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Energy Hubs' Structural and Operational Linear Optimization with Energy Storage Elements

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Abstract:. In this paper a robust optimization problem ofan energy hub operations is presented. An energy hub is amulti-generation system where multiple energy carriers inputto the hub are converted, stored and distributed in order tosatisfy energy demands. The solution to energy hub operationproblem determines the energy carriers to be purchased andstored in order to satisfy the energy requests while minimizinga cost function. A control approach using Robust Optimization(RO) techniques is proposed; bounded uncertainties on energyhub parameters are taken into account and RO methods areexploited to gain robust solutions which are feasible for allvalues, or foraselected subset, of uncertain data. Simulationresults underline the benefits resulting from the application ofthe proposed approach to an energy hub structure located inWaterloo, Canada.
Keywords: Power system, optimization, multiple energycarriers, simulationresults,proposedapproach

1. Introduction

Many of today's energy infrastructures evolved during the second half of the twentieth century and it could be questioned if they meet the requirements of tomorrow. Besides congested transmission systems, many facilities are approaching the end of their prospected life time. In addition to that, other issues such as the continuously growing demand for energy, the dependency on limited fossil energy resources, the restructuring of power industries, and the general aimof utilizing more sustainable and environmentally friendly energy sources raise the question whether piecewise changes of the existing systems are sufficient to cope with all these challenges or a more radical change in system design beneeded.Various scientific studies have investigated future scenarios based on boundary conditions given by today’s structures, such as standardized electric voltage and gas pressure levels. Although these studies provide important insights, they often result in solutions that comply with the existing systems; possibly interesting and more long-term oriented solutions are “hidden”, as they lie beyond system-given boundaries. In contrast to these studies, a project named Vision of Future Energy Networks was

initiated at ETH Zurich together with partners2 that aims at a greenfield approach for future energy supply systems. Restrictions given by the existing systems are basically neglected in order to determine “real” optima. The consideration of multiple energy carriers, not only electricity, represents one of the key characteristic of this project.[1] It is believed that synergies among various forms of energy represent a great opportunity for system improvements. Besides the possibilities of modern information technology, state-of-the-art as well as emerging and looming energy technologies, e.g. fuel cells, are taken into account. The time horizon for implementation is set to 30 to 50 years from now. Thus, the basic question to be answered is: “How should energy systems look like in 30 to 50 years, and what can be expected from them?” It was soon realized that only a few

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established tools are available for the integrated analysis of multiple energy carrier systems, thus the project focused in a first phase on developing a modelling and analysis framework. In the second phase, which recently started, optimal system structures and operation strategies are determined and compared with conventional infrastructures using the developed tools. The result of this phase is the greenfield approach. The final phase of the project is dedicated to identifying transition paths and bridging systems leading from today's systems to the Under these conditions, two key approaches are reasonable: transformation, conversion, and storage of various forms of energy in centralized units called energy hubs, and combined transportation of different energy carriers over longer distancesinsingletransmissiondevicesnamedenergyinterconnectors. identified optimal structures.[1]

2. Systems applications hub energy:

A concept hub energy systems with smart grid Microgrid and can also be used in the modeling and optimization of energy through the use of microgrid several hub energy systems linked Used in the modeling and the design Simulation and simultaneous use of electricity and gas network using the hub energy system

2.1. Model of operation of the elements the hub energy system:

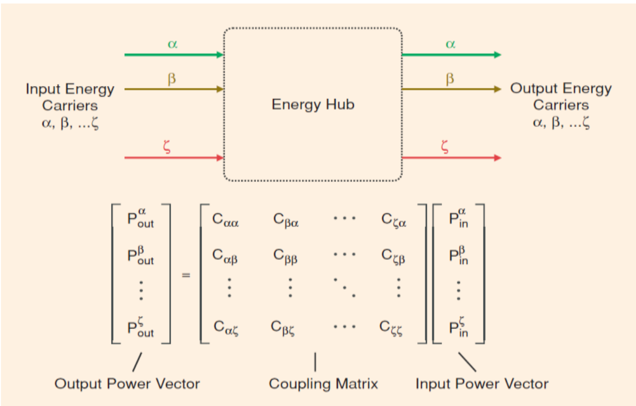

Figure 1: Modeling the transformation of power through an energy hub.

