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Combined Analysis of Electricity and Heat Networks

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Abstract

The use of Combined Heat and Power (CHP) units, heat pumps and electric boilers increases the linkages between electricity and heat networks. Two combined analysis methods were developed to investigate the performance of electricity and heat networks as an integrated whole. These methods were based on models of electrical power flow and hydraulic and thermal circuits together with their coupling components, focusing on CHP units and circulation pumps. These two methods were the decomposed and integrated electrical-hydraulic-thermal calculation techniques in the forms of power flow and simple optimal dispatch. The comparison showed that the integrated method requires fewer iterations than the decomposed method. A case study of Barry Island electricity and district heating networks was conducted, showing how both electrical and heat demand in a self-sufficient system (no interconnection with external systems) were met using CHP units.

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Keywords: combined analysis; power flow; CHP; district heating

1. Introduction

Energy supply systems are usually considered as individual sub-systems with separate energy vectors, e.g. electricity, heat, gas or hydrogen. In the present Smart Grid vision, the role of electricity is most prominent with limited consideration of other energy networks. However, there is much benefit to be gained by considering the energy system as an integrated whole. Energy flows can be controlled, loads supplied from alternative sources and so security of energy supply increased. The most energy efficient operating regime can be determined and energy losses, costs or gaseous emissions minimised. Independent planning and operation of separate energy networks will unlikely yield an overall optimum, since synergies between the different energy vectors cannot be exploited. Thus, an integration of energy systems is highly desirable [1].

One of the examples of integrated energy networks is district heating systems with Combined Heat and Power (CHP) units. CHP units and in case electric boilers connected to a district heating system and together with heat pumps act as linkages between electricity and heat networks. These allow a coupling of the electricity and heat networks, and make use of synergies of the two networks for energy storage and the utilisation of distributed energy. The coupling components increase flexibility for equalising the fluctuations from the renewable energy. As the penetration of the coupling components increases, the

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interaction of electricity and heat networks becomes tighter and modelling electricity and heat networks as a whole becomes more important.

Several conceptual approaches for modelling the integration of energy systems have been published. Examples include energy hubs [1], multi-energy systems and distributed multi-generation [2-4], community energy [5], smart energy systems [6], and integrated energy systems [7].

In this study, Two methods for combined analysis were developed to investigate the performance of electricity and heat networks as an integrated whole. These two methods were the *decomposed* and *integrated* electrical-hydraulic-thermal calculation techniques.

2. Combined Analysis

Two methods for combined analysis were developed to investigate the performance of electricity and heat networks. It is based on the hydraulic-thermal model of heat networks and the electrical power flow model [8]. The electricity and heat networks are linked through the coupling components. CHP units generate electricity and heat simultaneously while circulation pumps consume electricity to circulate water in the district heating network.

For the power flow analysis, the electrical power at each busbar is specified except for the slack busbar. Heat power is specified at each node except for the slack node. Thus, the linkages between electrical and heat networks are the generation components (CHP units and in case electric boilers) at the slack busbar or slack node and the non-generation components such as the circulation pumps.

As an addition to the power flow, the use of optimal dispatch was added to the combined analysis and was solved by the Newton-Raphson method. The heat and electrical power generated from all sources were unknown.

Two calculation techniques were developed to calculate the operating points of the electricity and heat networks as follows:

- In the *decomposed* electrical-hydraulic-thermal method, the independent hydraulic equations and thermal equations and electrical power flow equations were calculated sequentially and linked through the coupling components. The sequential procedure is iterated at each time step until the solution converges to an acceptable tolerance.
- In the *integrated* electrical-hydraulic-thermal method, the electrical power flow equations, the hydraulic equations, and the thermal equations were combined and solved simultaneously as an integrated whole.

The structure of the integrated electrical-hydraulic-thermal method is shown in Figure 1. The hydraulic and thermal model equations are linked through the mass flow rates. The electrical power flow equations and hydraulic-thermal model equations are linked through the coupling components.

