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# A LONG-TERM OPTIMIZATION METHOD FOR RESERVOIR MANAGEMENT IN A MARKET ORIENTED HYDRO-DOMINATED POWER SYSTEMS

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***Abstract:***

This paper presents an optimization-based method for the long-term scheduling of hydrothermal power system. The proposed method maximizes the profit of hydroelectric production in power system, based on monthly energy requirement of the system and unit commitment calculations. The method allows precise hydro chain modeling with numerous restrictions as well as computation for multiple-reservoir river systems with multiple-purpose operation. The method has been implemented in a computer program and tested on power system, which is very similar to Croatian Power System in the year 2000. Several testing results are presented.

Presented method can be applicable for long-term planning in a competitive electricity market due to possibility of unit commitment calculations with different electrical energy price during scheduling horizon.

**Key words:** hydro-dominated power systems, long-term optimization, reservoir management

## 1. INTRODUCTION

In hydrothermal power system with significant percentages of hydrogeneration a long-term multireservoir management has great impact on production cost of thermal units. Traditionally, long-term hydrothermal coordination is formulated as a cost minimization problem. As the deregulation process of the energy market is taking place, electricity generation planning methods have to be adapted to the new situation. Due to energy price variation a long-term optimization methods of electricity generation, based on minimizing the production cost, could not carry out with new condition.

This paper describes the approach used by the authors for solving the long-term multiple-reservoir scheduling of hydro-dominated power systems in market conditions. Main goal is to achieve maximum profit of water use, take into account limited water resources and all accomplishable restrictions. All input variables like reservoir and river inflows, electricity demands, electricity prices etc. are modeled deterministically.

Each reservoir as well as multiple-reservoir system has unique operating rules. For multiple-reservoir system, with reservoirs in series (cascaded reservoirs) as well as reservoirs in parallel, release decisions require more precise and more complex approaches. If the reservoirs have significantly different evaporation potential or other losses possibility, minimization of losses must be taken in considerations.

Besides above, there are many limitations on reservoir operation policy like:

- amount of empty space available for storing future flood waters to reduce downstream damages represented by designated top of conservation pool elevation,
- reservoir release to maintenance of specified minimum flow rates,
- water-surface-level fluctuation etc.

## 2. MATHEMATICAL FORMULATION

Profit of one hydroelectric power plant is function of diverted water (and reservoir level for storage hydroelectric plants) but also of water release on other conservation reservoirs. Profit in power system, which has to be maximized, depends of all reservoirs releases and many other system parameters. The resulting problem is generally constrained non-linear mathematical optimization problem with an extremely high number of optimization variables and system parameters.

In suggested method the optimization of S reservoirs is broken into S subproblems in which one reservoir is optimized while other reservoirs release is temporary kept constant. Scheduling horizon is divided into the smaller time period, called basic period t. Long-term operation policy or optimal solution for global objective function results from successive solving subproblems for all reservoirs (several times). In one subproblem, presented with local objective function (and constrains), all hydroelectric (and thermoelectric) plants participate in power system profit but power system profit is function of only one release. Solution for subproblem can be found with convenient non-linear programming algorithm for constrained problem.

Problem, which appeared in subproblem, is determining of power system profit function in dependence on water release from only one reservoir for each basic period. Power system profit functions are variably during computations. So, before each optimization calculation for one reservoir release (while other reservoirs release is temporary kept constant), power system profit functions for each period t must be calculated (fig. 1). It is very hard to calculate these profit functions analytically, so these functions are calculated by simulation model. Separate algorithm repeatedly executes the simulation model and calculates the unit commitment in power system with different values for reservoir release. Unit commitment calculation for one release from reservoir S in one basic period takes into account:

- load duration curve for energy demand,
- hydroelectric production in all hydroelectric plants (which include computation with turbines flow calculated from reservoirs release and river inflows as well as gross water head calculations),
- thermoelectric plants production cost,
- import electrical energy cost, etc.