Reliability and availability of energy supply is an importantdesign criterion; therefore, models have also been developedfor this kind of investigation. Failureandrepairratescan bedefined forallcomponents in the system. Considering anenergy hub, failure and repair rates of the coupling elementscan be stated in matrices similar to theconversion matrix. The influence of theenergy hub, i.e., an increase or decreaseof availability between input and outputof the hub, can be analyzed with thisapproach. Furthermore, the model can beused in the optimization process.Various optimization problems canbeidentifiedwhenconsideringintegratedmulticarrier systems. The basic questionof combined optimal power flowis how much of which energy carriersthe hubs should consume and how theyshould be converted in order to meetthe loads at their outputs [2]. This is anoperational problem. In the planningphase, the optimal structure of the hubmay be of interest, which can be foundby determining the optimal couplingmatrix that describes the conversions within the hub. Converterscan then be selected to establish this optimal coupling,and missing technologies can be identified. Theseand other optimization problems have been formulatedand analyzed using various criteria such as energy costs,system emissions, and transmissionsecuritymeasures.Multiobjectiveoptimization can be performed by combiningdifferent criteria in composite objective functions[2]

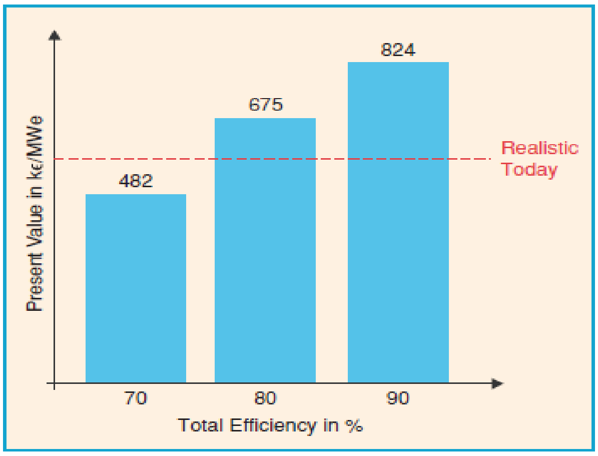

Figure 2: Result of investment analysis

The present valueof the device (per MW electrical output) increases with itstotal efficiency, since more energy cost are saved in eachperiod if the efficiency is higher. Today's investment cost forCHP units of comparable size are in the range of €500,000 per MW electrical output (rated). The conclusion that canbe drawn from this plot is that an investment is reasonable ifa total efficiency of more than 75% can be achieved.[2]

3.Evaluation of Investment

When talking about completely new systems on the greenfield, the question of cost plays one of the most importantroles. Energy prices and savings in energy cost can be estimated,although assumptions are often critical. The evaluationof investment costs is more difficult. How much willnew technologies such as fuel cells costs in 30–50 years?

Toavoid speculations based on doubtful assumptions, thequestion is put differently[3]. The justifiable investment costsare determined by comparing the performances of the conventionaland the proposed/assumed system. For example,energy cost and CO2 taxes can be compared for a conventionalsystem and an optimized greenfield structure. Fromthe annual savings due to higher energy efficiency and lessemissions of new technologies, a present value can bedetermined that represents the break-even investment costof the new technology. With this method, results stilldepend on critical assumptions as inflation, compounding,and risk. However, using this tool for sensitivity analysisyields deeper insight into economics; it enablesidentificationofthesignificantparameters.shows an example where the sensitivitybetween total energy efficiency ofa cogeneration-equipped energyhub and its justifiable investmentcost was determined. In this particularcase, results show that evenstate-of-the-art technology couldkeep up with therequirements,i.e.,installingsuchcogenerationdevices would be reasonable froman economic point of view (undercertain assumptions).[3]

