Journal of Engineering Science and Technology Review
Special Issue on Telecommunications, Informatics, Energy and Management 2019

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Conference Article

HEC-ResSim Optimization Model on Vidraru Hydropower Development

Eliza-Isabela Tică[1], Khalid Ahmad-Rashid[2], Octavian-Vlad Sima[1], Denisa-Mihaela Pisău[1],Andreea-Roxana Coman[1] and Bogdan Popa[1,*]

[1]*University Politehnica of Bucharest, Romania*
[2]*University of Sulaimani, Kurdistan, Iraq*

Received 28 September 2019; Accepted 25 February 2020

Abstract

In this paper, the applicability of the HEC ResSim program is tested on a simple optimization problem for the Vidraru hydropower development case study. The simulation model focused to achieving an established power generation plan over a year, realizing every month a fraction from the annual average energy. The obtained results are compared with some existing ones [1], demonstrating that the program is very appropriate to solve this kind of optimization problems.

Keywords: Optimization; Energy production; Hydropower; Reservoir operation; HEC-ResSim; Vidraru reservoir.

1. Introduction

The Hydropower Development (HPD) operation can be regarded as an optimization problem for which the obtained result provides an advantageous schedule of production at hourly, daily, or monthly level, depending on the state of the development, the available units, and the specific requirements of the national dispatcher or other beneficiaries.

The developments dispatchers must simultaneously meet the requirements for more needs such as: energy production, water supply to the population, flood control, environmental quality downstream of the reservoir, safety, and structural integrity of the dam. Each of these requirements imposes restrictions on the storage and release of water in the reservoir storage, which requires increased attention. For this reason, there has been a need to create simulation programs on how to operate HPDs, like is HEC-ResSim [2]. With this software, it can be done a prediction of the behavior of reservoir systems in water management studies and planning the releases in real time.

In [3], Wondye applied HEC-ResSim for Blue Nile catchment area from Ethiopia, to simulate the water distribution for irrigation and energy production. With the aim of identifying the optimal operating policy for electricity generation and for meeting the requirements downstream of the dam, Mariam in [4] has built a simulation model for the Ethiopian Tekeze River.

A HEC-ResSim simulation model using operation restrictions rules was made by Fagot et.al. in [5], for West Point development, Georgia. Olsen and Gilroy present in [6] a model to develop a risk assessment of the performance of water resource management under the threat of future climate change.

A HEC-ResSim presentation is made on paper [7], where this software is considered a unique among reservoir simulation models because it can reproduce the decision-making process that human reservoir operators must use to set releases.

Also, in other papers like [8] and [9] HEC-ResSim simulations based on reservoir operation are presented.

2. Case study: Vidraru hydropower development

This paper illustrates the process of solving a hydropower operation optimization problem using HEC-ResSim 3.1 that is tested to solve a deterministic optimization problem, a simple problem that was solved with evolutionary algorithms presented in papers [1], [10], [11], for which the exact solution is known.

As the case study was chosen the Vidraru hydropower development, which was, also, a case study for McKinny in [12], where used HEC ResSim 2.0 to simulate reservoirs system from Arges river basin. The aim of this was to perform the system function operation and selects the best alternatives for floods control to increase the energy production.

In figure 1 is presented the analyzed hydropower development, located on Arges River catchment area.

Vidraru reservoir (commissioned in December 1966) is located between the Fruntea and Ghitu mountains. It is the most important on the river basin of Arges River, being the second reservoir as volume in Romania (after the Izvorul Muntelui-Bicaz reservoir). The reservoir capacity is 465 Mm^3 and has the possibility of annual regulation of the inflows. It is intended for the energy production and water supply of the Pitesti and Bucharest towns, but, also contributes to the mitigation of flood, irrigation of agricultural land, and through the peak Hydropower Plant (HPP) Vidraru, performs voltage regulation in the national

* E-mail address: bogdan.popa@upb.ro
ISSN: 1791-2377

power grid through the operation of the hydroelectric units in the synchronous compensating regime and the provision of the technological services of the system.

