Conference Paper, Published Version

Ayros, Edwin; Arch, Alexander; Bárdossy, Ándras; Heimerl, Stephan; Thapa, Pawan

Determination of Peak Energy Generation at Hydropower Stations by Means of Synthetic Daily Runoff Series

Dresdner Wasserbauliche Mitteilungen

Zur Verfügung gestellt in Kooperation mit/Provided in Cooperation with:
Technische Universität Dresden, Institut für Wasserbau und technische Hydromechanik

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/103702

Vorgeschlagene Zitierweise/Suggested citation:
Ayros, Edwin; Arch, Alexander; Bárdossy, Ándras; Heimerl, Stephan; Thapa, Pawan (2009): Determination of Peak Energy Generation at Hydropower Stations by Means of Synthetic Daily Runoff Series. In: Technische Universität Dresden, Institut für Wasserbau und technische Hydromechanik (Hg.): Wasserkraftnutzung im Zeichen des Klimawandels. Dresdner Wasserbauliche Mitteilungen 39. Dresden: Technische Universität Dresden, Institut für Wasserbau und technische Hydromechanik. S. 185-193.

Determination of Peak Energy Generation at Hydropower Stations by Means of Synthetic Daily Runoff Series

Edwin Ayros, Alexander Arch, Ándras Bárdossy
Stephan Heimerl and Pawan Thapa

A very simple disaggregation model is presented. A comparison of the peak energy production simulation for two scenarios considering historical and generated daily flows for the period of 1982-1991 furnishes very similar results. The differences lie in a range between 2.6 % and 5.8 %. The presented disaggregation model can be applied for a simple estimation or approximation of the energy production in hydro power plants.

Ermittlung der Spitzenenergieproduktion bei Wasserkraftanlagen durch Verwendung von synthetisch erzeugten Tagesabflusswerten

Ein einfaches Dissagreagationsmodell wird hier vorgestellt. Ein Vergleich der Simulation der Spitzenenergieproduktion basierend auf historischen und generierten Tagesabflüssen im Zeitraum von 1982-1991 ergibt einen Unterschied von 2,6% bzw. 5,8%. Das präsentierte Dissagregationsmodell kann für eine Berechung der Energieerzeugung in einer ersten Schritt mit genügender Genauigkeit angewendet werden.

1 Introduction

With the development of new hydropower projects in the European region, more attention is given to the production of peak energy. For designing a power plant operated with the daily storage, the hydrological data with at least daily resolution is required to be able to estimate the energy production. But usually, only the monthly data are available for such projects. However, it is possible to generate mean daily values from the available mean monthly values which can be used for the peak energy estimation.

This article deals with the synthetic generation of mean daily flows from the available mean monthly flows. The new approach and the involved parameters for the generation are discussed. The comparison of the generated daily flows with the observed daily flows validates the approach. Therefore, this disaggregation approach is useful for the planning of hydropower projects where the use of available mean monthly flows would have estimate a different and less reliable annual energy production. The approach is applied, using an example from a hydropower plant and the subsequent results are presented.

2 Problem of the available runoff records

Usually, only the monthly runoff data are available for the water resources studies in many regions of the world. The daily outflow data are, in most cases, either not measured or are not available. The same is true for other climatological data. One of the reasons for this is the political instability of a country because of civil war e.g. in Rwanda, Congo, Burundi, Afghanistan, Sudan, or because of terrorism as in the Andes in Peru, etc.

After regaining stability in a country, reconstruction starts. At this time water resources studies for the establishment of new hydroelectric power plants (HEPP) or for the rehabilitation of existing hydropower plants are also started.

For the calculation of the peak energy production of a hydropower plant, daily runoff values are needed, which are mostly not available. However, by employing a simple disaggregation approach, it is possible to generate mean daily flows from available mean monthly flows that enable the estimation of peak energy production.

