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Multi-Energy Flow Calculation Method for Regional Integrated Energy System Based on Intelligent Recognition Energy Hub

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ABSTRACT

In order to show the significance of Distributed Generation (DG) based on renewable energy and energy storage units in Regional Integrated Energy System (RIES), a model of RIES including power system, gas network system, and heating network system is presented in this paper. Furthermore, an intelligent recognition energy hub model considering energy utilization priority is used to describe the coupling of multi-energy. Finally, a case study of three scenarios is employed to examine the feasibility of the proposed model.

Keywords: Regional Integrated Energy System, energy hub, energy utilization priority, multi-energy flow

NONMENCLATURE

Abbreviations	
MEF	Multi-energy Flow
RIES	Regional Integrated Energy System
PDS	Power Distribution System
GNS	Gas Network System
HNS	Heating Network System
EH	Energy Hub

1. INTRODUCTION

Regional Integrated Energy System (RIES) breaks the existing energy management. It can effectively mitigate the environmental pollution problem, increase the efficiency of multi-energy utilization while meeting the demand for power, thermal energy cool, and natural gas. A typical RIES couple multiple sorts of energy through units like CHP, heat pumps, and gas turbines. These units are known as energy hub (EH).

With the development of technology in renewable energy generation and energy storage, the accuracy of the EH model is required to meet higher requests in energy management. Recently, the study of energy hub in RIES received attention worldwide. In Ref. [1], a method in analyzing the gas-power-coupling system is proposed where the gas turbine is regarded as a gas load in GNS and generator unit in power system. The conception of EH was firstly proposed in Ref.[2], using an I/O two-port network to describe energy conversion. Moreover, models of CHP units and CCHP units are separately proposed in Ref.[3,4] in the combined analysis of energy flow of RIES under the model in Ref.[2]. The operation and planning optimization models are reviewed in Ref.[5] and potential research topics on EH based on the latest energy technology are also proposed.

In previous studies on RIES and EH, the superiorities of DG and energy storage cannot be embodied through the models. As the approach renewable energy connects to the power grid, DG reduces the heavy reliance on the high-pollution generation and gets high priority in end-used energy utilization. Meanwhile, energy storage units can shift multi-energy from peak periods to off-peak periods, which benefit to the stability of RIES. However,

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the existing model of energy cannot reflect such characteristics.

In this paper, the solution algorithm of multi-energy flow is reviewed first. Besides, a new EH model considering energy utilization priority is proposed to describe energy coupling. Finally, a case study is employed to examine the feasibility of the proposed model.

2. MULTI-ENERGY FLOW CALCULATION MODEL FOR RIES

Typical Regional Integrated Energy System consists of a regional power system (power distribution system, PDS), gas network system (GNS), heating network system, (HNS) and coupling units, as shown in Fig.1. The power flow calculation method based on Newton-Raphson or forward-backward algorithm is complete. To maintain the uniformity of the model of three subsystems of RIES, GNS and HNS are described as models in form of the node- branch parameters.

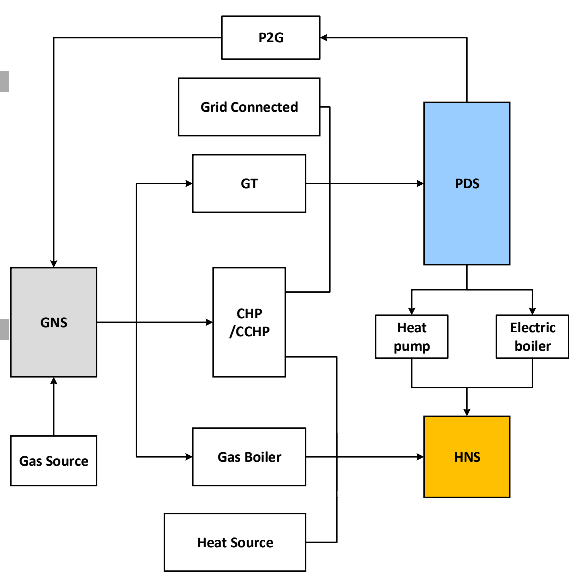

Fig 1 Architecture of RIES.