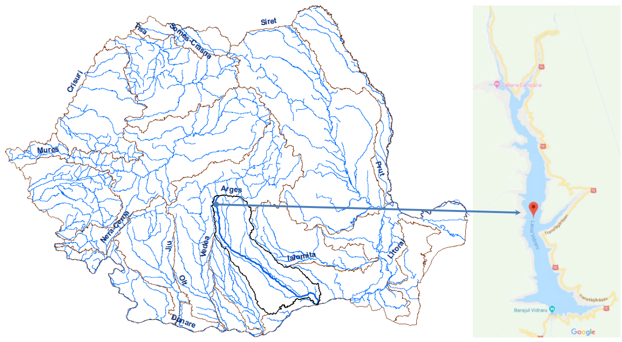

Fig 1. Arges river basin: the location of Vidraru reservoir.

Vidraru is an underground HPP located at 100 m below Arges riverbed, equipped with four vertical Francis turbines, which is mainly used at the peak of the load, and the main production is oriented to the winter season. The main HPP parameters are: 220 MW installed capacity, 90 m^3/s installed flow, 324 m gross head and the annual average energy production is of 400 GWh.

3. Formulation of simulation model

In order to achieve the long-term HPD Vidraru simulation model using the HEC ResSim software, a deterministic model for long-term optimization operation of a multi-purpose facility, described in [13], was considered. In order to simplify the mathematical model, this paper did not consider the water supply for the downstream users to compare the results with those presented in the paper [11].

In order to formulate the simulation model of the operation under deterministic conditions, it was admitted that the input data were known, namely: the monthly mean flows and the monthly energy demand, and for complying the restrictions applied to the operation of the assembly, such as flood control, the maximum and minimum monthly allowable reservoirs volumes, head at the Normal Retention Level (NRL), the characteristic reservoir curves, and the flow and power installed data are also included as inputs.

Taking into account that the Vidraru reservoir is located upstream of a heavily populated area, with significant water consumption for both the industry and water supply of the population, given the fact that it is a top-of-the-range hydropower plant, the aim of optimization is to find "an operation rule during the year that minimizes the amount of energy shortages per month in relation to planned production".

To define the problem in deterministic terms were established:

- the stage variable, representing the monthly range k, $k = 1, 2, \ldots, 12$ during a year;
- the stage variable represented by the storage volume at the beginning of the month, V_k^i;
- the decision variable representing the volume in reservoir at the end of the month, V_k^f.

In order to respect the relation of system state transformation, the volume at the end of the month k, will become the initial volume for the month k+1, thus also having to fulfill the equation of balance:

$$V_k^f = V_k^i + a_k - d_k , \tag{1}$$

where a_k is the inflow stock, and d_k is the released stock for the k step.

Restrictions (2) and (3) on the volumes in the reservoir appear in system operation:

$$V_k^{\min} \le V_k^f \le V_k^{\max},\ k = 2,3,\ldots 12 , \tag{2}$$

$$V_{12}^{\min} \le V_1^i \le V_{12}^{\max} , \tag{3}$$

where maximum and minimum allowable volumes (taking into account the necessary volumes for flood control), were marked with $V_k^{\max}$ and $V_k^{\min}$, at the end of k step.

Knowing that the reservoir has a much bigger volume of 400 Mm^3, at NRL, for the development operation the allowed levels were considered as: Maximum Level (ML) and Minimum Operation Level (MOL), presented on storage capacity for Vidraru reservoir (figure 2), where Z is the water level, in meters above the Black Sea level (MASL).

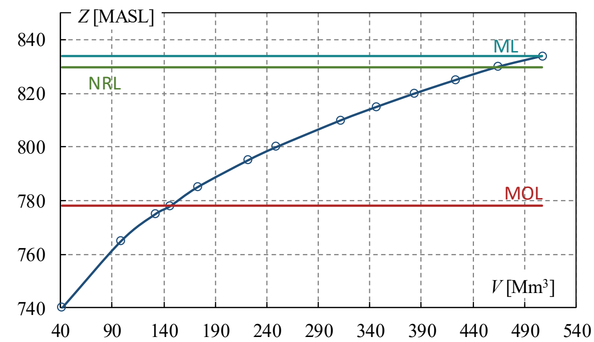

Fig 2. The capacity curve of Vidraru reservoir.

For runs it was considered the annual average energy production, EP = 400 GWh/a, which must be realized with monthly fractions α_k, presented in table 1.

