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Coordinated Operation of Water and Electricity Distribution Networks with Variable Renewable Energy and Distribution Locational Marginal Pricing

Introduction

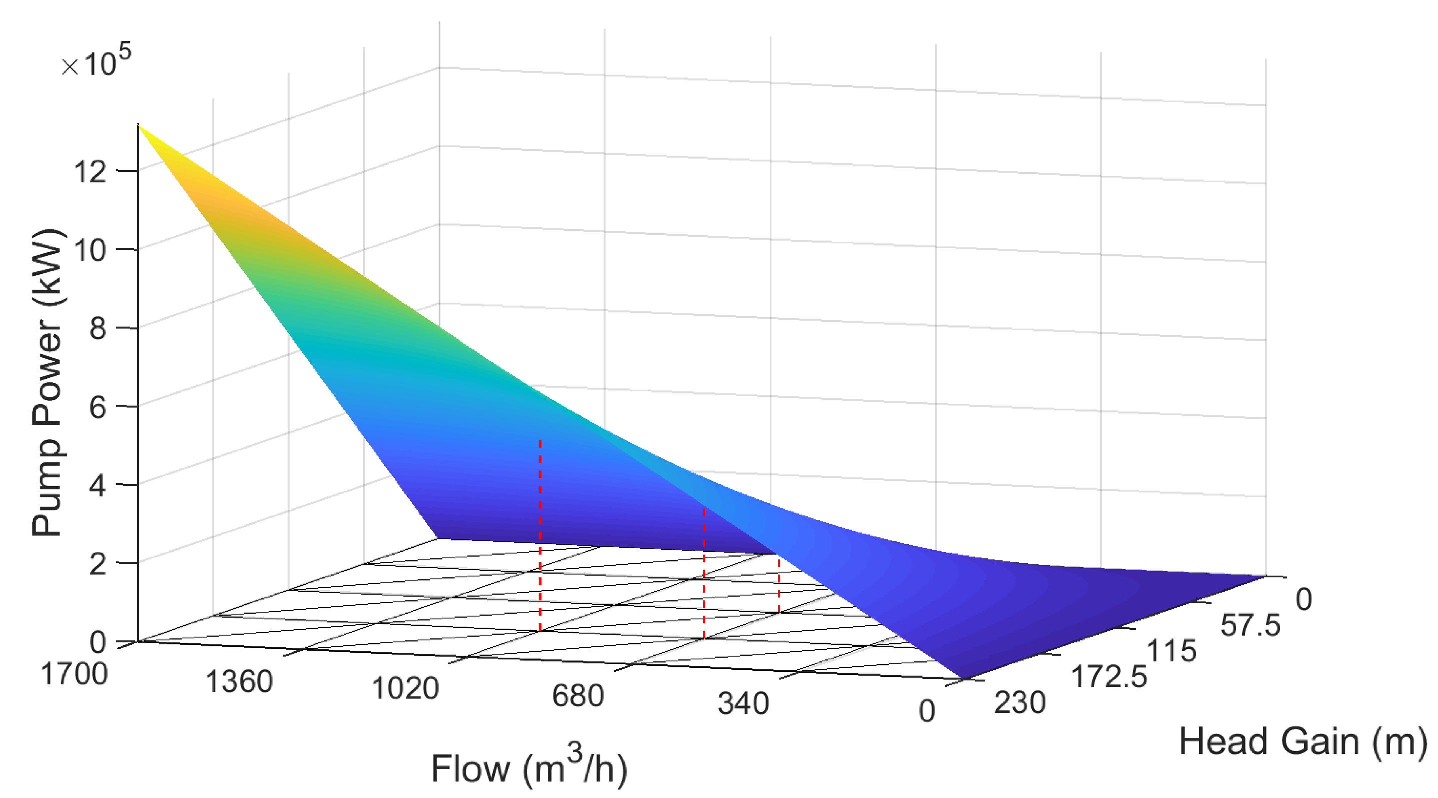
- Water and electricity distribution networks are two highly interdependent and critical infrastructures in the world today.
- Changes over recent years have caused water and electricity utilities to improve efficiencies through cooperation. With the rise in water demands and prices, water utilities are encouraged to look at ways to reduce their operational costs and electricity usage. Additionally, variable renewable energy (VRE) sources, such as wind and photovoltaics, have increased in electrical distribution networks. Such changes produce challenges when matching the generation to the load.
- Solutions commonly addressed in the literature for mismatches in power generation and load are demand response techniques and the use of energy storage resources. Traditional storage techniques can have substantial capital costs; therefore, cheaper energy storage ideas are needed. A less costly avenue for energy storage could be through gravitational potential energy storage in existing water tanks.
- The proposed model schedules distributed energy resources (DERs) and water pumps based on available resources and the distribution locational marginal price (DLMP), which is obtained as the Lagrange multiplier of the real power balance constraint at each distribution bus while maintaining physical grid constraints such.

