博士（工　学）　ジョージオス　ジョージアディス

学 位 論 文 題 名

ECONOMIC AND ENVIRONMENTAL EVALUATION OF DISTRICT HEATING COGENERATION SYSTEMS USING A NEW APPROACH BASED ON CLUSTERING PROCESS

（クラスタリング方式に基づいた新手法による地域エネルギー供給コジェネレーションシステムの経済性・環境性評価）

学位論文内容の要旨

Cogeneration or CHP (Combined Heat and Power) is the process where there is simultaneous production of usable heat and electricity in the same plant. The total energy efficiency of a cogeneration plant can be more than 80%.

For Sapporo City especially cogeneration represents a dynamic option for the city's energy structure. As a cold climate city, Sapporo has high heat demand for a long period throughout the year. This long heating period will secure extended operating time for the cogeneration plant and will contribute at the local level to the national challenge imposed from the Kyoto Protocol for reduction in carbon dioxide emissions.

The majority of works concerning cogeneration district heating networks deal with the problem of optimizing a system whose energy demand is already determined with a fixed service area or buildings. This work deals with a problem of non-fixed area. The objective of this work is to detect the optimum service area of a competitive cogeneration district heating network. The cogeneration network to be established will be more competitive compared to the conventional system of individual heating systems and electricity from the power grid.

The present thesis consists of 7 Chapters.

In Chapter 1 after a short briefing in the energy problem and the environment, an introduction to the concept of Local Energy Planning is presented. In the next sections the basic characteristics, main applications and the barriers for the wide introduction of cogeneration are presented, along with an overview of the research on cogeneration till recently. Finally the questions emerging during cogeneration planning, the objective and the assessment topics of the present work are presented.

In Chapter 2 there is an explanation of the model developed. In order to detect the service area and geographical expansion limits of the competitive cogeneration district heating network a new methodology based on clustering process, in other words combinatorial optimization, was developed. In the model the area in interest is divided into a number of small geographical zones. For each zone total floor area for each type of buildings, heat and electric demand and the zones coordinates are registered in a database. The aim of the model is to assemble under specific rules these zones in a group, named cluster. The model will connect in the cluster only the zones that give the highest potential to improve economic competitiveness of the system, offering also environmental benefits. The problem is generally complex involving numerous combinations of zones and pipeline routes as well as system structures. The final shape of the cluster to be created will represent the service area of the competitive district heating cogeneration network. The most important parameter in the computational method is the

Cost Reduction Factor (CRF), which is defined as the cost reduction rate that can be achieved if the conventional system is replaced by a district heating cogeneration network. During the clustering process the cogeneration network is optimized under two different objectives: minimum CO_2 emissions and maximum economic performance. The model according to the objective selected from the user will adjust for each hour the operation of the cogeneration system, either to the heat or to the electric demand for maximum performance. Effects of cogeneration hardware initial cost, hardware efficiencies, pipeline cost, fuel and electricity costs and hourly energy demand patterns are all included in the assessment. The model which is referred as Clustering Process (CP) model in the present work can be used also for the evaluation of cogeneration systems in individual buildings.

In Chapter 3 the database established in this work is presented. The area of Sapporo City was divided in 10,000 zones and for each zone total floor area for each type of building incorporated in the present work is registered. Hourly demand patterns for three seasons for the types of buildings, cogeneration hardware initial cost, hardware efficiencies, pipeline cost, fuel and electricity costs are shown in this chapter.

In Chapter 4 the model was applied for assessments of cogeneration for both cases, individual buildings and networks. For the cogeneration assessment in a network, a model area was created based on statistical analysis of Sapporo City data. The results showed significant reduction in CO_2 emissions compared to the conventional system. Concerning economic competitiveness over the conventional system, there was clear economic benefit only for hospitals and hotels for the case of cogeneration in individual buildings. The other types of buildings in the Sapporo study case did not offer any clear economic benefit. However the results showed that by networking zones, larger economic benefit can be obtained compared not only to the conventional system but to cogeneration in individual building as well. Building types which did not offer individually economic benefit with the introduction of a cogeneration system can be integrated cost effectively in a district heating cogeneration network due to better matching of electric and heat demand. The results showed for both cases that when minimum CO_2 is the objective the cogeneration system mainly adjusts to the heat demand. On the other hand the system mainly adjusts to the electric demand when maximum economic performance is the objective.