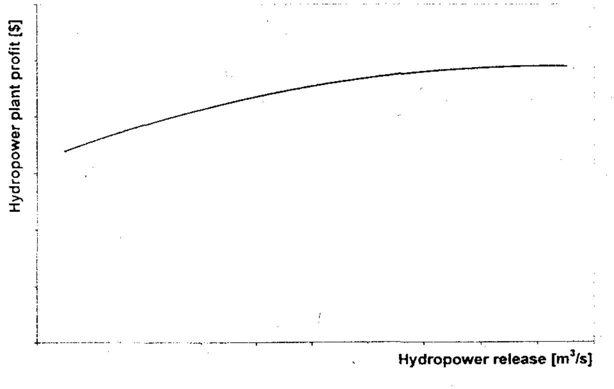


Figure 1. Example of hydropower plant profit function in dependence of hydropower release from reservoir in one basic period

After series of unit commitment calculations for each basic period, objective function for one iteration step is re-formed and optimal subproblem solution can be found.

Local objective functions include significantly lower number of decision variables. Due to problem decomposition, some of less dominated parameters, previously disregarded, can participate in each phase of calculation and simulation. Longer calculation time is neglected factor in such problem.

## 3. IMPLEMENTATION AND TESTING RESULTS

The proposed long-term optimization method is the basis of the new developed software package. The developed program has been tested on power system model, which is very similar to Croatian Power System of the year 2000. In median weather condition hydroelectric power plants production in Croatian is about 45% of electrical demand. Testing model includes 5 hydro chains with 6 reservoirs for seasonal regulation, several small sized reservoirs and 9 storage hydroelectric plants. The generation system also contained 12 thermal plants (various fuels) as well as several run-of river hydroelectric plants. Constrains in the hydro chains include minimum and maximum conservation storage levels for pollution and flood control, maintenance minimum flows specified for ecological reason, amount of water for other purposes (water supply, irrigation...) etc. Relationships between the gross head and the storage capacity are modeled for all reservoirs. The scheduling horizon in this case study was defined as one year. Basic time period was one month. The monthly electricity requirement was external calculated.

Program output list includes:

- volume, release and gross head for reservoirs in each basic period,
- hydroelectric power plants and thermal plants production in each basic period,
- system profit in each basic period etc.

The monthly productions of the storage hydroelectric plants are presented in table 1.

Table 1. Monthly Hydro Power Production

| **plant→**<br>**month↓** | **PERU.**<br>[GWh] | **ORLO.**<br>[GWh] | **DJALE**<br>[GWh] | **ZAKU.**<br>[GWh] | **SKLO.**<br>[GWh] | **SENJ**<br>[GWh] | **VINOD**<br>[GWh] | **VELEB**<br>[GWh] | **DUBR.**<br>[GWh] | **ΣMonth**<br>**[GWh]** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10,95 | 34,43 | 12,73 | 168,80 | 9,08 | 114,95 | 24,27 | 47,56 | 65,40 | **488,17** |
| 2 | 1,06 | 0,00 | 6,31 | 77,21 | 6,44 | 87,34 | 0,00 | 86,96 | 60,53 | **325,84** |
| 3 | 4,45 | 60,18 | 10,59 | 136,37 | 8,91 | 112,44 | 11,49 | 19,62 | 65,39 | **429,43** |
| 4 | 9,67 | 30,65 | 11,53 | 150,17 | 6,60 | 97,34 | 0,00 | 33,84 | 59,13 | **398,92** |
| 5 | 6,13 | 0,00 | 7,49 | 92,67 | 8,90 | 103,94 | 62,50 | 57,31 | 67,23 | **406,16** |
| 6 | 20,15 | 55,31 | 12,11 | 158,32 | 9,33 | 95,95 | 0,00 | 0,00 | 66,66 | **417,83** |
| 7 | 19,28 | 44,50 | 10,68 | 137,66 | 5,74 | 62,06 | 5,48 | 0,00 | 64,98 | **350,36** |
| 8 | 13,82 | 35,44 | 9,21 | 116,91 | 13,34 | 110,39 | 26,18 | 0,00 | 64,61 | **389,91** |
| 9 | 9,87 | 0,00 | 6,31 | 76,34 | 9,15 | 79,95 | 1,38 | 24,17 | 59,61 | **266,77** |
| 10 | 17,44 | 39,36 | 13,14 | 175,95 | 12,59 | 115,62 | 11,56 | 43,22 | 63,48 | **492,36** |
| 11 | 7,08 | 34,03 | 10,77 | 139,38 | 8,57 | 100,82 | 0,00 | 38,66 | 61,60 | **400,91** |
| 12 | 8,81 | 34,55 | 13,30 | 177,62 | 9,02 | 115,34 | 2,10 | 46,33 | 65,44 | **472,51** |
| Σ | **128,71** | **368,44** | **124,15** | **1607,40** | **107,67** | **1196,13** | **144,96** | **397,67** | **764,05** | **4839,16** |