Significance

- Future electricity distribution systems are expected to see an increased penetration of distributed energy resources with variable and unpredictable outputs. Therefore, market mechanisms, such as DLMP, storage solutions, and collaboration between flexible demands of interdependent networks are unique methods that assist with challenges that arise from large amounts of VRE sources.
- Further, the proposed model and method can offer utilities a new tool in managing the coordinated operation of water and electricity distribution networks under uncertain VRE generation. With the recent call for more energy-efficient systems, the approach provided in this work can serve as an energy-saving solution to water and electric utility operators.

Methodology

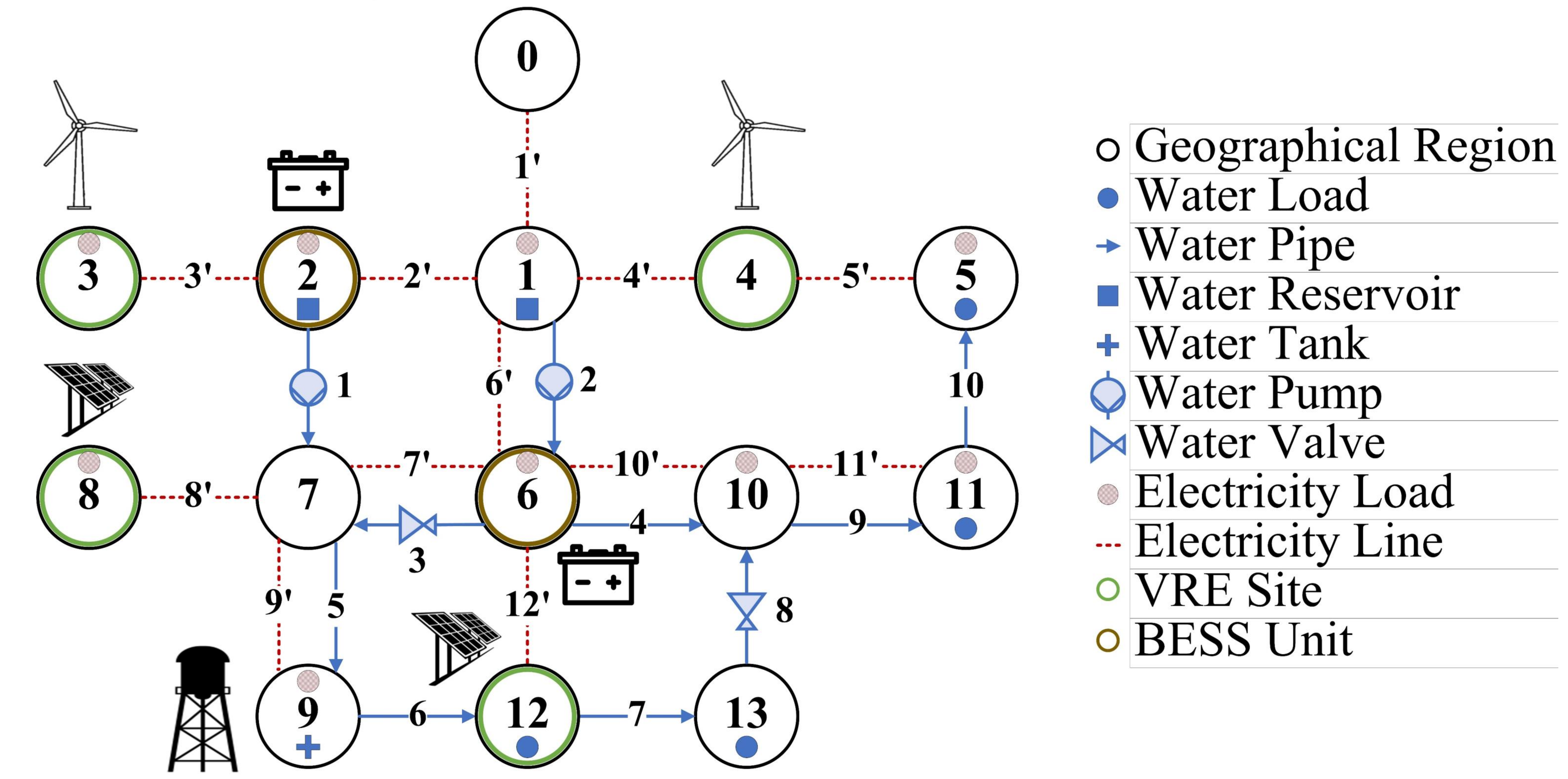
- We propose an MILP model of merged power and water networks to optimally schedule pumping, tank storage, and DERs, considering both electricity and water network constraints.
- The pumping demands are coupled with electricity utility demands and therefore serve as a flexible load. The water pumps respond to the price of electricity and available VRE generation.
- The objective function minimizes the cost of supplying power from the perspective of the electricity distribution system operator while considering physical constraints of both networks.
- A significant operational cost to the water utility is the cost of supplying power to pumps. If the cost of supplying electricity is minimized, electricity costs to the water utility can also be reduced.
- Due to multiple nonconvex constraints in the water model, exact solutions for the optimal water flow problem are hard to compute without using solution techniques, even when the network is small. Therefore, equations are linearized to reduce the computational burden. Convex relaxation and piecewise linear methods are used.
- For example, the power consumed by the pump is approximated using 2D convex combination theory.