4. A First Application

The energy hub idea was picked upby a municipal utility in Switzerland,the Regionalwerke AG Baden,
which plans to build an energy hubcontaining wood chip gasificationand methanation and a cogeneration plant. The idea is togenerate synthetic natural gas(SNG) and heat from woodchips, a resourcewhich is available in the company's supplyregion. The produced SNG can then either be directlyinjected in the utility's natural gas system, or convertedinto electricity via a cogeneration unit and fed into the electric distribution network. Waste heat, which accrues inboth cases, can be absorbed by the local district heatingnetwork. The whole system can be seen as an energy hubprocessing different energy carriers—wood chips, electricity,heat, and SNG[3]. In addition to these energy carriers, thegasification process requires nitrogen and steam, whichhave to be provided at the hub input. gives anoverview of the hub layout. The new thing here is not thetechnology used (converters), but the integrated planningand operation, which is believed to enable better overallsystemperformance.Thedevelopedmulticarrier analysis tools can be appliedto this energy hub to answer some fundamental questions.

1. How should the converters berated, i.e., how much electricity, SNG, and heat shouldthe hub be able to produce?

2.How should the energy hub be operated, how much electricity/SNG/heat should begenerateddepending on the actual load situation?

3.Which and how much of which energy carrier should the energy hub be able to store—wood chips,SNG, heat, electricity?

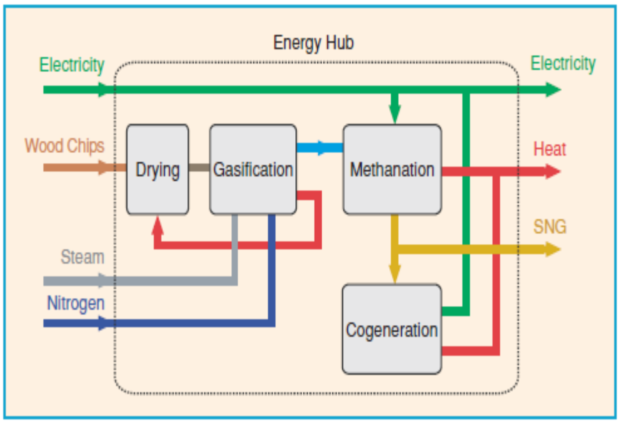

Figure 3: Sketch of the energy hub to be realized by Regionalwerke AG Baden,Switzerland.

How does the energy hub influence theoverall system performance in terms of reliability/availability, energy efficiency, and power quality?The project is still in the planning phase. A first version ofthe hub, which only contains wood gasification and cogenerationunits, should be realized by 2009. The full version, which then includes the methanation part thus enablinginfeed of SNG into the natural gas network should start runningin 2011.[3]

5. Use loud management

consumption generally refers to programs whose impact on consumption patterns of customer electricity consumption Bashd. of which are power companies to time power consumption, the field for the benefit of consumers and even provide their own.

5.1. loud Response:

Response time is one of the the new developments in the field of DSM, which means the participation of consumers in improve energy consumption patterns of. The overall objective of loud response programs to achieve two important features are network reliability and reduce prices.According to the definition provided the DOE in February of 2006, demand response, change in electrical energy consumption by consumers of normal consumption patterns, in response to changes in electricity prices or in response to stimulus spending set to reduce power consumption (at hours when electricity prices above market or system reliability dongerThe importance of loud responseToday's anticipated load curves of the growing consumption of electrical energy that supply a lot of disposable investment needs. In these circumstances, could help to solve this dilemma Barman meet the The importance of demand response, when it becomes clear that knowing the frequency Applied fiscal profits for consumers and even the network itself provides, inter alia, reducing the amount of blackouts, reduce production costssmooth undercarriage load curve, helping to stabilize market prices and ..[4]

6.Modeling hub energy

The model and the objective functions and constraints brought about the need to solve equations hub energy system. we. In this chapter the results of the simulation and change initiatives are taken to optimize the energy system. The result shows the CHP unit type 1 between 3 availableCHP units has been chosen because of its lower investmentcost and higher efficiency compared to other units. Also thetransformer unit 3 and the heat exchanger type 3 are chosenbased on their upper efficiency and nominal power. Bothenergy storage units are used in the hub structure. Obtainedstructure of the hub using this optimization is shown in Fig 4.

