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Planning of Multi-carrier Energy System (Energy Hub) with Considering Reliability Indices

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Abstract:. Planning and reliability are very significant factors in power systems. In this thesis, after introducing multi-carrier energy systems, reliability, planning and mentioning the optimization methods, an attempt has been made to statically investigate planning multi-carrier energy system with regard to energy reliability indices. Therefore, one multiple system containing different kinds of elements with various efficiencies is taken into consideration and the cost of energy carriers in different hours in the target year is calculated. By the genetic hybrid optimizing algorithms and with the help of the mathematical methods, the best condition for installing elements in different times in static model framework was determined and the exact amount of input energy is calculated with reference to rate of demand for electronic and thermal energy. Finally, by extending the period for planning system to one-year period, the results are evaluated in a sample system.

Keywords: Multi-carrier Energy System, planning Multi-carrier Energy System, Energy Reliability Indices, Multi-carrier Energy, Static,

1.Introduction

Energy hub acts as an energy receiving, converting andstoring unit in the consumer side and variety of equipmentssuch as combined heat and power units (CHPs), transformers,power electronic equipments, compressors, heat exchangers,energy storage units and etc are installed inside it based onrequired output load. Using these equipments, energy hubreceives energy carriers from their upstream network in itsinput and delivers required output loads to the consumers in itsoutput. Before raising the energy hub concept, studies onsimultaneous operation of gas and electricity networks andtheir optimal power flow were carried out Offering thenew concept of energy hub, variety of case studies wereopened in front of researchers such as extending new conceptsabout energyhubs modeling the hub and determiningenergy converting equations in different nodes defining the
coupling matrix between hubs input and output and optimizinghubs power flow structural optimization of energy hub anddetermining elements that should be
installed inside the hubbased on output loads and etc. In reference promotingthe concept of co and trigeneration systems, new systemstitled as multi-source multi-product systems (MSMP) areintroduced which are based on energy hub concept. References
present a stable model for conversion and storage of
multiple energy carriers like electricity, natural gas, hydrogenand local heat and use it for system optimization.Energy hub's concept has been developed in order toguarantee an optimal method for supplying different loads in amulti-carrier energy system. Optimal

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supplying of output loadsin a hub depends not only on the proper operation of energy
hub, but also depends on the structure of the hub and attributesof its energy convertor or storage elements. So, in order toachieve a global optimum condition for supplying hub's outputloads, it is required to optimize the structure and the operationof the hub simultaneously. Among all studies carried out upuntil now, most of them are focused on operational orstructural optimization separately and their simultaneousoptimization is rarely reported. In this paper, a simultaneousoperational and structural optimization of energy hubconsidering energy storage elements is proposed in acompletely linear format. In previous studies, the models wereoften non-linear (MINLP) which increases risk ofdiverging or sub-optimality and slower the solve process. In theproposed method, the whole model is linearized (MIP) whichleads to a faster solve process and globally optimal obtainedresults. Finally, a comprehensiveexample is presented andsimultaneous operational and structural optimization is appliedon a desired energy hub using GAMS optimization softwareObtained result shows the efficiency of supplyingelectrical and thermal loads using energy hubs, especially inpresence of energy storage elements and confirms its obviouspreference in comparison to the traditional methods ofsupplying consumer's demands. The superiority of proposedlinear method is observed obviously in its higher accuracy andspeed of calculations in comparison to the previous non-linearmethods.[1].

