Energy 160 (2018) 979–985

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A new field-levelling procedure to minimize spillages in hydropower reservoir operation

Jinwen Wang [a, b, *], Cheng Chen [a, b], Shuangquan Liu [c]

[a] School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan, Hubei, 430074, China
[b] Joint International Water Security Research Center, Huazhong University of Science and Technology, Wuhan, Hubei 430074, China
[c] Kunming Power Exchange Co. Ltd., 73Tuodong Road, Kunming, Yunnan, 650011, China

ARTICLE INFO

Article history:
Received 3 April 2018
Received in revised form
12 July 2018
Accepted 14 July 2018
Available online 17 July 2018

Keywords:
Hydropower reservoir
Operation
Optimization
Spillages
Field-levelling procedure

ABSTRACT

This paper proposes an innovative procedure to improve an initial hydropower schedule by minimizing spillages in the short-term operation of multiple reservoir systems. This procedure is named as the field levelling (FL), which tries to eliminate scheduled spillages as much as possible by pushing forward and pulling backward the spillages in turn to explore spaces so as to absorb them, emulating the flied-levelling practice that pushes and pulls the protruding dirt in turn to find valleys to take it in. Even for a large-scale reservoir system, the procedure solves the problem very fast attributable to its stage-by-stage property. The procedure has the ability to handle the water travelling time between reservoirs and the nonlinearity in the optimization, and it is very useful in locally modifying an either feasible or infeasible scheduling solution to a feasible and satisfactory one. The model and procedure are applied to deal with the Yunnan provincial hydropower system that consists of 45 reservoirs. Start with a very good initial solution derived in our previous work, the present FL improves the solution by 0.58% and 1.34% reduction in water and energy spillages respectively.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Water resources are playing a role extremely important for development or even survival of a country or territory, and reservoirs, serving mainly as “warehouses” of surface water resources, are playing a vital role in developing and utilizing the water resources. A reservoir, either to promote the beneficial or abolish the harmful, brings benefit to our society by controlling and changing distribution of water resources over time and space. And the operation and management of reservoirs, due to its importance and complexity in managing water resources systems, has received extensive attention from so many experts and scholars [1,2].

The problem of hydropower reservoir operation, typically a challenging nonlinear and nonconvex programming problem, has attracted into application almost all the optimization algorithms we can think of. Among them, the dynamic programming (DP) is extensively used in the operation of hydropower reservoirs, but still suffered from dimensional difficulty in handling large scale hydropower systems, though many good efforts, Feng et al. [3,4] for instance, have been made to alleviate its dimensionality problem. The progressive optimality algorithm (POA) takes less time to solve a DP problem but strongly depends on the initial solution [5]. Nonlinear optimization methods based upon differential or derivative, truncated Newton method and interior point method applied by Oliveria and Soars [6] and Azevedo et al. [7], for instance, were successful in solving many problems where the objective function and constraints are smooth. More likely, the procedure will converge to the local optimum closer to the original solution, or even the convergence cannot be guaranteed when applied to nonconvex problems. Even more, the converging speed and reliability will deteriorate with increasing of complexity and scale of the problem. Some efficient programming methods, linear programing (LP) and quadratic programming (QP) when applied to solve this problem by Borghetti et al. [8], Catalao et al. [9] and Niu et al. [10] for instance, generally require the problem to be formulated into a simplified one by making assumptions and/or linearization. The inaccuracies due to the simplification will more likely lead to an infeasible solution to the original problem and/or an inferior solution with unnecessary spillages occurred when

* Corresponding author. School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan, Hubei, 430074, China.
E-mail addresses: jinwen.wang@hust.edu.cn (J. Wang), 630455954@qq.com (C. Chen), epdc.yepg@foxmail.com (S. Liu).

https://doi.org/10.1016/j.energy.2018.07.089
0360-5442/© 2018 Elsevier Ltd. All rights reserved.

enforcing feasibility upon the infeasible solution.

Apart from the traditional mathematical programming methods, the intelligent/metaheuristic algorithms bio/nature-inspired, due to their global searching capability, have come into our field of vision and aroused an upsurge of research interests in reservoir operation for about 20 years [11–13]. These intelligent algorithms usually need to generate a group of solutions at random, imposing issues on how fast it converges and how capable it is in handling complex constraints. Nicklow et al. [14] provided a comprehensive review of state-of-the-art methods and their applications in the field of water resources planning and management. One of difficulties with metaheuristic algorithms is to handle constraints of the problem. More often, the intelligent algorithms, when applied to optimal reservoir operation, employ penalty functions to convert a constrained problem into an unconstrained [15,16]. This, however, will create a new objective function highly abnormal and then impose numeric difficulty to obtain the optimum, showing weakness very similar to the penalty methods used in mathematical programming. Another option, more efficient in randomly generating feasible solutions, is called repair method, which employs a policy to modify a randomly generated infeasible solution into a feasible one [17–19]. However, without guide from a proper objective function and control of deviation, this repair method in handling constraints will very likely generate too many inferior solutions far from their starting/original points, which naturally reduces the search efficiency of the procedure.

