SHP sites in Table 1, Dodon site selected for performance prediction. Drainage area of Dodon site shown in Fig. 3 is measured to 733.0km^2 and divided by small areas affected from seven rain gauging stations. The characteristics of divided areas are shown in Table 2.

Fig. 4 shows the flow duration curve of Dodon site obtained by combining the characteristics of small drainage areas in Table 2.

Fig. 5 shows the variation of operational rate, plant capacity and annual electricity

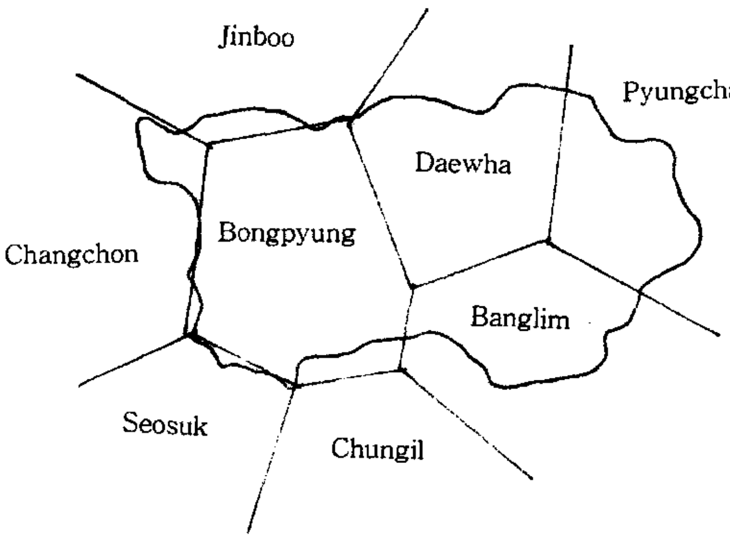

Fig. 3. Divided drainage area of Dodon site

Table 2. The characteristic of divided drainage area

rain gauging station	drainage area (A_i, ㎢)	weight (W_i, %)	scale parameter (β, m³/sec)	shape parameter (α)
Changchon	24.9	3.4	0.015410	0.631990
Jinboo	16.1	2.2	0.015264	0.643107
Bongpyung	255.1	34.8	0.016606	0.664584
Daewha	184.0	25.1	0.016610	0.690516
Banglim	133.4	18.2	0.017048	0.686524
Pyungchang	115.1	15.7	0.019082	0.770748
Seosuk	4.4	0.6	0.018882	0.734603
Total	733.0	100.0	-	-

production with variation of design flowrate. In order to analyze the performance charac teristics of sites, plant efficiency was assumed to 0.8 and effective head was applied