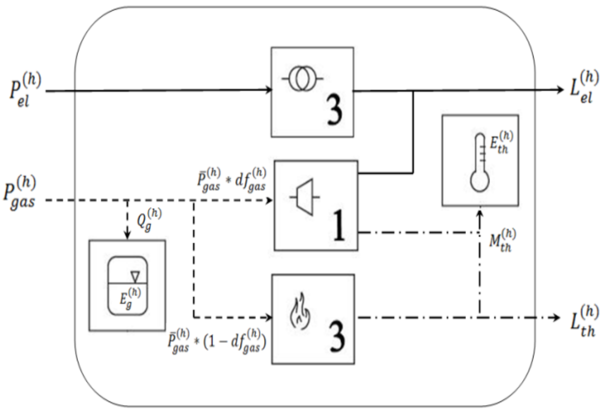

Figure 4: Hub structure which is obtained through optimization

Modeling of the problem is in a way that the optimizationsoftware will check all the generation scenarios, containingusage of two or more energy convertors or storages from eachtype at the same hour. but based on output loads, aftersimulation it is decided to use one unit of each element asshown in Fig 4.

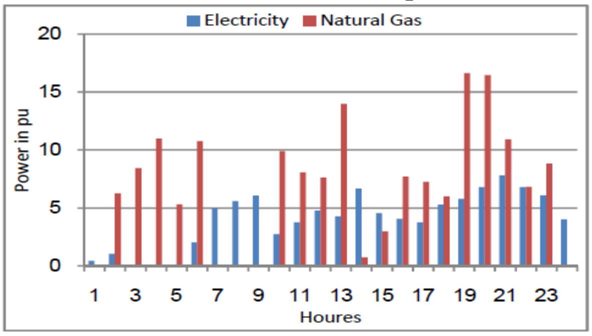

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Figure 5: The types and amounts of the energy hub inputs

As an operational result of the optimization, the types andamounts of the energy hub inputs are shown in Fig. 5. Also thestored energy in the gas and thermal storage units are shown inFig. 6. This figure shows the storage units stored the energyin the off-peak hours and use this energy to serve the loads inthe peak hours which the input energy cost is higher.[5]