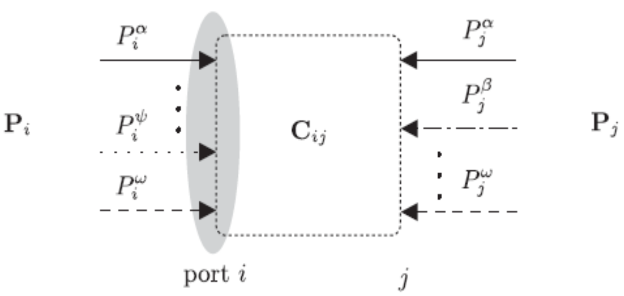


Figure 1: Port to port coupling for a hub containing input and output ports

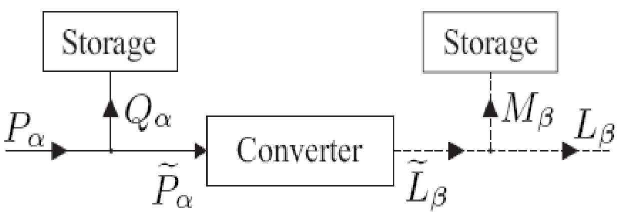


Figure 2: Input and output power of energy converter in a hub with energy

2. Modeling of energy storage in hub

Considering Fig. 1 that contains a storage interface and an idealenergy storage element, the relation between transferred power$Q\alpha$ and internal stored energy $E\alpha$ is defined as stated in

$$\tilde{Q}_\alpha = e_\alpha Q_\alpha = \frac{dE_\alpha}{dt} \approx \frac{\Delta E_\alpha}{\Delta t} \quad (1)$$

In $e\alpha$ is declared as the storage efficiency that containsthe efficiency of storage interface which converts the energycarrier exchanged with the system to the internal stored carrier.Energy hub can include energy storage elements in its input,output or between the energy converter elements. Input andoutput powers of converters are modeled as depicted in Fig. 2input powers of converters are shownby P and output powers are shown by L.

$$\tilde{P}_\alpha = P_\alpha - Q_\alpha \quad (2)$$

$$L_\beta = L_\beta + M_\beta \quad (3)$$

Consequently, the coupling of energy between hub's input andoutput is modeled as in

$$[L + M] = C[P - Q] \quad (4)$$

In M shows total stored power in output and Q shows totalstored power in input side[2].

3.Applyinglinearoperational andstructuraloptimizationinenergy Hub and its Results

In this part it is considered that we have an empty hub asdepicted in Fig. 3. The hub is connected to the electricity andnatural gas networks in its input and must supply electrical andthermal loads in its output
As depicted in Fig4, a set of elements are available fordesired hub and the appropriate ones should be selected usingstructural optimization. We have three types of combined heatand power (CHP) units in the first row of the figure, three typesof power transformers in the second row and three types ofheat exchangers in the third row. Finally in the last row of thefigure we have heat and natural gas storage units.

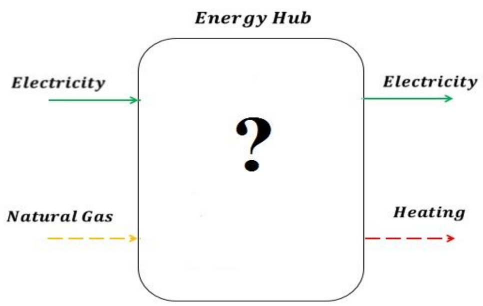


Figure3: Desired energy hub for structural and operational optimizations

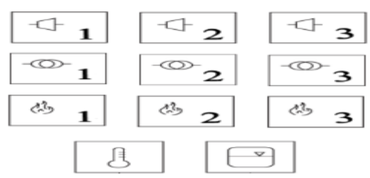


Figure4: Available energy converter and storage elements for the desiredhub

4. Reliability

Reliability and availability of energy supply is an important issue, therefore models have also been developed for this kind of investigations. Failure and repair rates can be defined for all components in the system. Considering an energy hub, failure and repair rates of the coupling elements can be stated in matrices similar to the mentioned coupling matrix in and this has been elaborated in . It is out of the scope of this paper to go into the details of such an analysis, but the general conclusions can be illustrated by an example. shows the German standard weekday electrical load profile for a small business, scaled to a total annual consumption of 20 MWh. The electrical load can be supplied by: Direct electrical connection, capacity[2].

$$C_{ee} = 10\text{ kW} \quad (5)$$

Conversion chemical to electrical, capacity

$$C_{ce} = 2\text{ kW} \quad (6)$$

Conversion thermal to electrical, capacity

$$C_{te} = 0.5\text{ kW} \quad (7)$$

As can be seen from Figure 4 the load can during different time intervals be supplied through different combinations of the three supply channels given above.