2.1 *Model for PDS*

Different with traditional power flow method for PDS, the power system in RIES is solved by the forward-backward algorithm to improve calculation speed. A method based on BIBC-BCBV matrix is used in this paper proposed in Ref.[6]:

$$S_i = P_i + jQ_i = (P_{Gi} + jQ_{Gi}) - (P_{Li} + jQ_{Li}) \quad (1)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \quad (2)$$

Where, S_i is apparent power of node i, I_i is injection current node i.. Then,

$$[\mathbf{I_{branch}}] = [\mathbf{BIBC}][\mathbf{I_{bus}}] \quad (3)$$

$$[\mathbf{V_{bus}}] = [\mathbf{V_1}] - [\mathbf{\Delta V}] = [\mathbf{V_1}] - [\mathbf{BCBV}][\mathbf{I_{branch}}] \quad (4)$$

Where BIBC refers to a matrix of Bus-Injection to Branch-current and BCBV refers to a matrix of Branch-Current to Bus-Voltage. $\mathbf{I_{bus}}$ is a column vector of I_i; $\mathbf{V_{bus}}$ is the column vector of each node voltage; $\mathbf{V_1}$ refers to the same dimension column vector composed of voltage at the slack node.

2.2 *Model for GNS*

The Gas Networking System is composed of gas source stations and pipeline networks. The model of GNS mainly based on the steady-state node injection flow rate linking with each node pressure [7]. The steady-state flow rate f_r of pipeline r is:

$$f_r = K_r^{-1} s_{mn} \sqrt{s_{mn}(\Pi_m - \Pi_n)} \quad (5)$$

$$\Pi_m = P_m^2 \quad (6)$$

$$K_r = 27.24 \times \frac{L}{D^{4.848}} \quad (7)$$

Where, m, n are the two-side node of pipeline r; s_{mn} is sign function; K_r refers to the pipeline parameter relates to the length L and diameter D of the pipeline; P_m is the pressure at node .

The continuity of flow of GNS is expressed as:

$$Q = \mathbf{A_g} f \quad (8)$$

Where $\mathbf{A_g}$ is the network incidence matrix that relates the nodes to the branches; f is the flow rate of branches and Q is the flow rate injection to each nodes.

And loop pressure equation is expressed as:

$$\Delta \prod = -\mathbf{A_g^T} \prod \quad (9)$$

2.3 *Model for HNS*

Heat cannot be transferred without medium, and sometimes hot water and steam are chosen as the carrier of heat. Thus HNS usually consists of supply and return pipelines to deliver heat [3].

2.3.1 Hydraulic model

The hydraulic model of HNS is similar to the model of GNS. That is continuity of flow equation and loop pressure equation, in which h_f is head losses of pipelines; $\mathbf{K}$ is the vector of resistance coefficients of each pipelines.

$$\mathbf{A_s m} = \mathbf{m_q} \quad (10)$$

$$B_h h_f = 0 \quad (11)$$

$$h_f = \mathbf{K} m|m| \quad (12)$$

Where, $\mathbf{A_s}$ is the network incidence matrix that relates the nodes to the branches; $\mathbf{m}$ is the vector of the mass flow of each pipeline; $\mathbf{m_q}$ is the vector of mass flow injected of each node.

