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HYDROPOWER ENERGY SIMULATION USING MIKE 11 MODEL: A CASE STUDY IN SOUTH GERMANY’S SMALL RUN-OF-RIVER HYDROPOWER PLANT

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The essence of this paper is to justify the correspondence between the simulated discharge and the energy production of a hydropower plant and to prepare a hydropower energy production forecast. To obtain a forecast model, a calibrated coupled hydrodynamic and hydrological model and a calibrated discharge to energy model are needed.

INTRODUCTION

Renewable energy production is a basic supplement to stabilize rapidly increasing global energy demand and price, to balance the fluctuation of supply from non-renewable energy sources in the electrical grids and to reduce carbon emission. Information of both stream flow and power production of hydropower stations ahead of time is the main motivation for energy producers. The European energy traders, government and private company energy providers and other stakeholders have been a major beneficiary, customer and clients of Hydropower simulation solutions DHI et al. [1], DHI Group [2].

The relationship between rainfall-runoff model outputs and energy productions of hydropower plants has not been clearly studied. Until recently, stream flow forecasts have been used to optimize the efficient use of water and energy supply for hydropower stations and reservoirs using different techniques Lima et al. [3], Coulibaly et al. [4].

In this paper, an association of rainfall, catchment characteristics, river network, and runoff and energy production of two particular hydropower stations is examined. The primary objective of the study is to develop an energy model which is capable of simulating energy production for selected hydropower stations located in Southern Germany. Specific objectives of this study are:

1. To design and setup a coupled hydrological (rainfall-runoff) and hydrodynamic model using MIKE 11.
2. To calibrate catchment parameters of the coupled rainfall-runoff and hydrodynamic model using observed discharges.
3. To collect and import the available hydropower plant data and information.
4. To employ a unique technique to convert runoff to energy based on statistical and graphical trend analysis.
5. To calibrate power output with observed power production.
STUDY AREA AND DATA INPUTS

Figure 1 Study area

The study area is located in Southern Germany and Austria specifically in the Upper Danube River Basin. The catchment has 35,526 km² area subdivided in to 27 sub catchments ranging from 20 to 7000 km² (Figure 1). The average catchment slope varies from 5° in lowlands to 40° in highlands and the elevation extends from 240 masl in the border of Germany and Austria to 3800 masl in the alpine areas of Austria and Switzerland. The area comprises of 5 main river sections; namely Alz, Inn, Donau, Saalach and Salzach Rivers. The total length of the rivers is about 1050 km.

The average annual precipitation depth in the area is recorded as 411.5 mm in summer and 385.4 mm in winter Sui et al. [6]. For the current study, hourly precipitation and temperature data are gathered from 222 meteorological observation stations spatially distributed in the model area. The Thiessen polygon method was adopted to obtain a weighted rainfall and temperature data for each sub-catchment. Mean monthly evapotranspiration data have been extracted from the Hydrological Atlas of Germany HAD [7].

RAINFALL-RUNOFF MODEL CALIBRATION

For rainfall-runoff model calibration, observed discharge data from gauging stations is necessary. In Danube catchment of Upper Austria and southern Germany, 12 gauging stations are available that are spatially distributed in 5 river branches (Alz, Inn, Donau, Saalach and Salzach) as shown in Figure 1 and Table 1. Simulated discharge from the MIKE 11 hydrodynamic model (HD) will be extracted to compare with the observed discharge.

**Calibration technique**

The NAM model has major parameters which need to be calibrated to qualitatively describe the catchment. A coefficient of determination (R²) or Nash-Sutcliffe coefficient, as given in Eq. (1), is used to test the goodness-of-fit of the simulated hydrograph. Eleven major
surface and groundwater catchments parameters are manually calibrated for each sub-catchments in the study area.

\[
R^2 = 1 - \frac{\sum_{i=1}^{n}[Q_{\text{obs},i} - Q_{\text{sim}}]^2}{\sum_{i=1}^{n}[Q_{\text{obs},i} - \overline{Q}_{\text{sim}}]^2}
\]

(1)

Where: \(Q_{\text{obs},i}\) is observed discharge at time \(i\); \(Q_{\text{sim},i}\) is simulated discharge at time \(i\); \(\overline{Q}_{\text{sim}}\) is mean simulated discharge at time.

**Calibration results**

As shown in Figure 2, a calibration plot at the catchment outlet indicates that there is a good correlation and goodness-of-fit between simulated and observed discharge. A coefficient of determination \((R^2)\) of 0.91 has been calculated. Gaps in meteorological and gauge data in some months in 2008 can be seen in the figure which doesn’t affect the calibration process.

**ENERGY MODEL SETUP AND CALIBRATION**

**Concept**

The overall concept of energy model is illustrated in Figure 3.
The catchment and river network are calibrated using a coupled MIKE 11 hydrologic (NAM) and hydrodynamic (HD) model. The next step is to prepare the structure of the energy model. Inputs are simulated discharge from MIKE 11 at a hydropower station, the hydropower energy generation time series data and hydropower property. In this paper, a case study is analyzed at Oberwoessen hydropower plant located in Alz sub-catchment along Woessener Bach River. The station is a small run-of-river plant with installed capacity of 120 KW.

Simulated discharge at the hydropower location is extracted from MIKE 11 to compare it with energy production. MIKE 11 model has a Structural Operating (SO) module used for control structures analysis. This module is required to examine and adopt the statistical relation between discharge and energy time series data. Using this module, a control strategy will be introduced at the hydropower station to define different policies with set of priorities. These definitions are executed by linking with logical operands.