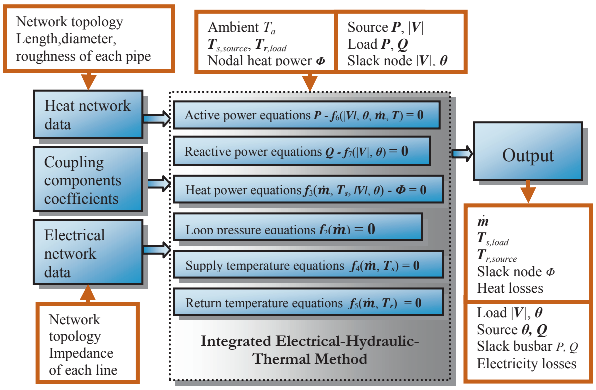


Figure 1: Structure of the integrated electrical-hydraulic-thermal method

In Figure 1, $\dot{m}$ is the mass flow rate (kg/s) within each pipe. Φ is the heat power (W_{th}) consumed or supplied at each node. T_s is the supply temperature. T_r is the return temperature. T_a is the ambient temperature. θ is the voltage angle. $|V|$ is the voltage magnitude. P is the active electrical power. Q is the reactive electrical power.

3. Case study

To demonstrate the capabilities of the combined analysis, a case study was conducted. The decomposed and integrated calculation techniques were used to investigate the Barry Island electricity and district heating networks, as shown in Figure 2. The heat network is a low temperature looped pipe district heating network fed by three CHP units.

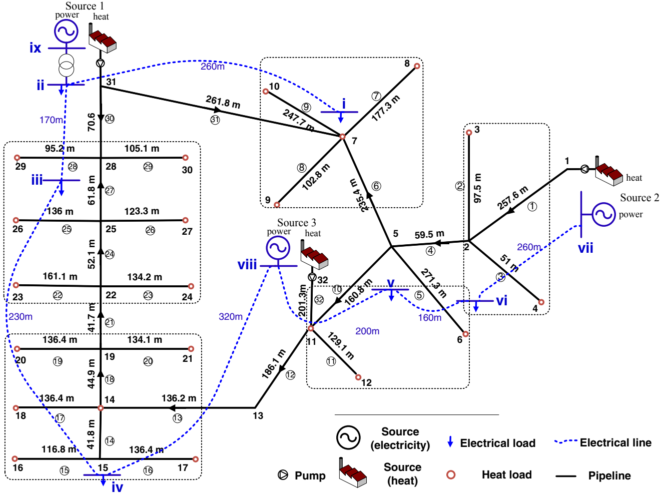
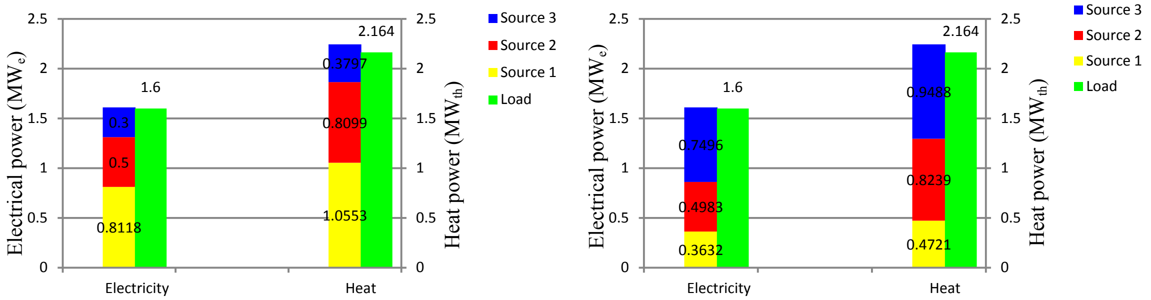


Figure 2: Schematic diagram of the electricity and district heating networks of the Barry Island case study

The Barry Island case study examined how electrical and heat demands in a self-sufficient system (no interconnection with external systems) were met using CHP units. The variables of the electrical and heat networks with reference to peak heat load conditions were calculated as shown in Figure 3.