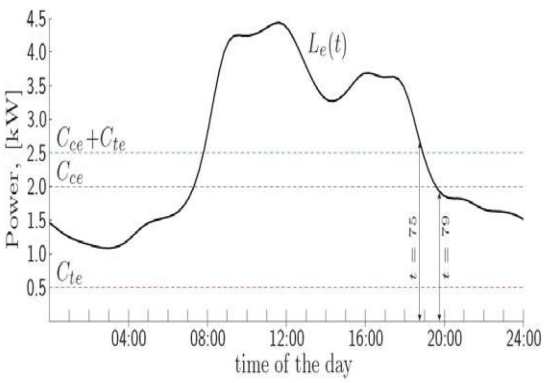


Figure 5: Electrical load curve of a small business of total annual consumption of 20 MWh. Indicated are the capacities of the different converters as given in text.

Obviously the load can be supplied by the electrical connection alone, but during different time intervals the load or part of the load can be supplied by the chemical to electrical connection alone or in combinationwith the thermal to electrical connection. This will increase the reliability indicators of the system, e.g. the availability and the Expected Energy Not Supplied, EENS. The detailed modelling using Markovtechniquesandnumerousapplication examples can be found in

5.System optimization

Various optimization problems can be identified when considering integrated multi-carrier systems. The basic question of combined optimal power flow is how much of which energy carriers the hubs should consume and how should they be converted in order to meet the loads at their outputs. This is an operational problem. In the planning phase, the optimal structure of the hub may be of interest, which can be found by determining the optimal coupling matrix which describes the conversions within the hub. Converters can then be selected in order to establish this optimal coupling, and missing technology can be identified. These and other optimization problems have been formulated and analysed using various criteria such as energy cost, system emissions, transmission security measures, etc. Bi- and multi-objective optimization can be performed by combining different criteria in composite objective functions. In reference [4] the details of the optimization procedure have been described. Here only one interesting result will be highlighted. The relationship between the outputs, i.e. the load vector **L**, and the input vector, **P**, in Figure 5can in matrix form be written as:

$$L = Cp \quad (8)$$

where **C** is the coupling matrix in Figure 4. A general optimality condition of the hub can then be written as:

$$\Psi\Lambda = C \quad (9)$$

where is the vector of system marginal prices and Λ the vector of hub marginal prices. This latter equation is the equivalent to the well-known economic dispatch rule for generators in electrical systems, the so called “equal incremental cost rule” as illustrated in Figure 6.

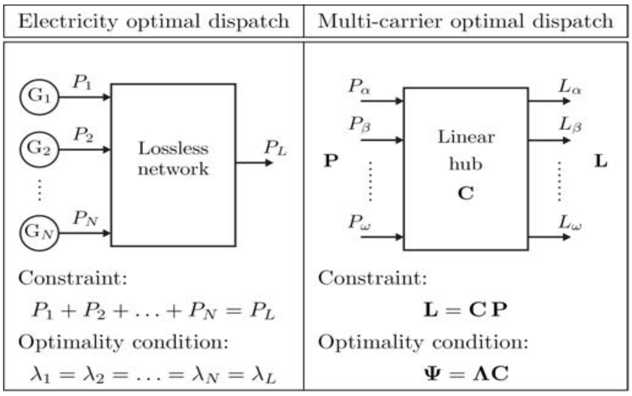


Figure 6: Electricity and multi-carrier optimal dispatch.

6. The objective function

$$F = Operation\ cost + Emission\ cost + cost(Ens) \quad (10)$$

That objective function consists of three parts. The first part is related to the cost of installing equipment in one year's time:The first part of the energy costs and the cost of operation of the equipment, including the cost of buying electricity from the grid . production at prices determined by the network, the cost of energy produced by the plant is the simultaneous production of electricity and heat.