**Case Study: Oberwoessen Hydropower station**

**Model Setup**

Oberwoessen hydropower station is located in Wossener Bach river tributary of the Alz River and in Alz sub-catchment (Figure 4). The first step is to setup an independent river-section that extracts water from the Alz sub-catchment. Hence, Wossener Bach River of 2km length (Chainage 2843 to 4843) and its corresponding sub-catchment are extracted and linked with the cross-section, boundary condition and hydrodynamic parameter editor.

Figure 4 Oberwessen hydropower station location.
Control definition and simulation

As shown in Figure 5, Alz subcatchment where Oberwoessen hydropower located is digitized independently to setup a control point as discharge and target point as energy. Measured time series energy production data is collected from Oberwoessen plant for a period between 04.04.2011 - 31.01.2012 with 15 minute time step. Discharge collected from upstream catchment is plotted together with the energy time-series data in Figure 6.

In addition to the above comparison, a scatter plot of simulated runoff against energy measurement is shown in Figure 7 to study the behavioral relationship.
The statistical correlation between runoff and energy is best fitted by two linear equations. Hence, energy as function of discharge can be represented by these two equations and set of points, as presented in Table 1.

<table>
<thead>
<tr>
<th>Runoff (m³/s) as x</th>
<th>Energy (kwh) as y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>5</td>
</tr>
<tr>
<td>0.9</td>
<td>32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Runoff (m³/s) as x</th>
<th>Energy (kwh) as y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>32</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
</tr>
</tbody>
</table>

To implement the above relationship as a Control Strategy in MIKE 11 SO module model, a control structure is inserted in 'Alz turbine' river section at chainage 500. The Control Structure has two variables (dependent and independent) at control and target point respectively. A control point is a point where the runoff from Alz subcatchment is collected and linked to Wossene Bach river network chainage 2843. A target point is the point in the supplementary dummy network (Alz turbine) at chainage 500. The target point will be treated as the turbine of the hydropower station and its output will be defined as energy. Then, the statistical relationship between runoff and energy is configured as the following two control definitions that are connected by a logical operand. If the logical operand of the control definition with priority 1 is TRUE, the control strategy will be executed. And if the logical operand is FALSE, the control strategy with next priority level (Control Strategy 2) will be executed. i.e.

IF runoff at Branch:WosseneBach, Chainage:2843 < 0.9 m³/s ⇒ Execute Control Strategy 1
IF runoff at Branch:WosseneBach, Chainage:2843 ≥ 0.9 m³/s ⇒ Execute Control Strategy 2

Where: Control Strategy 1 is defined by the first linear equation and Control Strategy 2 is the second linear equation in Table 1.

A screen shot of MIKE 11 model is provided in Figure 8. In MIKE 11 Structural Operation (SO) module, the control and target points for this particular case were edited in figure.

Figure 8 MIKE 11 screen shot
**Calibration result**

After executing the model as per the above control definitions, a calibration is required to check the target point value (i.e., the simulated energy). MIKE 11 software has been applied to setup a coupled hydrological and hydrodynamic model. The discharge from the coupled model has been calibrated in the previous steps. The simulated discharge is then compared with the energy generation data at Oberwoessen hydropower station. The statistical and graphical analysis between discharge and energy has been inserted in the energy model and simulation has been performed. The setup is simulated for a time period between April 01, 2011 and January 31, 2012 with a time step of 15. Simulated energy from Alz turbine branch, chainage 500 is compared with measured energy data. The result is plotted in Figure 9.

![Energy calibration plot for Oberwoessen power plant](image)

Figure 9 Energy calibration plot for Oberwoessen power plant (light blue: Measured energy, black: Simulated energy)

The above graph indicated that simulated energy is relatively consistent with measured energy data. A coefficient of determination (R²) of 0.85 shows that simulated energy fits well with observation data. In spite of the noisiness and hourly fluctuation of observed energy graph, the model simulation represents the energy production of Oberwoessen hydropower plant. Overall, the dynamics of simulated and measured energy generation has been maintained. The model can be useful to provide smooth energy data such as daily and weekly time steps with only runoff time series information.

**CONCLUSION**

Once a well-calibrated catchment runoff at a particular hydropower station is attained, this study observes that it is plausible to create a typical and unique correspondence between discharge and energy production.

At Oberwoessen run-of-river hydropower station, two successive calibrations are conceded to test the model; one for rainfall-runoff model and other for energy simulation. A unique control policy between simulated runoff and energy production has been established based on statistical and historical relation. Using logical operands set of different definition and priorities are linked. Once this typical relation have been determined and set in the model, the result of the simulation has been tested and results from coefficient of
determination and goodness-of-fit of the calibration plots have shown that the model produces qualitative and outstanding simulation.

The main significance of this case study is to set up an energy model that converts discharge into energy without the knowledge of formal parameters such as water head, hydropower specification and machine efficiency of plants. Using forecast data of rainfall and evapotranspiration, runoff will be forecasted which in turn adopts the model for day-ahead and weekly energy forecasting solutions. The energy forecasting method were applied using different techniques such as data assimilation, batch programing and MIKE CUSTOMIZED model Schulz et al. [8]. DHI-WASY [9], Frezer A. [10].

REFERENCES