2.1 The Disaggregation Model

The Disaggregation model is a simple stochastic model which satisfies the following two hydrological conditions. It is assumed that daily flow to be generated follow the Gamma distribution (Ayros, 1996). The two parameters gamma distribution are described by the following equation (Plate, 1993):

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \cdot x^{(\alpha-1)} \cdot e^{-x/\beta}, \quad \alpha, \beta, x > 0 \qquad (1)$$

where, α and β are the form parameter and the scale parameter respectively, characterized with the probability distribution:

$$F(x) = \int_0^x f(y) \cdot d(y) \qquad (2)$$

A random number series $x_i,\ i=1,2,...,n$ with length n, is generated which follow a uniform distribution. n is the number of days in a month. The discharges $Q_i(x_i)$ will be calculated with the inverse probability function:

$$Q_i(x_i) = F^{-1}(x_i), \qquad (i=1,2,...,n) \tag{3}$$

The parameter of the Gamma distribution α and β can be determined through the optimization of the follow objective function:

$$\Phi_{\min} = \left(E(Q) - MQ_H\right)^2 + \left(MaxQ - k \cdot MQ_H\right)^2 \tag{4}$$

where $E(Q)$ is the expected value of the generated discharges data $Q_i(x_i)$ and $MaxQ$ is the maximal daily discharge in the month. The optimization should satisfy the following conditions:

a) The mean calculated from the generated daily discharges $Q_i(x_i)$ should be same as the observed mean monthly discharge MQ_H:

$$E(Q) = MQ_H \tag{5}$$

b) The ratio of generated maximum daily flow $E(Q\max)$ to observed mean monthly flow should be a constant k:

$$E(Q\max) = k \cdot MQ_H \tag{6}$$

3 Hydropower System

The system, where this approach was recently applied, is located in the south-eastern part of Europe. The project includes approx. 200 km² watershed and is located just in the upstream of the confluence of two rivers. This watershed is forested with a mountainous terrain. The average elevation above the sea level is about 1,540 m. The main characteristic of the streams in the catchments area is that streams have relatively deep incised river beds, with significant longitudinal inclination and steep slopes.

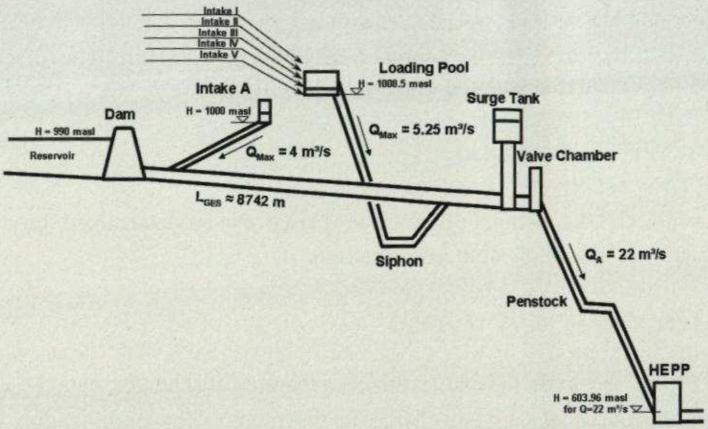

Figure 1: Hydraulic System of the HEPP

The proposed project concept includes impounding flow from two streams within the watershed by construction of the Dam. Water from the reservoir is directed to the headrace tunnel (approximately 9 km long) that discharges the flow through a penstock into the powerhouse. In addition to the flow from the dam, there are several other intakes, channels, and inverted siphons that are proposed to gather runoff for power generation (see Figure 1).

In Table 1 the gauge station and the tributary area for the intakes as well as the dam of the project are listed. The mean annual flow in Main River is 5.61 m³/s. The flows for the intake were estimated using regional relation of the catchment areas.

Table 1: Mean Annual Flows and Catchment Areas

Station	Watershed/Intake	Area	Flow
[-]	[-]	[km²]	[m³/s]
A	Main River/gauge station	200	5.61
B	Dam	80	1.78
C	Intake I	27	0.962
D	Intake II	28	0.404
E	Intake III	12	0.124
F	Intake IV	7	0.211
G	Intake V	6	0.418
H	Intake VI	7	1.713

4 Energy Production simulation

The generated daily flows, which were generated using the disaggregation model, were applied with the aim to estimate the peak energy of the hydropower plant for a long period. For this the ratio value of k=2.5 (ratio of maximum daily flow to observed mean monthly flow) was selected based on practical experiences. The value of the selected ratio 2.5 is inside the confidence interval between 1.2 and 2.6. This confidence interval was estimated using daily records which could be obtained for short the period from 1982 to 1991, after the disaggregation model was developed. The selected value 2.5 represents in this case a conservative value. Using this model, daily flows for the entire period 1946 to 2001 were generated. The optimization was realized using the Conjugate Gradient Method (Press, 1992).

For lower discharges no limiting factor was chosen in the disaggregation model. Therefore lower flows in the range between 0 and 1.5 m³/s were generated based on the monthly flow values compared to the daily flow values (**Figure 2**). Nevertheless it can be stated, that this simple disaggregation model furnishes reasonable flow values within an acceptable accuracy.