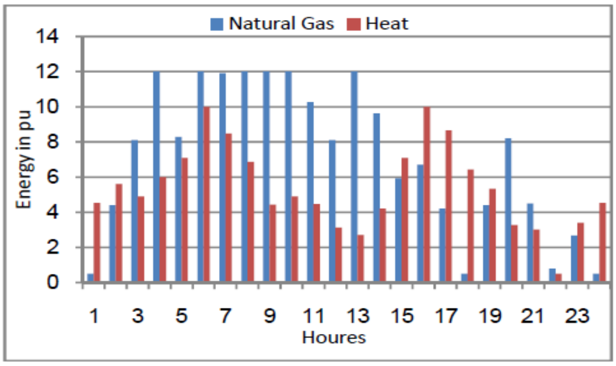

Figure 6: The stored energy in the gas and thermal storage units

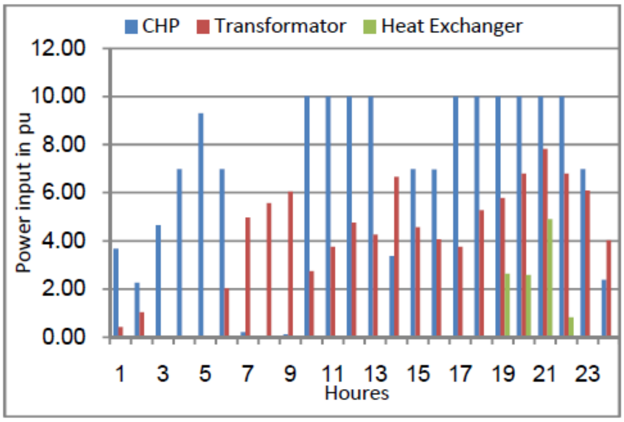

Figure 7: The input power of the energy converter units in the hub

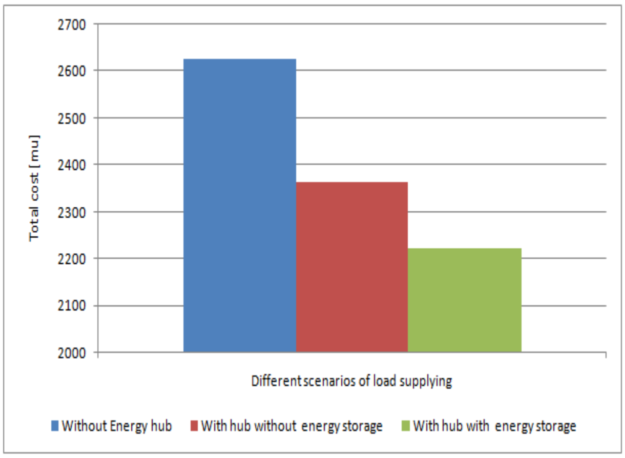

Figure 8: Economical comparison of different load supplying scenarios

The input power of the energy converter units are shown inthe Fig. 7. As shown in this figure, in the peak hours the CHPunit works in its full load which shows the economic benefitsof CHP units. On the other hand in the night hours (18 to 23)which in addition to the peak of the electrical load, the peak of thermal load occur, the heat exchanger unit is used to serve afraction of thermal load.Finally, total cost of the hub's 24-hour operation whichconsists of the energy cost and the units depreciated installationcost is 2222.62 mu. To investigate the economic impact of thestorage units, the problem is solved again without these units.The total cost of the hub's 24-hour operation in this situation is2364.93 mu, which is higher than the situation with the storageunits. This result shows the economic benefit of the storageunits which in addition to improving the system's reliabilitydecrease the operational cost of the system. In another scenariothe output loads are supplied directly with the network'selectricity and a typical boiler which consumes natural gas,without using the hub. Total cost of 24-hour operation in thisscenario is 2625.7 mu which is significantly higher than thetwo. previousscenarios.Fig.8showstheobtainedeconomicalresults in different scenarios briefly.[5]

7.Conclusions

The research project Vision of Future Energy Networks distinguishes itself from others by aiming at a greenfield approach, integrating multiple energy carriers, and considering a timeframe of 30 to 50 years from now. The definition of energy hubs and the conception of combined interconnector devices represent key approaches towards a multi-carrier greenfield layout. Models and tools for technical (e.g. power flow, reliability), economical (e.g. energy and investment cost), and environmental (e.g. CO_2 emissions)investigationsinmulticarrierenergysystems have been developed and used in various case studies. The energy hub concept enables new design approaches for multiple energy carrier systems. The flexible combination of different energy carriers using conversion and storage technology keeps potential for various system improvements. Energy cost and system emissions can be reduced, security and availability of supply can be increased, congestion can be released, and overall energy efficiency can be improved. The developed modelling and analysis framework provides suitable tools for the planning and operation of multiple energy carrier systems. Future work includes the development of dynamic modelling and analysis tools (e.g. for evaluating stability), and the control of a system of interconnected energy hubs (centralized versus decentralized, agent-based, etc.). A further activity just started concerns the risk analysis, including financial risks, of the system. The concepts will be further refined and elaborated in more detail using realistic examples and case studies.

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