Efficient Assessment of Credible Regulation Potential from Uncertainty Affected Gas Networks

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A. Detailed Parameters of the Systems in Case Studies

1) E22-N10 system

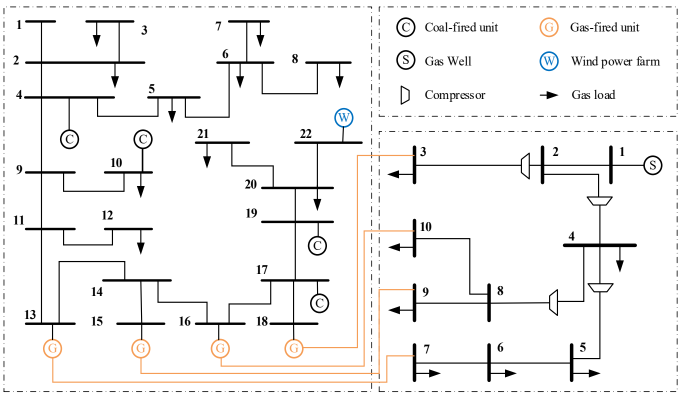

Fig. 1. E22-N10 system

TABLE I
Parameters of the pipeline network

Pipe	Form node	To node	Friction coefficient	Lengths (m)	Diameter (m)
1	1	2	0.01	10000	1
2	2	3	0.01	25000	0.7
3	2	4	0.01	10000	0.7
4	4	5	0.02	20000	0.7
5	5	6	0.02	20000	0.7
6	6	7	0.02	20000	0.7
7	4	8	0.01	15000	0.7
8	8	9	0.02	25000	0.7
9	8	10	0.02	25000	0.7

TABLE II
Parameters of the units

Unit[1]	Bus	Max output (MW)	Generation price ($/MWh)
C1	10	200	4800
C2	17	200	5400
C3	19	200	6000
C4	4	200	6600
G1	16	1000	3000
G2	13	1000	2760
G3	18	1000	2520
G4	15	1000	2160

[1]:C1-C4 denote the thermal power units, and G1-G4 denote the GFUs.

TABLE III
Gas loads in N10 system

Gas load	Node	Demand (kg/s)
1	3	10
2	4	11
3	5	10
4	6	10
5	7	9
6	9	10
7	10	10

2) E39-N20 system

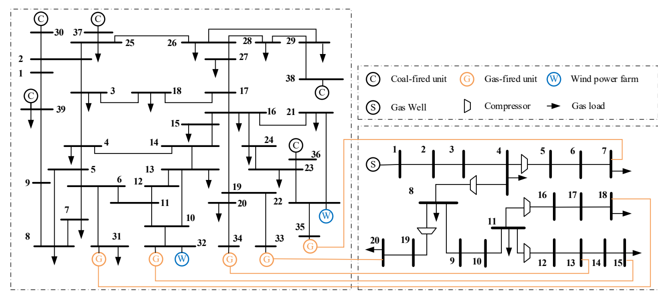

Fig. 2. E39-N20 system

TABLE IV
Parameters of the pipeline network

Pipe	Form node	To node	Friction coefficient	Lengths (m)	Diameter (m)
1	1	2	0.01	10126	1
2	2	3	0.01	10061	1
3	3	4	0.01	9928	1
4	4	5	0.05	10102	0.7
5	5	6	0.05	10120	0.7
6	6	7	0.05	10066	0.7
7	4	8	0.02	10083	0.8
8	8	9	0.02	10080	0.8
9	9	10	0.02	10004	0.8
10	10	11	0.02	10061	0.8
11	11	12	0.02	9957	0.7
12	12	13	0.02	10072	0.7
13	13	14	0.02	9927	0.7
14	14	15	0.02	9980	0.7
15	11	16	0.02	9930	0.7
16	16	17	0.02	9941	0.7
17	17	18	0.02	10097	0.7
18	8	19	0.02	10069	0.7
19	19	20	0.02	9988	0.7

TABLE V

Parameters of the units

Unit[1]	Bus	Max output (MW)	Generation price ($/MWh)
C1	30	200	4800
C2	37	200	5040
C3	38	200	5280
C4	39	200	5520
C5	36	200	2160
G1	31	1000	2400
G2	32	1000	2880
G3	33	1000	3360
G4	34	1000	3840
G5	35	1000	4320

[1]:C1-C5 denote the thermal power units, and G1-G5 denote the GFUs.