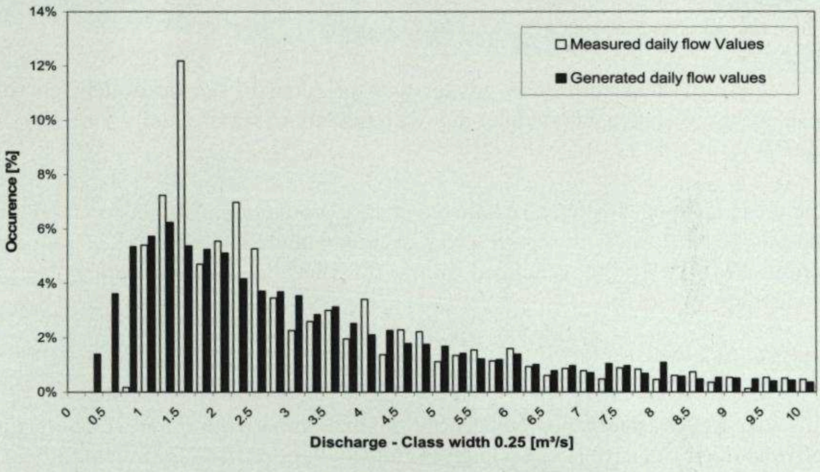

Figure 2: Comparison measured and generated daily flow values

The HEPP is designed to cover a period of daily peak consumption in the electric-power system. The energy simulation was performed and represented on the daily inflow basis. In the first step of the energy production the hourly energy demand was not known. Moreover the operation of the HEPP regarding daily production and regional conditions was not defined. Therefore, as a first attempt, two scenarios were developed in order to assess the peaking energy production.

4.1.1 Scenario 1

In general, in this scenario the system was treated as a run-off-river plant. The operating rules of this scenario contain three cases for estimating the amount of peak energy. To generate peak energy for a period of 5 hours at maximum release, which represents the maximum capacity of the turbine(s), a daily flow of at least 4.583 m^3/s (Q_{lim}) to the system is required. Under these conditions three cases can be defined as follows:

- Case 1: If the inflow is less than Q_{lim}, peak energy will be estimated for 5 hours by using a release R, which differs from the maximum discharge (Q_{design}). If this release R is smaller than the minimum release required for turbine operation (50 % of $Q_{Tdesign}$), this release R is set equal to the minimum release and the time period will be calculated accordingly.

- Case 2: In this case, at least 5 hours of peak energy is generated per day, while the inflows vary between Q_{lim} and Q_{design}.

- Case 3: If the inflow is greater than or equal to the maximum release, peak energy will be generated per day with maximum release and a period of 24 hours.

The mean difference between estimated energy production using historical flows and generated flows with regard to the average annual energy is 5.82 % for the period 1982-1991, the generated flows furnishes in average higher energy production (Figure 3).

4.1.2 Scenario 2

This scenario considers the peak energy production between 5 and 10 hours, the active storage capacity is considered in the simulation. If, at minimum, 5 hours of peak energy can not be generated per day, then the inflow has to be stored/used for filling of the reservoir for the next day. If the power generation is possible for more then 10 hours per day, then the power generation is limited to 10 hours, and the rest of the inflow is used for filling up of the reservoir, or released over the spillway. In this scenario the annual average difference of the energy production based on measured and generated daily flows is approx. 2.6 % for the period from 1982 to 1991. Hence the energy production will be slightly overestimated by using the generated flows (Figure 4).