2.3.2 Thermal model

The thermal model for HNS is used to analyze the energy loss and changes in temperature through delivery. Three temperatures associated with each node are defined: the supply temperature T_s; the outlet temperature T_o and the return temperature T_r. They are used to describe the temperature of water at the heat source; at the outlet of each node before and after mixing with water from other nodes. The model can be described as:

$$\Phi = C_p m_q (T_s - T_o) \quad (13)$$

$$T_{end} = (T_{start} - T_e) e^{-\frac{\lambda L}{C_p m}} + T_e \quad (14)$$

Where Φ is the heat power at each node; C_p is the specific heat of water; T_{end} and T_{start} are the temperature of a pipeline at the start node and the end node; T_e is the environment temperature; λ is the heat transmission coefficient of each pipeline and L refers to the length of each pipeline.

The equation of the mixture temperature of water is:

$$\left(\sum m_{out}\right) T_{out} = \sum (m_{in} T_{in}) \quad (15)$$

Where $\sum m_{out}$ and T_{out} are the total mass flow rate and temperature after mixing and m_{in} and T_{in} are these of each single pipeline before mixing.

2.4 *Model for Energy Hub*

The general model of energy hub in Ref.[2] is shown in Fig.2 in form of an I/O two-port network [5].

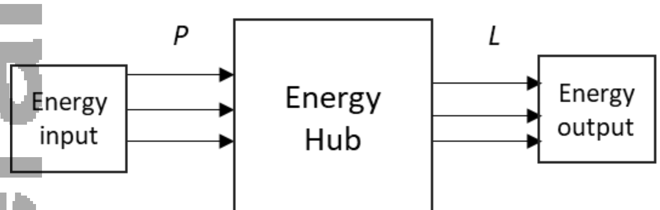

Fig 2 General model of energy hub

The left side of the model is the energy input port P and the right side is output port L. The relationship between P and L can be described as a function as follow:

$$L = f(P) \quad (16)$$

However, there are some limitations of the model, especially in describing the priority in end-used energy utilization and the benefit in the usage of energy storage units. An intelligent recognition energy hub model considering energy utilization priority is proposed in this paper. The ranking of an energy hub is defined by the number of sorts of energy at two ports and the energy utilization priority. According to this concept, coupling units of RIES can be divided into four classes.

2.4.1 I-Class energy hub

I-Class energy hubs include all kinds of renewable energy generation units, i.e. DGs, such as photovoltaic units (PV) and wind power generation. A common feature of I-Class energy hub is that the emissions of these EHs during power generation is extremely low. Thus they should be ranked first in terminal utilization owing to environmentally-friendly characteristics.

2.4.2 Ⅱ-Class and Ⅲ-Class energy hub

These two types of EHs both have only one sort of energy on the input side, and on the output side, there is one sort of energy in Ⅱ-Class EH, such as HP, GT and P2G only. Ⅲ-Class EHs have more than two types of energy output, like CHP units, and CCHP units. These EHs describe the conversion of more than two types of energy, and the elements conversion function f includes energy distribution ratio (DR) ν and energy conversion efficiency (CE) η, that is:

$$L = \eta \nu P \quad (17)$$

2.4.3 Ⅳ-Class energy hub

Ⅳ-Class energy hubs consist of all sorts of energy storage units. These EHs have only one half-duplex channel as the I/O port for energy transport, as shown in Fig.3

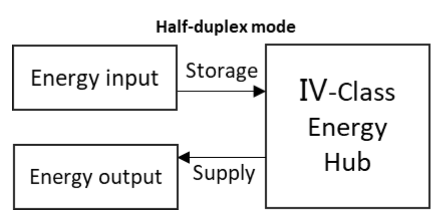

Fig 3 Ⅳ-Class energy hub model

These EHs can shift multi-energy from peak periods to off-peak periods by storing energy when energy load is small and supplying energy when the load is too heavy. As the "alternate" energy supply, Ⅳ-Class EHs hugely relieve stress from variable load on time scale.

For a given RIES with different kinds of EHs, their priority determines energy supply order at demand side. Only when high-ranked EHs come into service, low-ranked EHs can connect to the grid. The aim is to minimize emissions and pollutions to the environment.