Table 1. Monthly fractions and monthly energy production

Month	**1**	**2**	**3**	**4**	**5**	**6**
α_k [-]	0.1	0.09	0.085	0.08	0.07	0.07
E_k^p [-]	40	36	34	32	28	28
Month	**7**	**8**	**9**	**10**	**11**	**12**
α_k [-]	0.07	0.07	0.075	0.09	0.1	0.1
E_k^p [-]	28	28	30	36	40	40

The monthly energy productions are determined with the formula:

$$E_k^p = \text{EP} \cdot \alpha_k \ \text{[GWh]}. \tag{4}$$

Using the data presented above, a simple model was developed to simulate HPD Vidraru operation, a model that consists of long-term regulation of accumulated inflow stocks to achieve the required monthly energy demands over a year, depending on storage reservoir capacity and the rules imposed for the operation hydropower development.

For the studied problem, the starting value of initial storage capacity is set up at $V_0 = 300$ Mm^3 and the monthly mean inflows (Q [m^3/s]) are shown in figure 3.

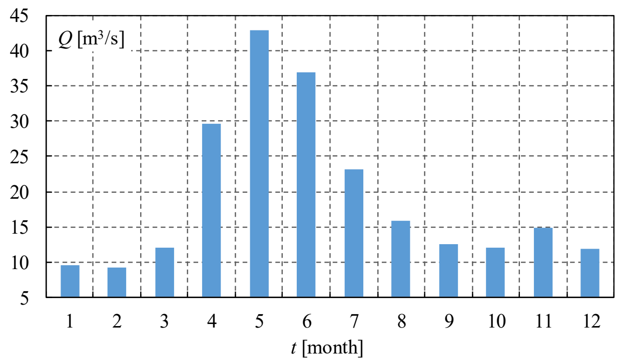

Fig 3. The monthly mean inflows.

4. HEC-ResSim simulation

Using the data presented above, a model was developed which consists of the long-term regularization of accumulated inflow stocks, Q, in order to obtain the energies required for each month in a year, E_k^p, depending on the storage capacity of the reservoir and the rules required for the operation of the hydropower development.

To do this, the three separate modules in the HEC-ResSim, namely: "Watershed Setup", "Reservoir" and "Simulation" were configurated.

In figure 4 it can be observed the configuration of the analyzed development.

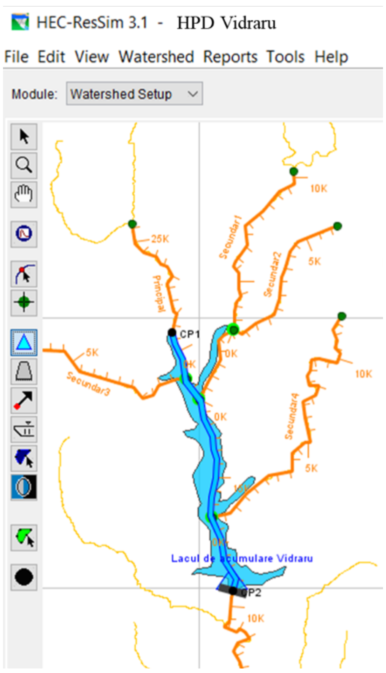

Fig 4. The HPD Vidraru watershed.

Once the configuration of the analyzed area has been created, the time step for calculations is selected (in this case, the chosen time step is one day, because the program does not allow a one-day step).

In „Reservoir Network" the physical and operational elements of the reservoir were described, and the operating simulation alternative was created using, as a template, the configurations applied in the first module.

After all the physical components required for a simulation have been introduced, a set of operations that characterizes the operation of the arrangement is created, and is represented by three basic characteristics: areas, rules and identification of the guiding curve.

In order to achieve the energy task, knowing the planned annual energy output and monthly fractions of its achievement (table 1), an operating rule was entered the program by inserting a guiding curve into the selected area (Flood Control) which will condition turbine flows. In the publisher of this rule, the monthly production of planned energy was introduced.

The basis of a simulation is to set up an alternative by which a description of the state of construction is made practically before the start of the simulation. At this stage, the initial volume was set at the beginning of the year, $V_0 = 300 \text{ Mm}^3$ and a value for the Lookback Release, where the installed flow of the plant was introduced, $Q_i = 90 \text{ m}^3/\text{s}$.

