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Defining priorities in the design of power and water distribution networks

Ramón González-Bravo, Luis Fabián Fuentes-Cortés, José María Ponce-Ortega*

Chemical Engineering Department, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, 58060, Mexico

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A B S T R A C T

This paper presents an approach for designing power and water distribution networks involving the sizing, geographic location, as well as the economic, environmental and social impacts, and taking into account the multiplicity of criteria for the stakeholders involved in the development of operational policies and new facilities. In this paper is presented a method for defining solutions concerning to the design of power and water distribution networks based on a multi-stakeholder environment. A multi-objective model, considering economic, environmental and social factors, is used for illustrating how the different criteria, about priorities of the stakeholders, affect the design of the system and how to propose a solution for achieving a tradeoff between the multiple stakeholders. The proposed method was applied to an electric and water stressed scheme in the north of Mexico, the results show that the minimization of the dissatisfaction of the involved systems can provide an optimal solution that meets the objectives of all stakeholders.

1. Introduction

Energy and water are very important resources for the development of the modern society. The growth of the urban areas, agricultural crops and industrial facilities has increased the use of both resources [1]. The distribution problems have increased significantly because of the availability of water and the current scheme of water and power distribution (centralized distribution) [2]. The development of liberalized electricity and water markets impels the design of new strategies [3], taking into account economic, environmental and social aspects [4]. In the case of water, the first problem is the allocation of water resources. The natural sources of fresh water are limited and the access is restricted by factors such as political issues [5], transportation cost, treatment [6], lack of adequate pricing policy on water supply [7], exploitation limits [8], policies based on rationalization of resources [9] and scarcity [10]. Due to these factors, the current water distribution systems have to consider the external consumption. Usually, water is transported from a source in remote areas. This way, the problems involved in the design of water distribution networks have different dimensions. The economic dimension of water distribution networks has been addressed considering aspects as cost of treatment intended for human consumption [11] or for sanitary use [12], cost of pipelines [13], maintenance of the network [14], pumping [15], efficiency in energy consumption [16], cost of utilities [17] and cost of extraction [18]. The environmental dimension has considered the life cycle assessment analysis [19], emissions generated by system [20] and reducing water losses [21]. The social dimension has focused on improving the behavior of the final user [22], final usage [23] and conflicts in the distribution between different communities and users [24].

The design of power distribution networks has similar problems to the water distribution networks. The economic dimension of the design has considered sizing system [25], reducing energy losses in distributed generation [26], and transmission based on centralized generation [27], increasing the generation efficiency [28], maximizing the profit [29], improving the fuel consumption [30] and the maintenance of the transportation lines [31]. The environmental dimension has focused on the emissions [32], life cycle assessment [33] and water consumption [34]. The social impact involves the response of the system to the behavior of the end user [35] and the economic benefit to local communities [36]. The power distribution

* Corresponding author.
E-mail address: jmponce@umich.mx (J.M. Ponce-Ortega).

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networks have been studied by several authors, where the prices of electricity consumption and the future growth have important roles in the decision making process, these strategies have been applied in the electricity sector in Italy [37], Hong Kong [38], Japan [39], Denmark [40] and Hungary [41].

Other strategies have been introduced to analyze the use of desalination systems to provide fresh water in water-stressed areas [42]. In this context, macroscopic water networks have been incorporated to involve seawater, groundwater and desalination plants in system [43]. Furthermore, other approaches considered the monthly fluctuating demands in designing macroscopic water networks [44]. Nowadays, the integration of renewable energy based on existing desalination technologies is very important [45], involving small and large power capacities [46] and also to reduce the CO_2 emissions [47]. It should be noticed that the integration of desalination and power production is a good option to reduce the desalination cost [48]. Power-desalination schemes have been widely used in cities of the Middle East, where the production of water and electricity has the advantage of reducing the environmental impact and energy consumption [49]. The integration of power-desalination systems in the synthesis of water distribution networks represents an attractive option to satisfy water demands in arid regions [50].