2.5 *MEF Calculation Method*

Based on the above, a MEF model for RIES can be established including electricity, thermal and gas networks. In this paper, a decoupling method is used for MEF calculation. Three subsystems are decoupled at EHs and calculated separately for final results.

Besides, the type of EHs determines the dependency relationship and energy conversion between several subsystems. High-rank energy systems, as the "source", supply energy to low-rank ones. For example, CHP units make it possible for conversion from natural gas to electricity and heating. Thus nature gas is regarded as high-rank energy and electricity and heating are deemed as low-rank ones. Meanwhile, Ⅳ-Class will be put into operation when necessary. The specific calculation process is shown in Fig.4,5 and the extra Algorithm B is specially designed for energy storage units.

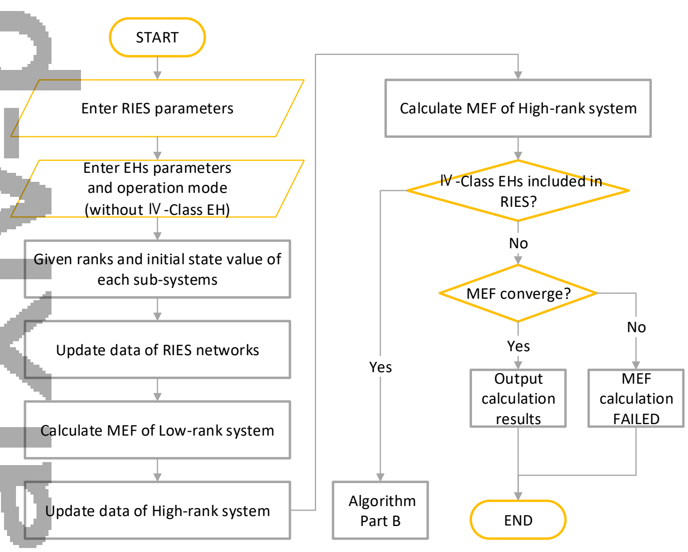

Fig 4 MEF calculation algorithm flow chart

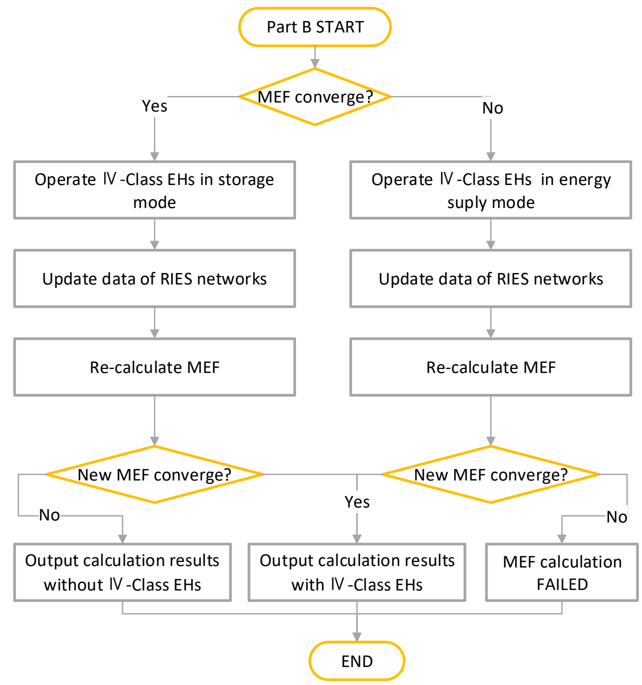

Fig 5 Algorithm part B flow chart

3. CASE STUDY

The proposed model is applied to a typical RIES with different combinations of three EHs. In this system, topological structure and parameter settings of networks are shown in Appendix I.

3.1 *Case description*

The parameter settings of three EHs are shown in Table 1 and 2:

Table 1

Node -linked parameter of EHs

Name	Class	EN	GN	HN
PV	Ⅰ	8	-	-
CHP	Ⅲ	7	9	12(Slack)
Gas- Storage	Ⅳ	-	9	-

Where EN, GN and HN refer to nodes in PDS, GNS and HNS.