5. Results

Charts and tables in the simulation module provide detailed views of model data and results. The following graphical representations were obtained:

- figure 5 shows the monthly multiannual average inflows (blue) and the release flows (green). The simulation model calculates the flows so that it complies with the rule previously introduced for power generation;

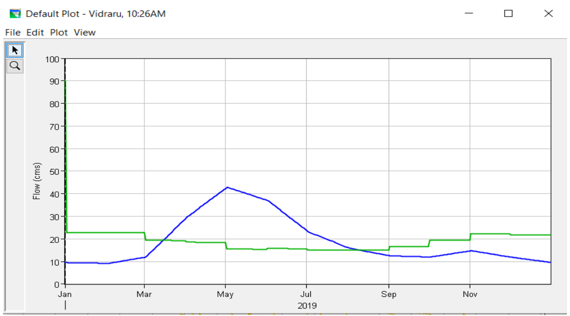

Fig 5. Monthly average inflows (blue) and the release flows (green).

- figure 6 shows the obtained power with software HEC ResSim. It is noted that the program respects the imposed monthly energy. On the same graph was also the electricity generation capability to see how the arrangement was operating in case there is no operating rule;

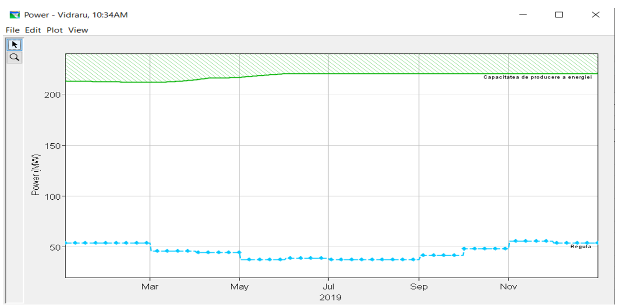

Fig 6. Monthly power variation.

To observe if the results obtained with HEC-ResSim are close to those obtained with the Honey Bees Mating Algorithm and the "correct" variant obtained with Newton method, presented in [10], graphically represented the variation in the end-of-month volumes stored in the reservoir for one year, along with the lower and upper limits imposed on the monthly final volumes stored in the reservoir for

$V_0 = 300\,\text{Mm}^3$. In figure 7 it shown the obtained energy compared with the imposed energy.

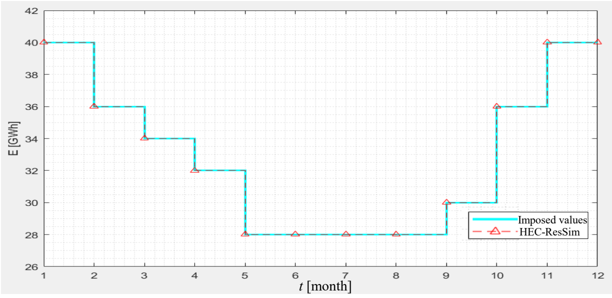

Fig 7. Time variation of monthly energy yields.

As it can be seen in the figure 8, the variation curve obtained with HEC-ResSim is higher than the solution obtained by the Honey Bees Mating Algorithm, but it is within the required limits.

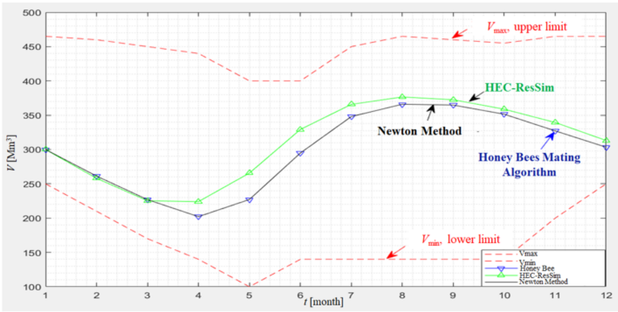

Fig 8. Time variation of monthly final volumes in reservoir.

6. Conclusions

The program is unique in simulating facilities as it attempts to replicate the decision-making process that designers should do. The program represents the physical behavior of planning systems with a combination of hydraulic calculations for flow through control and hydrological structures to represent the delay and flow attenuation through river segments.

Through the HEC ResSim program, it was succeeded in making a simulation model for a simple optimization problem for Vidraru hydropower development operation, and the results obtained were compared to those in the paper [14].

There was a difference in time variation of the monthly final water volumes in the reservoir, calculated using the HEC ResSim program and those calculated with the reference solutions, such as the Honey Bees Mating Algorithm and the Newton method [10].

The curve variation of the monthly final volumes in the reservoir obtained from the simulation is higher than the reference solutions.

This difference is generated by the time step for simulation because the HEC ResSim program allows a maximum of one day as a simulation step. Thus, the program accurately calculates the daily inflows entering the reservoir compared with the rest of the methods used up to now. This is an advantage because the result is as close as possible to actual operation.