(11)

$$Operation\ cost = 365 \times \sum_{t=1}^{24}\left(\sum_{i=1}^{Ni}[c_1 + c_2 P_i(t) + c_3 P_i^2(t)] + \sum_{\alpha=1}^{N\alpha}[P_\alpha(t) \times \text{cost}\,P_\alpha(t)]\right)$$

In the above passage c_ (1) the fixed cost maintenance and c_2 and c_3 represents the variable costs and exploit are chp, α type and i-type fuel energy input to the system integrated components installed.Cost P (t) electric In energy prices according to pu be purchased from the grid. The second part of the cost of offenses pollution and emissions of toxic carrier of change

$$Emission\ cost = 365 \times \sum_{t=1}^{24} \sum_{\alpha=1}^{N\alpha} [E_1 + E_2 P_\alpha(t) + E_3 P_\alpha^2(t)] \quad (12)$$

E_3 and E_2 E_1 coefficients and coefficients are apply the cost of pollution and air quality are determined by the controller.Here factor θ is added to the system of power sharing between the boilerthe inlet gas chp defines the value of θ is between zero and one

Equations describing the system can be expressed as a matrix:

$$L(t) = CP(t) \quad (13)$$

$$\begin{bmatrix} L_e(t) \\ L_h(t) \end{bmatrix} = \begin{bmatrix} \eta_T & \vartheta \times \eta_{chp_e} \\ 0 & \vartheta \times \eta_{chp_h} + (1-\vartheta)\eta_B \end{bmatrix} \begin{bmatrix} P_e(t) \\ P_g(t) \end{bmatrix} \quad (14)$$

In the above passage coefficients Pe and Pg by express carrier power and carrier gas are also η_T efficiency of trans-η (chp (e)) electrical efficiency chp and η (chp (h)) thermal efficiency chp and η_B efficiency heat Boilers are The fourth part of the cost of supply of energy is not cost Reliability

$$cost(ENS) = ENS_i \times Rens_i \quad (15)$$

In the above passage coefficient r Ens and Ens are not represents cost and lack of energy not supplied

The importance of an integrated system to optimize the use of energy carriers according to the constraints is that the current system, it becomes clear. Thus, the constraints to specify some of the variables are used such the limitations include the following

$$0 \le P_i(t) \le P_{i_{max}} \quad (16)$$

$$i \in e, g \quad (17)$$

And of the the limitations is that the variable values in the relationship between input and output connection and apply a matrix parameters

$$L_e(t) = \eta_T P_e(t) + \vartheta \eta_{chp_e} P_g(t) \quad (18)$$

$$L_h(t) = \vartheta \eta_{chp_h} P_g(t) + (1-\vartheta)\eta_B P_g(t) \quad (19)$$

At this stage, in addition to the proposed constraint must be considered in the limit θ

7. The introduction of an integrated system of exploitation

Hub energy system under consideration is taken to include transformers, combined heat and power system (CHP) and boiler (Boiler) system consists of electrical energy and natural gas and the electricity and heat output is obtained. Duration of operation 24 hours a day, 365 days is taken into account. The system can select the most suitable equipment options.[3].