Table2

Distribution ratio and conversion efficiency of EHs

Name	DR	CE	Remark
PV	$\nu_{ee}=1$	η_{ee}=0.8	P=0.4MW
CHP	ν_{gh}=0.8	$\eta_{gh}=0.9$	$c_{eh}=0.11$
Gas Storage	$\nu_{gg}=1$	η_{gg}=1	$Q=150m^3$

Three different operation mode of EHs are as follow:

Case 1

CHP, and PV units are in operation state.

Case 2

Only CHP is in operation and the heating load of HN4,6,8 increases 0.4MW, 0.6MW and 0.3MW respectively.

Case 3

Based on Case 2, the Gas Storage unit (Full) supplies energy to gas node linked.

3.2 *Result and discussion*

The results of steady-state multi-energy flow are shown below:

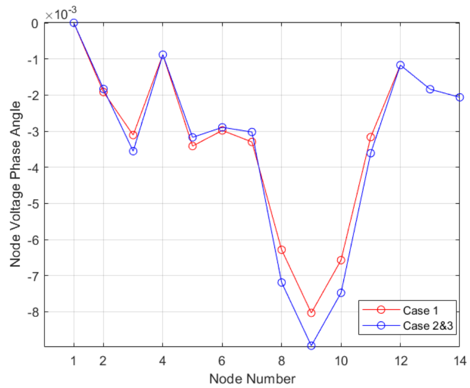

Fig 6 Phase angle of EN

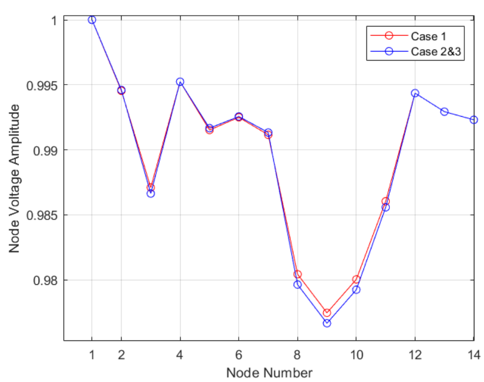

Fig 7 Voltage amplitude of EN

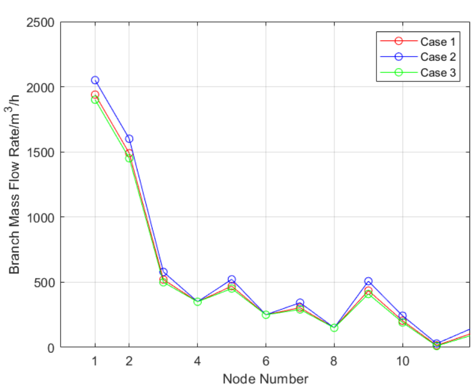

Fig 8 Branch flow rate of GN

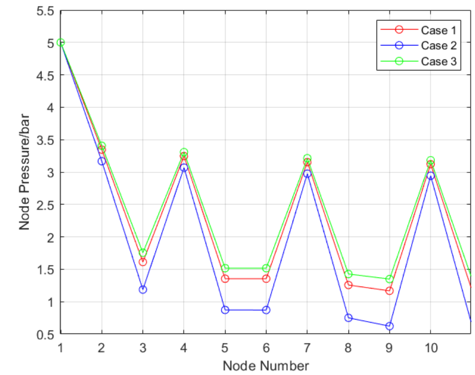

Fig 9 Node pressure of GN

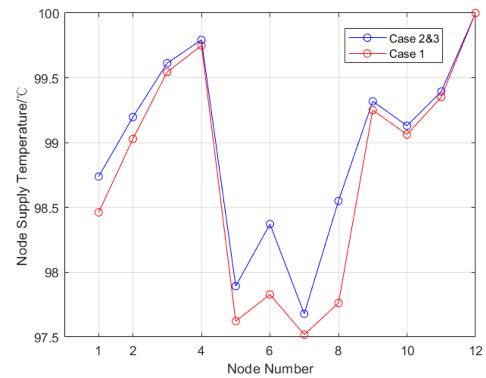

Fig 10 Node supply temperature of HN

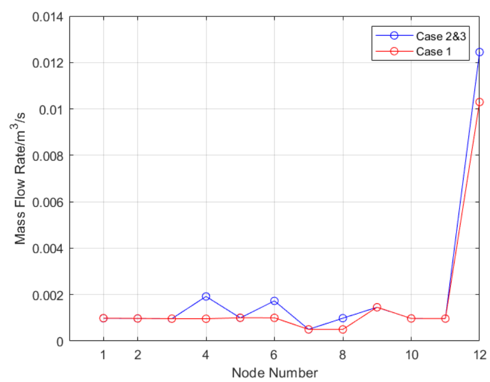

Fig 11 Node mass flow rate of HN

As shown in figures, the algorithm figures out steady-state multi-energy flow of given RIES. In Case 1, when PV works, RIES is running safely. But in Case 2 when PV does not work and Gas storage unit does not link with network, the node pressure of GN 9 is lower than settings. And in Case 3 when Gas storage units are put into operation, the load demand of GN 9 is cut down and the system runs back in the state of security.

4. CONCLUSION

This paper presents an algorithm of multi-energy flow to make combined analysis of PDS, GNS and HNS. Then a design of an intelligent recognition energy hub is given considering the priority of each EH. A case study is employed to examine the feasibility of the proposed model.