After comparing the results from the simulation program HEC ResSim to the required values, it was found that the program strictly complies with the required monthly energy demand.

Another positive aspect identified in this simulation is the achieved value of annual energy production because, compared to other calculation methods used in the optimization field, this method obtained the lowest relative error relative to the required value.

Therefore, it is said that the program optimizes the arrangement to produce the required energy demand using a minimum volume of water.

Comparing the current simulation model results with the results of previous studies considered for the same fitment showed that the results obtained with HEC ResSim are the closest to the actual operation of the fitting.

This is due to the program that is specifically designed to simulate hydropower developments operation, besides considering several variables that were not taken in the previous studies, which led to a model capable of simulating the actual functioning of the arrangement.

Concluding, the efficiency of using the HEC ResSim program is driven by the generation of results as close to reality as contributing to the proper functioning of a hydropower development in order to achieve the proposed energy demand.

References

1. Eliza-Isabela Tică, Angela Neagoe, Sanda-Carmen Georgescu, and Silvia Năstase "HBMOA Computational Efficiency Assessed for a Hydropower Optimization Problem", International Conference on ENERGY and ENVIRONMENT (CIEM), 2017, pp 255-259.
2. U.S. Army Corps of Engineers, HEC-ResSim Reservoir System Sumulation - User's Manual, version 3.0, 2007.
3. Fanuel Wondye, "Abay Basin Water Allocation Modeling Using HEC-ResSim", Ph.D. Thesis, Addis Ababa University, 2009.
4. M.G. Mariam, "Modeling of Tekeze Hydropower Reservoir Operation with HEC–ResSim", M.Sc. Thesis, Civil Engineering, Faculty of Technology, Addis Ababa University, Ethiopia, 2012.
5. K. Fagot, P.E. Bartel, M. Ashley, and M. Schimdt, "Development of a Restricted Reservoir Operating Plan at West Point Dam, Georgia", 2011.
6. Rolf Olsen, and Kristin Gilroy, "Dniester River Basin Reservoir Simulation Model", Alliance for Global Water Adaptation (AGWA), Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, Virginia, USA, 2013.
7. Joan D. Klipsch, and Thomas A. Evans, "Reservoir operations modeling with HEC-ResSim", U.S. Army Corps of Engineers.
8. E.A. Jebbo Baraa, Taymoor, and A. Awchi, "Simulation Model for Mosul Dam Reservoir Using HEC-ResSim 3.0 Package", ZANCO Journal of Pure and Applied Sciences, Vol. 28, No. 2, 2016, pp 92-98.
9. P.G. Lara, J.D. Lopes, G.M Luz, and N.B. Bonuma, "Reservoir operation employing HEC-ResSim: case study of Tucuruí dam, Brazil", 6th International Conference on flood management, Sao Paulo, Brazil, 2014.
10. Eliza-Isabela Tică and Radu Popa, "Recent evolutionary algorithms for optimization problems, with an application in hydropower" (in original in Romanian: "Algoritmi evoluționiști recenți pentru probleme de optimizare, cu o aplicație în

hidroenergetică”), Hidrotehnica, Vol. 60, No. 8-9, 2015, pp 16-24.

11. Eliza-Isabela Tică, Angela Neagoe, Silvia Năstase, Radu Popa, and Sanda-Carmen Georgescu, “Optimization of hydropower operation: actuality and prospects” (in original in Romanian: “Optimizarea exploatării amenajărilor hidroenergetice: actualitate și perspective”), Hidrotehnica, Vol. 63, No. 1-3, 2018, pp 14-21.
12. D. McKinny, “Arges Basin ResSim Model”, Support to Enhance Privatization, Investment and Competitiveness in the Water Sector of the Romanian Economy (SEPIC), 2005.
13. Radu Popa, and Bogdan Popa, “Hydropower developments operation optimization of hydropower developments operation” (in original in Romanian: “Optimizarea exploatării amenajărilor hidroenergetice”), Technical Publishing House, Bucharest, 2003, pp 205-216.
14. Eliza-Isabela Tică, “Contributions to the optimization of hydropower developments operation with evolutionary algorithms” (in original in Romanian: “Contribuții la optimizarea exploatării amenajărilor hidroenergetice cu algoritmi evoluționiști”), Ph.D. thesis, Power Engineering Doctoral School, University Politehnica of Bucharest, 2019.