## 4. CONCLUSIONS

A long-term optimization method based on power system profit maximization has been developed and implemented in a computer program. The method can successfully deal with varying electrical prices in market conditions. Proposed method allows precise hydro chain modeling with numerous restrictions as well as computation for multiple-reservoir river systems with multiple-purpose operation.

The global objective function decomposition simplifies optimization problem and enables it to be solved. Iterative computation, with systematic optimization process and apropos programming algorithm application for continual solving the local objective function, leads to the optimum.

If fixed electrical energy prices are modeled in each basic period of time presented method for maximizing the profit of hydroelectric system would give a same result as a conventional long-term optimization method.

Numerical results show that the method is applicable in real systems.

## REFERENCES:


1. H. Požar: Snaga i energija u elektroenergetskim sistemima, Informator, Zagreb, 1983.
2. J. Keglević: Optimalno korištenje sezonskih akumulacijskih bazena hidroelektrana, doktorska disertacija, ETF Zagreb, 1975.
3. Ralph A. Wurbs: Modeling and Analysis of Reservoir System Operations, Prentice Hall PTR, Upper Saddle River, NJ 07458
4. A. J. Wood, B. F. Wollenberg: Power Generation, Operation and Control, John Willey & Sons, Inc. 1984.
5. S. Niessen, H. J. Haubrich, J. L. DelaFuente, C. Garcia, N. Nabona, F. J. Heredia, R. Dobiasch, P. Stelzner, J. Albrecht: Short and Long-term Optimization of Electricity Generation And Trading in a Competitive Electricity Market – The SLOEGAT project, ref. br. 38-206, XXXVII CIGRE, Paris, 1998.
6. O. B. Fosso, A. Gjelsvik, A. Haugstad, B. Mo, I. Wangensteen: Generation Scheduling in a Deregulated System. The Norwegian Case, IEEE Transactions on Power System, Vol. 14, No. 1, February 1999.
7. V. R. Sherkat, R. Campo, K. Moslehi: Stochastic Long-Term Optimization for a Multireservoir System, , IEEE Transactions on Power Apparatus and System, Vol. PAS-104, No. 8, August 1985.
8. H. Duran, C. Puech, J. Diaz, G. Sanchez: : Optimal Operation of Multireservoir System Using an Aggregation-Decomposition Approach, IEEE Transactions on Power Apparatus and System, Vol. PAS-104, No. 8, August 1985.
9. X. Guan, E. Ni, R. Li, P. B. Luh: An Optimization-Based Algorithm for Scheduling Hydrothermal Power System with Cascaded Reservoirs and Discrete Hydro Constraints, IEEE Transactions on Power System, Vol. 12, No. 4, November 1997.
10. C. Li, B. Johnson, A. J. Svoboda, C. L. Tseng, E. Hsu: A Robust Unit Commitment Algorithm for Hydro-Thermal Optimization, IEEE Transactions on Power System, Vol. 13, No. 3, August 1998.
11. Z. Yu, F. T. Sparrow, B. H. Bowen: A New Long-term Hydro Production Scheduling Method for Maximizing the Profit of Hydroelectric System, IEEE Transactions on Power System, Vol. 13, No. 1, February 1998.
12. R. A. Duncan, G. E. Seymore, D. L. Striffert, D. J. Engberg: Optimal Hydrothermal Coordination for Multiple Reservoir River Systems, IEEE Transactions on Power Apparatus and System, Vol. PAS-104, No. 5, May 1985.