Illuminated by the farming practice that levels a field by pushing and pulling soil back and forth, this paper proposes a new procedure called "field-levelling (FL)" to improve an initial hydropower schedule by minimizing spillages in the short-term operation of multiple reservoir systems. Guided by the objective of minimizing spillages and constrained to deviate as small as possible from the initial solution, the FL aims to locally modify an infeasible solution into a feasible one, and simultaneously, to improve the solution by abating both water and energy spillages. This procedure is very useful in helping both the mathematical programming and metaheuristic algorithms to either improve the solution or make it feasible by local modification.

2. Problem formulation

The model aims to locally modify an operational solution by minimizing spillages during a planning horizon, with the new solutions deviating from the original solution as small as possible. The problem is formulated as a preemptive goal programming to minimize the spillage and the deviation from the initial storages, mathematically expressed as

$$\min_{\mathbf{v},spl,q}\left\{\sum_{t=0}^{T-1}\sum_{i=1}^{N} spl_{it},\quad \sum_{t=1}^{T}\sum_{i=1}^{N}\left|v_{it}-v_{it}^{(0)}\right|^{\beta}\right\}, \tag{1}$$

subject to the minimum and maximum storages,

$$v_{it}^{\min} \le v_{it} \le v_{it}^{\max}, \tag{2}$$

the lower and upper bounds of the release from a reservoir,

$$Q_{it}^{\min} \le Q_{it} \le Q_{it}^{\max}, \tag{3}$$

the minimum and capacity of the generating discharge,

$$q_i^{\min}(h_{it}) \le q_{it} \le q_i^{\max}(h_{it}), \tag{4}$$

and the water balance equation,

$$v_{i,t+1} = v_{it} + \left[\sum_{k\in\Omega(i)} Q_{k,t-\tau_k} - Q_{it} + I_{it}\right]\cdot\Delta t, \tag{5}$$

with the release expressed as

$$Q_{it} = q_{it} + spl_{it}, \tag{6}$$

the initial storage observed as

$$v_{i0} = v_{i0}^{(0)}, \tag{7}$$

and the target storage at the end of the planning horizon fixed as

$$v_{iT} = v_{iT}^{(0)}, \tag{8}$$

where i, t = subscript indices of reservoirs and time-steps, respectively; N, T = numbers of reservoirs considered in this study and time-steps during the planning horizon, respectively; $\mathbf{v}$, $\mathbf{spl}$, $\mathbf{q}$ = vectors of storage in hm^3, spillage in m^3/s and generating discharge in m^3/s, respectively; spl_{it} = water spillage from reservoir i in t, in m^3/s; v_{it} = water storage in hm^3 of reservoir i at the beginning of t; $v^{(0)}{}_{it}$ = water storage at the original solution of reservoir i at the beginning of t, in hm^3; β = a positive coefficient; $v_{it}^{\min}$ and $v_{it}^{\max}$ = minimum and maximum storages in hm^3 of reservoir i at the beginning of time-step t; Q_{it} = release in m^3/s from reservoir i in t; $Q_{it}^{\min}$ and $Q_{it}^{\max}$ = maximum and minimum outflows in m^3/s from reservoir i in t; q_{it} = generating flow in m^3/s from reservoir i in t; $q_i{}^{\min}(h)$ and $q_i^{\max}(h)$ = minimum and capacity in m^3/s of generating discharge from reservoir i, functions of water head (h); h_{it} = average water head in m of reservoir i in t; $\Omega(i)$ = set of the reservoirs immediately upstream to i; τ_k = water travelling/delay time in hours from reservoir k to its immediate downstream reservoir; I_{it} = local inflow in m^3/s to reservoir i in t; Δt = length of one time-step, in hours.

Apparently, the problem is a nonlinear programming due to the nonlinearity of the second term in the objective function as well as the constraints (4) on the generating discharge, the lower and upper bounds that are functions of water head.

3. Solution procedure and techniques

The solution procedure is called "field-levelling" because it simulates the farming practice that levels a field by pushing and pulling the soil back and forth. For example, we suppose a rectangular groove that has a rugged surface, a height of H, and a reference plane. The surface can be levelled to the reference plane by pushing and pulling the soil back and forth. Certainly, the soil cannot overflow the groove during the pushing and pulling process. This flied-levelling practice pushes and pulls the protruding dirt in turn to find valleys to take it in. Compared to the operation problem of a hydropower reservoir, the rugged surface corresponds to the fluctuant inflow, the reference plane corresponds to the capacity of generating discharge, and the pushing and pulling back and forth corresponds to the solution modifications forward and backward in time in field-levelling procedure.

Fig. 1 illustrates how the field-levelling procedure works in operating one reservoir to minimize the spillages during a planning horizon (T). The procedure tries to eliminate scheduled spillages as much as possible by pushing forward and pulling backward the spillages in turn to explore spaces so as to absorb them, involving the following three steps:

Download English Version:

https://daneshyari.com/en/article/8071001

Download Persian Version:

https://daneshyari.com/article/8071001

Daneshyari.com