Because in the macroscopic power and water distribution networks there are involved several actors and users, it is important to implement an optimization strategy that satisfies the specific objectives for the different stakeholders. These multiple objectives in the design of water and energy distribution networks have increased the complexity of the design process. The decision-makers have different criteria about the objectives. Most of the investors have preferences for the economic benefits [51], the communities and government have focused on the environmental impact and social benefits of the new systems [52]. Sometimes, these actors show different interest levels about the design objectives according to local or personal priorities and perspectives about the project. These different criteria have led to conflicts between the different stakeholders. A compensated solution or a multi-objective analysis is not enough in these cases. When the problem implicates a conflict of interest between all the involved stakeholders, the analysis considering the Pareto optimal solutions, using the own criteria of the designer based on a multi-objective approach, could not be enough for sensitizing to the actors about the effects of their priorities in the final configuration of the system. Then, it is not possible to provide an effective framework for discussing solution paths to the conflict and to propose a compromise solution that could reach the satisfaction between all the part-takers. Therefore, a tool that can show the impact of the priorities established by the stakeholders in the design can help to solve the conflicts or show different impacts in the design caused by the different levels and preferences in the priorities and it can lead to a dialogue between the part-takers in the final decision about system [53].

In this paper is presented a method for designing water and energy distribution networks considering the multi-stakeholder environment. Economic, environmental and social objectives are considered for defining the priorities of the stakeholders. The proposed solution approach takes into account different levels or weights in the preferences about the objectives of the stakeholders. Finally, an approach for trading-off the different criteria is introduce as well as the levels of dissatisfaction of the stakeholders with this configuration in the design.

2. Mathematical model

The mathematical formulation for synthesizing power and water distribution networks is based on the superstructure shown in Fig. 1. In this figure, there are defined the water and electricity demands for domestic users (r), industrial users (o) and agricultural users (g), in which the water demands can be supplied by the existing water in the aquifers (i), by extracting water from the existing deep wells in each region (j) and also the water in dams (x). Here, there is considered the location of existing storage tanks (p) as well as the installation of new storage tanks (p), if it is necessary. The storage tanks represent the artificial storages for water. On the other hand, the energy demand is satisfied by the electricity produced in the existing power plants (n) as well as the possible installation of new power-desalination plants (u), where the fuel requirements of the dual-purpose power plant can be fully satisfied using fossil fuels (f), biofuels (b) and/or solar energy.

The proposed mathematical model includes accumulation balances in aquifers, mass balances in deep wells, equations to account the water demand for domestic, industrial and agricultural users, as well as accumulation balances in dams, new and existing storage tanks, also the mass balances of the existing and new power and desalination plants. The electricity production is performed using energy balances of the existing and new power and desalination plants, these equations account for the energy demands of domestic, industrial and agricultural users. The formulation includes binary variables to determine the existence of new storage tanks as well as the existence of new power and desalination plants, where the operations include fixed and variable costs, the formulation also includes pumping and piping costs. The details for these equations are described in the electronic supplementary material section.

2.1. Objective functions

In this case, it is needed a multi-objective optimization problem, this formulation includes the maximization of the gross annual profit (economic objective) and the maximization of the jobs generated by the project (social objective), also the formulation accounts for the minimization of the overall greenhouse gas emissions (GHGE) as environmental objective.

$$OF = \text{Max}\ AnnualProfit;\ \text{Min}\ \ OGHGE;\ \text{Max}\ \ ONJobs \tag{1}$$

The multi-stakeholder decision problem implies the priorities of investors ($AnnualProfit$), environmental damage ($OGHGE$) and the social acceptability ($ONJobs$). Where the economic objective includes the maximization of water sales, power sales, tax credit reduction at the minimum total annual cost of the power and water distribution network, according to the next equation:

$$Annual\ Profit = Water\ \ Sales + PowerSales + TCR - TAC \tag{2}$$

where, the water sale involves the water consumed by the domestic, industrial, and agricultural users:

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