In Chapter 5 the model was applied in an actual area in the downtown of Sapporo City. Different scenarios were established representing different electricity price policies from the utility company, CO_2 taxation and distribution pipeline network initial cost. The results showed that a wide cogeneration network can be established, when the excess cogenerated electricity is remunerated at 75% of the utility price, and will offer 20%cost reduction compared to the conventional system. If the utility will not buy the excess cogenerated electricity the performance will slightly deteriorate, as the excess electricity is relatively low. However there is a significant deterioration if the utility will lower the price of electricity (user standpoint) and it will result in a shrinking of the cogeneration network. An increase in the cost of the pipeline network will lower the economic performance and will result in significant reduction of the network service area. Finally CO_2 taxation will improve the economic competitiveness of the cogeneration network. However it will not offer a significant increase in the service area, and further CO_2 reduction could not be achieved in the examined area.

In Chapter 6 using the model the concept of integrating solar photovoltaic energy on a district heating cogeneration system was examined. The suggested configuration of the hybrid solar-cogeneration network will have photovoltaic substations (nodes) placed in the wider area of the cogeneration network. The major objective of the solar network is to supply energy in a shelter site (school, large gymnasium centers, etc.) in case of emergency events as earthquakes or major damage in the central commercial power plants. During normal period is integrated in the cogeneration network and contributes to the energy savings. The initial cost of the solar system is generally high so that substantial subsidy is necessary for the system to be economically available. The critical subsidize rate for the solar photovoltaic system to be available in the hybrid network and the most cost effective area of the solar cogeneration network was assessed.

In Chapter 7 the conclusions concerning the present research are presented.

学位論文審査の要旨

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コジェネレーションシステム（CHP）はエンジンで発電を行う一方、その排熱を暖房や給湯に利用するものであり、総合的なエネルギー利用効率が８０％程度に達する省エネルギー機器の一つである。特に札幌のような北国では熱エネルギー需要が高いため、地域エネルギー供給システムとして有望である。コジェネレーションの研究はこれまでも多数あるが、限定された建物群を対象とし、そのシステムの最適化を行ったものが多い。これに対して近年、電力事業の自由化進展にともない、より広域をネットワーク化した地域エネルギー供給事業による高度な省エネルギー化実現のための環境が整ってきた。この場合、地域エネルギー供給の検討に際して、そのサービス領域が不確定であり、充分な最適化解析を行うことができないという問題が発生する。

そこで本研究はサービス領域が不確定な問題に対して、経済的に最も有利となる領域を探索する手法を提案し、従来システムと比べた地域エネルギー供給の経済性ならびに炭酸ガス削減の効果等について解析を行った研究をまとめたものである。その成果は以下のように要約される。

1）最適なサービス領域を決定することは、地域をメッシュに切った場合、小ゾーンの無数の組合せ問題となり、しかも温水パイプラインルートについても種々の選択が考えられるため、複雑なパズル問題となる。これを解く手法として、経済性を評価するCRF (Cost Reduction Factor) なる指標を定義し、このCRFが有利となるゾーンを組合せて領域を拡大していくクラスタリング方式を考案した。この手法により、クラスタリング過程中のコスト変化や炭酸ガス削減効果を比較検討することができ、目的に応じたサービス領域の決定を可能とした。

2）本解析では建物ごとの時間別エネルギー需要変化、エネルギー価格、システム価格などのデータが必要であるが、一般にこうしたデータの入手は容易ではない。本研究では北海道におけるこうしたデータの収集を行った。

3）コジェネレーションは高い省エネルギー性があるものの、従来システムと比べて経済的に有利となる条件は限られており、ホテルや病院以外ではむしろコスト高となることを示した。しかし、地域エネルギー供給により建物群をネットワーク化することにより、熱電比のバランスの向上ならびにガス料金単価の低減効果が生じ、大幅に経済性が向上することを明らかにした。また、経済性のみを追求して稼働率を単に上げるような運転をした場合には、コジェネレーションによってむしろ従来システムよりも炭酸ガス排出量が増加する場合のあることを見出した。

4）電力系統との電気の売買価格、電気料金変化、パイプラインコスト、ならびに環境税の導入などに関したシナリオについて、地域エネルギー供給コジェネレーションシステムの評価を行った。その結果、系統連系の可否による影響は少ないが、僅かな電力料金の低下によりコジェネレーションシステムの成立領域が大幅に減少すること、また環境税の導入は大きなサービス領域の拡大に繋がらないことなどを明らかにした。

5）地域エネルギー供給コジェネレーションシステムに太陽電池を組み合わせ、非常時のエネルギー供給と平常時の経済性向上を図るシステムについて解析を行った。その結果、従来システムと同程度の経済性を保つためには太陽電池パネルのイニシャル価格の約５５％程度の補助が必要であることを明らかにした。

これを要するに、著者はサービス領域が不確定な地域エネルギー供給問題に関して、新しいクラスタリング手法を提案し、従来システムと比較した地域エネルギー供給の経済性ならびに炭酸ガス削減の効果等について解析したものであり、熱工学およびエネルギー工学の発展に寄与するところ大である。

よって、著者は北海道大学博士（工学）の学位を授与される資格あるものと認める。