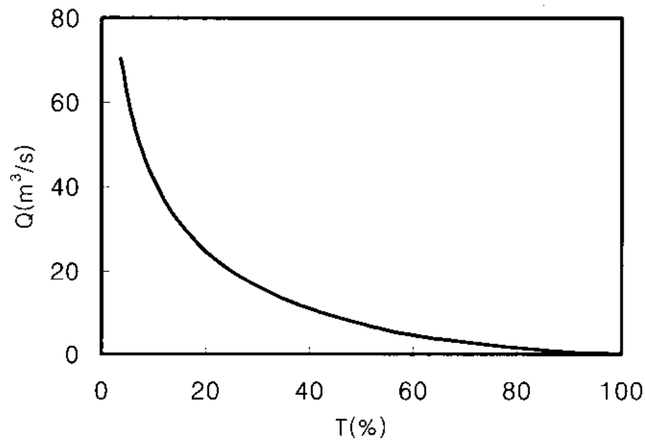

Fig. 4. Flow duration curve at Dodon site

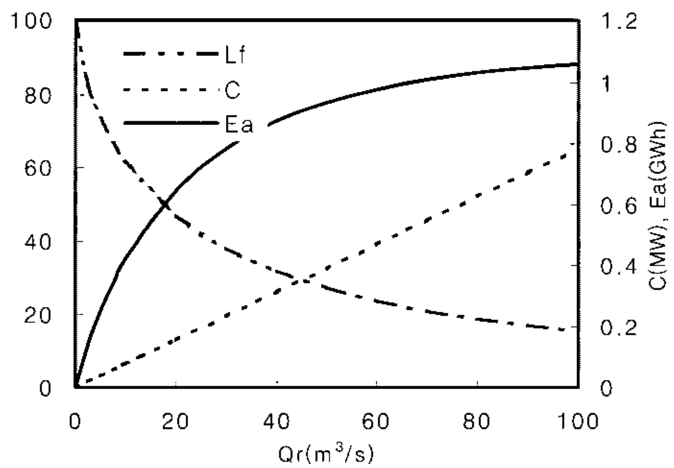

Fig. 5. Capacity operational rate and electricity production with flowrate

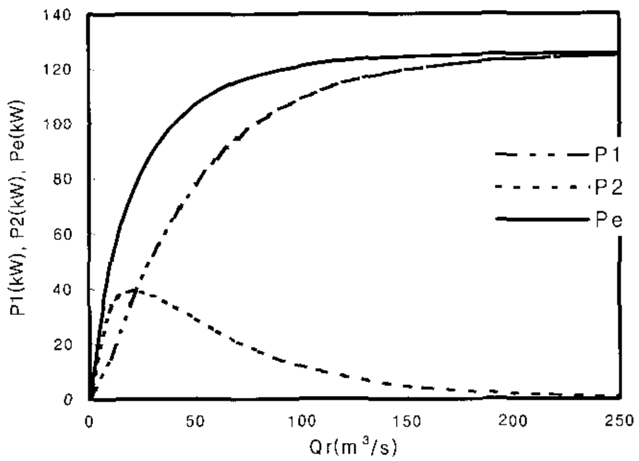

Fig. 6. Comparison of electricity production with variation of design flowrate

to 12.2m. Capacity of SHP plant vary linearly with the variation of design flowrate, but operational rate decrease with increase of design flowrate. Also, operational rate is decreased rapidly at the region of lower design flowrate and decrease gradually at higher region. Annual electricity production increase gradually in the higher region. This is due to decreasing of operational rate with increasing of design flowrate.

Fig. 6 shows comparison of electricity production with variation of design flowrate. As shown in Fig. 6, the electricity production of SHP plant consist of two parts, electricity which produce at rated power P_2 and at part load condition P_1. In order to design and operate SHP plant effectively, it is important that flowrate to maximize P_2 can be selected as design flowrate. For the case of Dodon SHP site, design flowrate and capacity per unit head are determined in 21.5m^3/s and 39.24kW respectively.

The system characteristics and design flowrate for twelve SHP sites are summarized in Table 3. The performance prediction model in this study is recommended for determining the optimum design flowrate of SHP sites.

5. CONCLUSIONS

The methodology of performance prediction model for SHP sites were studied and developed. The performance characteristics and prediction for twelve SHP sites in Korea were analyzed, using developed model. Additionally, the primary design specifications including capacity and design flowrate for each SHP plant were suggested. It was found that the methodology developed in this study was useful tool to analyze the performance of SHP sites.

NOMENCLATURES

A : drainage area (km^2)

C : capacity of SHP plant (kW)

D(Q) : function of flow duration characteristic

E_a : annual electricity production (MWh)

F(q), F(Q) : cumulative probability distribu-

Table 3. Summary of feasibility for SHP sites

Sites	Flowrate (Q_r, m³/sec)	Head (H_e, m)	Capacity (C, kW)	Operational rate(L_f, %)	Remarks
Daeki	6.0	29.2	1,370	43.1	Tunnet-type
Duckcon	38.5	17.8	5,370	51.2	Tunnet-type
Kujul	7.0	26.1	1,430	41.3	Tunnet-type
Dondon	21.5	12.2	2,056	45.4	Tunnet-type
Misan	10.0	17.1	1,340	43.5	Tunnet-type
Kikok	7.0	22.8	1,250	49.9	Tunnet-type
Hwoiryong	23.5	16.0	2,940	56.1	Tunnet-type
Daiya	4.5	25.5	900	48.0	Tunnet-type
Yangchon	28.5	9.2	2,050	54.9	Tunnet-type
Keowoon	85.5	10.7	7,170	37.0	Dam-type
Woonchon	94.0	3.2	2,350	58.7	Dam-type
Sasuk	53.5	5.0	2,090	51.9	Dam-type

tion function

g : gravitational acceleration (m/sec^2)

H : head (m)

H_e : effective head (m)

k : discharge coefficient (=0.7)

L_f : operational rate (%)

P_i : hydro energy (kWh)

P_e : electricity production per unit time (kWh)

P_1 : part electricity production(kW)

P_2 : rated electricity production(kW)

$P(q)$, $P(Q)$: probability density function

Q : flowrate (m^3/sec)

Q_a : annual average flowrate (m^3/sec)

Q_m : monthly average flowrate (m^3/sec)

Q_r : design flowrate (m^3/sec)

q : monthly average flowrate per unit drainage area (m^3/sec)

R : amount of rainfall (mm)

R_m : monthly amount of rainfall (mm)

R_t : annual amount of rainfall (mm)

T : time ratio (%)

W : weight of drainage area

α : shape parameter of Weibull distribution

bution

β : scale parameter of Weibull distribution (m^3/sec)

ρ : density of water (=1,000kg/m^3)

η : efficiency of SHP plant (=0.8)

SUBSCRIPT

i : i_{th} rain gauging station

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