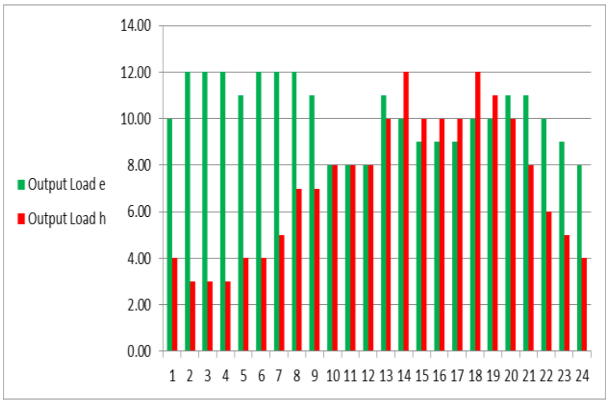
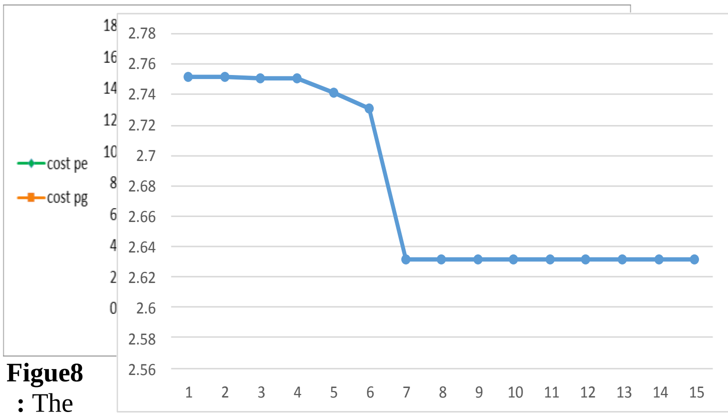


Figure 7: The question of electricity and heat

In energy prices in the calculation and determination of the amount of gas and electricity is very effective input, this model in energy prices is evaluated according to the following diagram



Figue8 : The cost of electricity and gas energy input to the system

After the simulation and run the software according to the demand of electricity and heat, the system of transformers 2, Chp 2 and boiler 1 usesElectric and gas input is calculated by the optimization software in the following diagram[4].

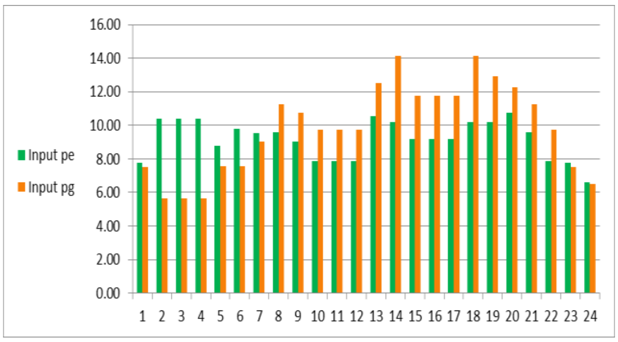


Figure 9: The amount of electrical energy input to the system in the first scenario study

Electricity and gas energy input to the systemIn this model, taking into consider the amount of gas boiler in the hub energy input by a factor θ is divided between the boiler and Chp Gams is determined by optimization software, the following diagram to determine the value of θ[5].

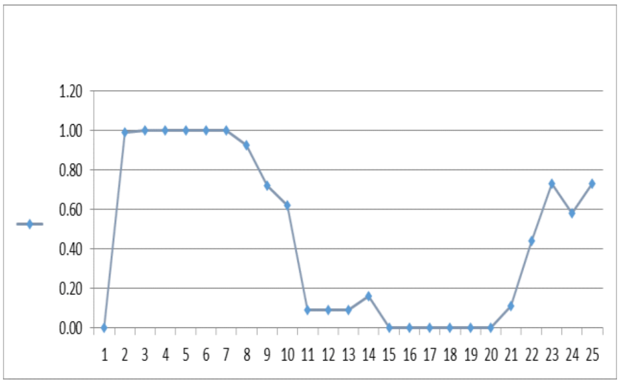


Figure **10**: The division of power between the inlet gas Chp, boiler

Figure 11: The results of the objective function reliability for multiple repeat

7.conclusion

In this paper a linear method is presented for modeling andformulation of the energy hub's structural and operationaloptimization problem. The MILP model of this problem hasbeen introduced here. Branch and cut algorithm is used forsolving this problem and because of the model's linearity, it isguaranteed to obtain the global optimum solution and thesolution would be converged with a higher speed incomparison to the non linear models. The gas and thermalstorage units are considered and a multi-period optimizationproblem is solved. Utilizing the energy hub increases the loadserving reliability and decreases the operational cost. Theresults show the usefulness of storage units and the benefit ofMILP modeling.

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