However, what is presented in this paper can only be used in steady-state power flow analysis. The dynamic process of gas and heat are not taken into account. Thus a new modified model of energy hub and algorithm of RIES are needed for further research.

ACKNOWLEDGEMENT

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REFERENCE

[1] Y.B.Zhang Study on the methods for analyzing Combined gas and electricity network[D]. China Electric Power Research Institute,2005.

[2] Favre-Perrod P． A vision of future energy networks [C]//2005 IEEE Power Engineering Society Inaugural Conference and Exposition in Africa． Durban：IEEE，2005： 13-17．

[3] Liu X , Jenkins N , Wu J , et al. Combined analysis of electricity and heat Networks[J]. Energy Procedia, 2014, 61:155-159.

[4] C.Quan, X.F.Dong, T.Jiang. Optimization planning of integrated electricity-gas community energy system based on coupled CCHP [J].Power System Technology, 2018,42(08):2456-2466.

[5] Y.Wang, N.Zhang, C.Q.Kang. Review and Prospect of Optimal Planning and Operation of Energy Hub in Energy Internet [J]. Proceedings of The Chinese Society for Electrical Engineering, 2015, 35(22):5669-5681.

[6] S.M.Li. Efforts on three-phase load flow of distribution network by DG and its siting and sizing [D]. South China University of Technology, 2011.

[7] Y.R.Wang, B.Zeng, J.Guo, et al. Multi-energy flow calculation method for integrated energy system containing electricity,heat and gas[J]. Power System Technology, 2016(40):2942-2950.

Appendix I Topology and parameter of RIES

1. POWER DISTRIBUTION SYSTEM

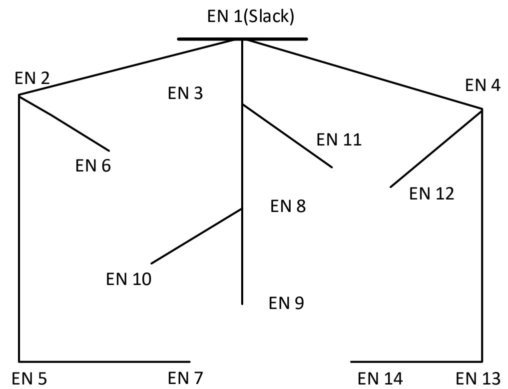

Fig A1 PDS topology

Table A1
PDS bus parameter

Number	P/MW	Q/MVar
1	Slack	
2	1	0.8
3	2	1.35
4	0.5	0.45
5	1	0.4
6	1.5	0.75
7	0.75	0.6
8	2.5	1.5
9	2.25	1
10	0.3	0.05
11	0.5	0.45
12	0.5	0.35
13	0.5	0.45
14	1.05	0.5