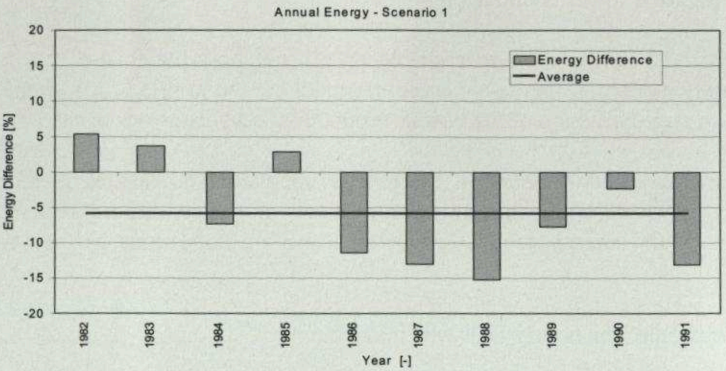

Figure 3: Annual energy production – Scenario 1

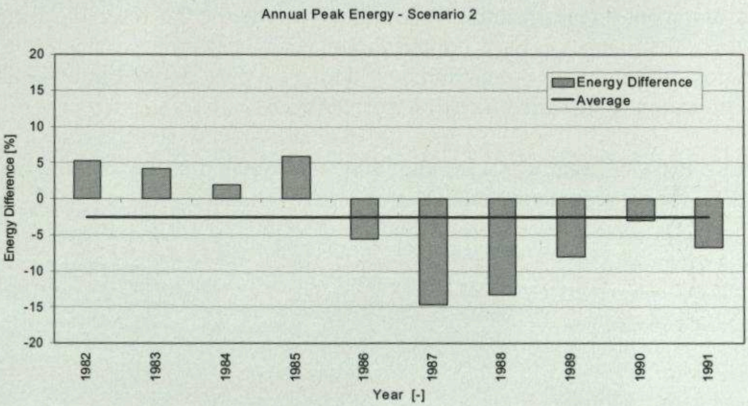

Figure 4: Annual energy production – Scenario 2

5 Conclusion

A very simple disaggregation model is presented here. A comparison of energy production simulation considering historical and generated daily flows for the period of 1982-1991 furnishes very similar results for both scenarios ; the differences lie in a range between 2.6 % and 5.8 %. We can conclude that the results applying generated daily flows reflects the hydrological processes in a realistic way and therefore can be considered as representative. In further steps the influence of constant *k* should be discussed in more detail also with respect to a definition for a lower boundary.

If either daily discharge is not available or it's not possible to use a daily rainfall-runoff modeling, the disaggregation model can be applied for a simple estimation or approximation of the energy production in hydropower plants.

Two scenarios were considered in the energy analysis. The applied method furnishes realistic and applicable flow values. For a more accurate and realistic calculations of the energy production, following main conditions have to be considered:

- Estimation of the hourly energy demand curve

- Estimation of energy production considering on-peak and off-peak energy according to the hourly energy demand curve,

- Development of an operating rule policy (curve) for the reservoir using optimization approaches. Here optimization can be, for example: a) maximization of the energy production considering on-peak as well as off-peak or b) maximization of the firm energy (Ayros, 2008a,b).

The authors express grateful to Dr.-Ing. Jörg Grossman for the constructive comments on the disaggregation model.

References

Ayros, E.: Stochastic modeling of mean annual floods for several gauging stations in Peru, Institut für Wasserwirtschaft, Hydrologie und landwirtschaftlichen Wasserbau der Universität Hannover. Technischer Bericht, Juni, 1996.

Ayros, E., Bárdossy, A., Hildebrandt H., Peissner: Optimization of the Energy Production for the Baghdara Hydropower in Afganistan using Simulated Annealing, WasserWirtschaft 7-8, S. 35-39, 2008a.

Ayros, E., Bárdossy, A., Peissner K., Heimer S.: Simulated annealing, un algorithmo inteligente aplicado a la optimización de la produción de energía de centrales hidroelectricas con embalses (in Spanish). XXIII Congreso Latino Americano de Hidraúlica, IAHR, Cartegana de Indias Colombia, Sept. 2008b.

Plate, E.: Statistik und angewandte Wahrscheinlichkeitslehre für Bauingenieure, Ernst&Sohn, Berlin 1993.

Press, H., Vetterling, W., Teukolsky S., Flannery, B.: Numerical Recipes in Fortran 77. The Art of Scientific Computing, Cambridge University, 1992.

Autoren:

Dr.-Ing Edwin Ayros
Dr.-Ing. Alexander Arch
Dr.-Ing. Stephan Heimerl
Fichtner GmbH & Co. KG
Hydropower Department
Sarweystrasse 3
70013 Stuttgart – Germany
Phone: ++49 711 8995 468
Fax: ++49 711 8995 459
Email: Edwin.Ayros@fichtner.de

Prof. Dr. rer. nat. Dr.-Ing. habil. Ándras Bárdossy
M.Sc. Eng. Pawan Kumar Thapa
Institute of Hydraulic Engineering
University of Stuttgart
Pfaffenwaldring 61
70569 Stuttgart - Germany
Phone: ++49 711 6856 4663
Fax: ++49 711 6856 4681
Email: Andras.Bardossy@iws.uni-stuttgart.de