Pump power linear approximation using the 2D piecewise linearization method.

Model

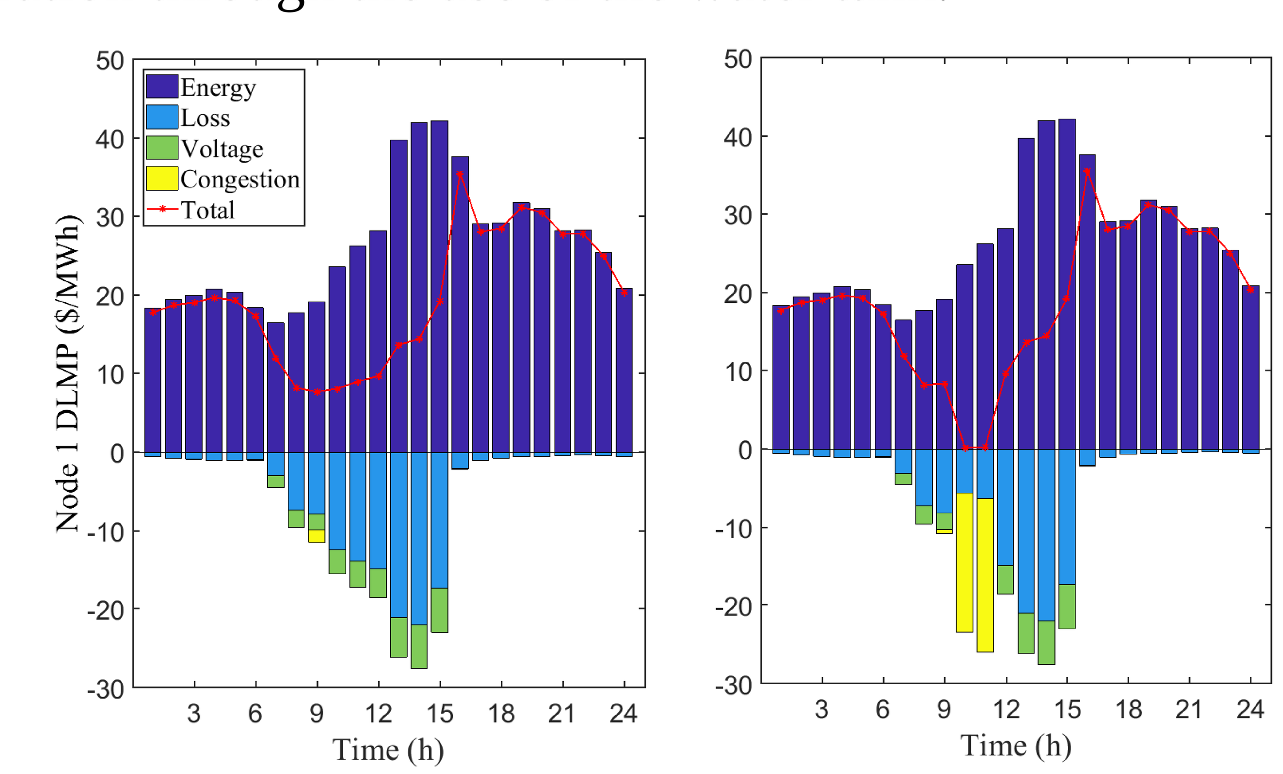
- An IEEE 13-bus distribution system connected to a 10-node water distribution network was used as a model to conduct case studies. The energy demands for the pumps in the water network are included in the electricity load for Nodes 1 and 2.



Integrated IEEE 13-node electricity and 10-node water distribution networks.

Conclusions

- The water network can positively impact the DLMP by reducing voltage violation and congestion penalties when VRE penetration is high. As a result, it can ease the operational challenges in the electricity distribution network.
- When combined with VRE generation, the coordinated water and electricity network offers a unique storage solution of excess VRE generation through the use of the water tank.



Node 1 component-wise DLMP for cases with (left) and without (right) a tank.