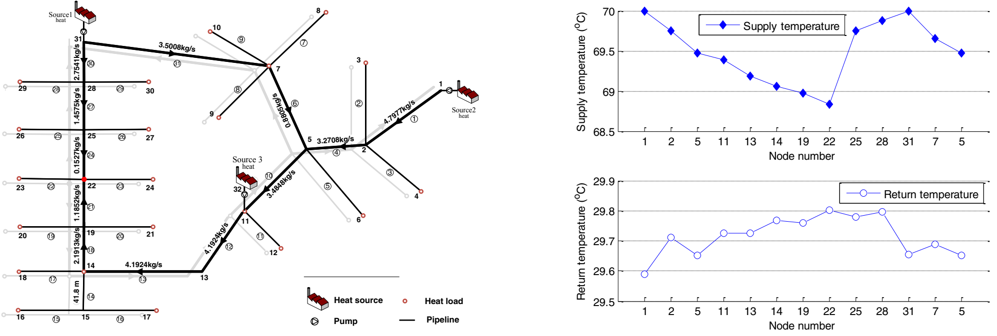
- For the power flow, the result of the heat and electrical power supplied from CHP units was shown in Figure 3 (a), where the generation of Source 3 was given. For the simple optimal dispatch, the results were shown in Figure 3 (b).
- For the power flow, the result of the mass flow rates within each pipe was shown in Figure 3 (c). The main flow route 1 – 2 – 5 – 11 – 13 – 14 – 19 – 22 – 25 – 28 – 31 – 7 – 5 is indicated using bold lines. The supply and return temperatures at each node in the heat network was shown in Figure 3 (d). Due to the nodal temperature mixing, the return temperature from node 22 to node 1 decreases unevenly.
- Voltage magnitudes at each load and voltage angles at each busbar in the electricity network were calculated.

The convergence characteristics of two methods: decomposed and integrated calculations, were compared. In the power flow, the *decomposed* method was solved in 33 iterations and the *integrated* method was solved in 14 iterations. In the optimal dispatch, the *decomposed* method was solved in 43 iterations and the *integrated* method was solved in 15 iterations. The comparison showed that the *integrated* method required fewer iterations. In a simple example network with 5 nodes, the *decomposed* method was solved in 16 iterations and the *integrated* method was solved in 12 iterations. The comparison showed that the number of the iterations of the *decomposed* method increased with the size of the networks.



(a) Heat and electrical power supplied from three sources for the power flow analysis

(b) Heat and electrical power supplied from three sources for the simple optimal dispatch



(c) Pipe mass flow rates (kg/s) in a flow route

(d) Supply and return temperatures of the nodes in a flow route

Figure 3: Results of the Barry Island case study

4. Conclusions

Two methods for combined analysis were developed to investigate the performance of electricity and heat networks as an integrated whole. Using the combined analysis, an engineering solution was provided to the Barry Island case study. These two methods were the *decomposed* and *integrated* electrical-hydraulic-thermal calculation techniques in the forms of the power flow and simple optimal dispatch. The *integrated* method required fewer iterations and the number of the iterations of the *decomposed* method increased with the size of the networks.

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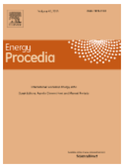

Biography

Xuezhi Liu is currently a Research Associate at the University of Manchester. Prior to this, he finished his PhD study at Cardiff University in 2013. His research topic is smart multi-energy systems.

Prof. Nick Jenkins

Dr. Jianzhong Wu is a Senior Lecturer in Institute of Energy, Cardiff School of Engineering. Prior to this, he was a Research Fellow at the University of Manchester from 2006 to 2008. He received his PhD in 2004 from Tianjin University, China and then worked there from 2004 to 2006. His final position in Tianjin University was Associate Professor. His research activities are focused on Energy Infrastructure and Smart Grids. He is a member of IEEE, IET and ACM.

Dr Audrius Bagdanavicius obtained PhD degree in the area of turbulent combustion at Cardiff University in 2010. From 2010 to 2013 he was working as research fellow at Cardiff. He conducted research on energy conversion and storage systems, and energy networks. In October 2013 he has joined Thermofluids research group at University of Leicester where he continues research in the areas of turbulent combustion, thermal energy conversion systems and energy networks. Before joining academia he spent almost 14 years in industry.