DISTRIBUTED SOLUTION TO ECONOMIC DISPATCH PROBLEM OF ENERGY-WATER NEXUS SYSTEMS

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Overview

The power energy and water are essential resources for the development of the society and economics. Faced with mega-trends such as resource scarcity, population growth and environmental pollution, the cost of producing power and water becomes higher and higher. Traditionally, the production of potable water and power generation are thought of as separable problems. However, with the development of technology, they are becoming increasingly correlated and this complex relation is called energy-water nexus. For example, multi-stage flash (MSF) seawater desalination systems are usually coupled with power plants because they can use the wasted energy of used gas (which exits from gas turbine cycles) to produce potable water, while the gas turbine generator needs water to produce energy [1]. Although this subject attractes some policy and regulation agents's attention, it is rarely addressed as an interdisciplinary consideration. This work considers the economic dispatch problem of water and power which aims to satisfy the power and water demand and minimize the cost of production. Specially, we assume that the system supplying the power and water consists of many power generations, water plants and co-production plants and all the plants can exchange the information over a connected graph.

Many optimization methods have been established for energy-water nexus systems [2][3]. However, there exist some disadvantages for the conventional algorithms since these algorithms are centralized and generally need a control center to access and process the data from all the plants. As the number of power plants, water plants and co-production plants becomes larger and larger, the control center cannot effectively process all the data from the whole network. To overcome this constraint, it is desired to proposal a distributed algorithm to solve the economic dispatch problem of energy-water nexus systems. First, the system can be modled as a complex network with the nodes representing the plants and the edges denoting the communication channel. Then, a distributed algorithm is proposed for the nexus optimization model. It is worth noting that the distributed algorithm will not need a control center any longer and only requires the local data from the neighboring plants. To the best of our knowledge, the result is the first attempt in the distributed solution of the economic dispatch problem for energy-water nexus systems.

Methods

We provide the problem formulation of the economic dispatch problem of the energy-water nexus system. Consider n plants in the system interacting on a communication network. Each plant has a local cost function and a local feasible constraint set. Moreover, the summation of power generated and water produced should be equivalent to the total demand of the external system. To model the water and power production system, we assign a 2-dimention decision vector for every plant in the production system. In the 2-dimention decision vector, the first component denotes the water produced by the facilities and the second component represents the quantity of power produced by plants. To model that the power plants only produce the power energy and the water palnts don't generate the power, we add a local constraint for each power plant and water plant.

To handle the local constrains, we adopt the exact penalty function method to transform the original economic dispatch problem into an equivalent problem without local constraints. It implies that the optimal solution of the equivalent problem is also the optimal solution to the original economic dispatch problem. The exact penalty method needs to choose a penalty function and a constant. The constant is closely related with the gradient of the cost functions of the plants when the local constraints are box constraints.

We propose a distributed algorithm to solve the equivalent problem based on the primal-dual method. If we directely apply the gradient flow method into the dual problem associated with the equivalent problem, the update of the Lagrangian multiplier will need all the decision state information of plants and thus the algorithm is not distributed. To overcome this problem, we modify the dual problem associated with the equivalent problem. We allocate a local Lagrangian multiplier for each agent or plant and then add a constraint based on the Laplace matrix to ensure that all the local Lagrangian multiplier are equal. Next, we obtain the dual problem of the modified problem and then apply the gradient flow method to obtain the distributed algorithm. The update of the state of each plant is only related with its local information and its neighbors' information, and thus the designed algorithm for each plant is fully distributed.

To prove the algorithm effective, we provide a theoritical proof by using a Lyapunove function method, graph theory and noonsmooth analysis theory. In the theoretical analysis, we firstly prove that the plants' decision variates can converge to the optimal solution if the communication network is undirected and connected and the solution to the proposed algorithm converge to the equilibrium point. Then, we prove that the solution to the proposed algorithm indeed can converge to the equilibrium point. Thus we can conclude that the proposed algorithm can solve the economic dispatch problem for the energy-water nexus system.

Results

The proposed algorithm can be effectively applied to the large-scale water and power network which consists of numerous plants. Compared with many existed algorithms which cannot get the correct optimal solution if the initial condition has an error, the proposed algorithm in this paper allows a group of hetweogenous plants to solve the economic dispatch problem for any initial condition. The no-initialization is required so that the proposed algorithm is still effective when the operation environment or the communication network time-varying. Moreover, in our algorithm, we do not require the agents share their respective gradient information with their neighbors. In other words, the proposed algorithm can favorably protect the agents' privacy so that it can be applied to the privacy-sensitive applications.

Finally, we provide a modest-size example to demonstrate that the proposed algorithm is effective for the large scale water-power supply system. For the test case, we assume that the system consists of 2 power plants, 2 water plants and 2 co-production facilities. We find that the proposed algorithm can guarantee the optimal solution. Moreover, it is worth noting that the co-production plants are always the first-choice unites. However, the power plants and water plants are only used in the period of high demand of their respective product. This result implies that the co-production plants play an important role in the water-power supply system.

Conclusions

In this paper, we have designed a distributed continuous-time algorithm which allows a group of power, water,and co-production plants to solve the economic dispatch problem with local inequality constraints starting from any initial allocation. To accomplish this, we have transformed the original problem by using the exact penalty function method into an equivalent problem without local inequality constraints. Then a distributed algorithm has been proposed to solve the equivalent optimization problem. A theoretical analysis has been presented for the proposed algorithm with the help of algebraic graph theory, Lyapunove function method and non-smooth analysis. The simulation result indicated that the algorithm is effective and it will save plenty of production cost for the economic dispatch problem of energy-water nexus. In the future, we will further investigate the economic dispatch problem of the energy-water nexus system which not only includes the electricity-storage devices but also the water storage facilities. Moreover, we will consider the power-water production ratio for the coproduction plants in the co-optimization model such that the model is more practical.

Referrence

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