Table A2
PDS branch parameter

Number	From Bus	To Bus	R	X
1	1	2	0.075	0.1
2	1	3	0.11	0.11
3	1	4	0.11	0.11
4	2	5	0.09	0.18
5	2	6	0.08	0.11
6	5	7	0.04	0.04
7	3	8	0.08	0.11
8	8	9	0.08	0.11
9	8	10	0.11	0.11
10	3	11	0.11	0.11
11	4	12	0.09	0.12
12	4	13	0.08	0.11
13	13	14	0.04	0.04

2. GAS NETWORK SYSTEM

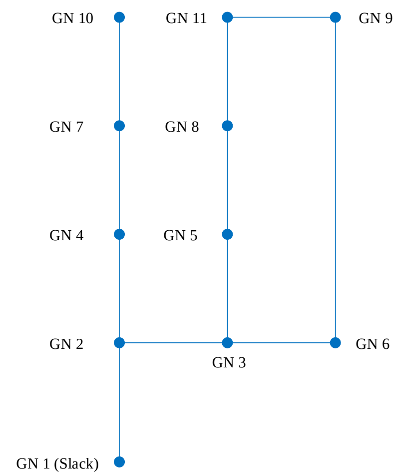

Fig A2 GNS topology

Table A3
GNS bus parameter

Number	Load/ $m^3 \cdot h^{-1}$
1	Slack
2	100
3	500
4	100
5	150
6	100
7	100
8	100
9	0
10	150
11	100

Table A4
GNS branch parameter

Number	From bus	To bus	Diameter/ mm	Length/ m
1	1	2	110	300
2	2	3	110	500
3	3	6	110	500
4	2	4	110	400
5	3	5	110	600
6	4	7	110	700
7	5	8	110	500
8	7	10	110	600
9	6	9	110	500
10	8	11	110	800
11	5	6	110	500
12	11	9	110	500

The pressure of gas slack node is 5000 mbar.

3. HEAT NETWORK SYSTEM

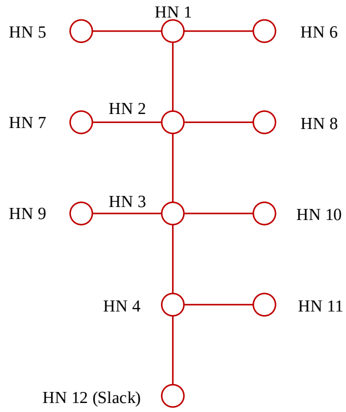

Fig A3 HNS topology

Table A5

HNS bus parameter

Number	Heat load/ MW	Return temperature/℃
1	0.2	50
2	0.2	50
3	0.2	50
4	0.2	50
5	0.2	50
6	0.2	50
7	0.1	50
8	0.1	50
9	0.3	50
10	0.2	50
11	0.2	50
12	Slack	--

Table A6

HNS branch parameter

Num.	From bus	To bus	Diameter/ mm	Length/ m
1	1	2	200	400
2	2	3	200	600
3	4	3	200	400
4	12	4	200	600
5	1	5	200	200
6	1	6	200	150
7	2	7	200	180
8	2	8	200	150
9	3	9	200	100
10	3	10	200	110
11	4	11	200	90

The environment temperature T_e=10℃, and the supply temperature T_s at the heat source is 100 ℃.