TABLE VI

Gas loads in the N20 system

Gas load	Node	Demand (kg/s)
1	4	40
2	7	30
3	8	10
4	11	30
5	15	40
6	18	30
7	20	20

This study focuses on the impact of gas withdrawal fluctuations of gas turbines on the gas network, and other gas loads are assumed to remain unchanged within a 1-hour real-time dispatch period.

B. Results in Case Studies

1) Time-varying Gas Load Profiles

The time-varying gas load profiles of gas turbines in Section V.C are shown in Fig.3.

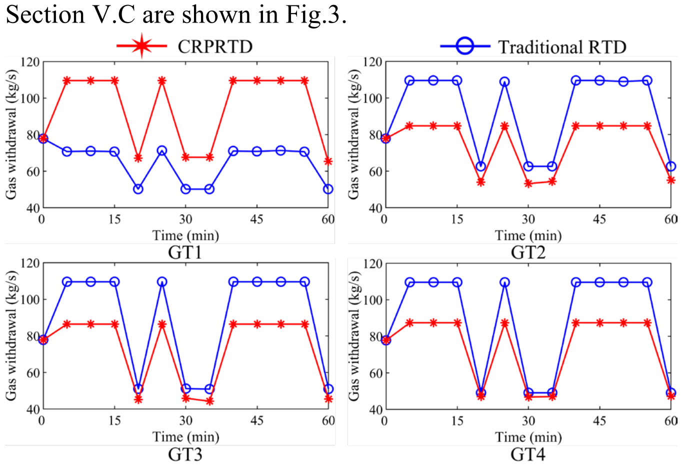

Fig. 3. The gas withdrawals of GTs in the E22-N10 system.

2) Time-varying Linepack Profiles

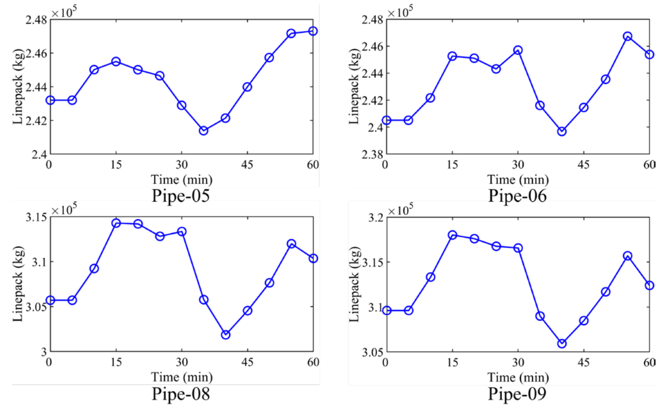

Fig. 4. The linepack of pipelines in the E22-N10 system.

3) CRP Model with Different Spatial Resolution

Finer spatial resolution for the pipeline discretization will lead to a greater computational burden. In our case studies, we set the number of discrete segments to N^d=2 and N^d=3, respectively, and compare the computational performance of the CRP assessment model on the N10 system. The results are shown in TABLE I. According to the results shown in TABLE I, the CRP assessment results with different spatial resolutions are similar, with an average relative error of about 0.83%. However, the solution time of the CRP assessment model with N^d=2 is significantly shorter than the model with N^d=3. Therefore, the spatial resolution for the pipeline discretization in our case studies is set to N^d=2. Moreover, it is worth mentioning that the selection of the above discretization spatial resolution may be applicable to the case studies of this manuscript, but for different systems in other studies, specific tests are still needed.

TABLE I

Solution time and CRP obtained by the model with different spatial resolutions

Spatial resolution	Solution time (s)	Gas turbine	Lower bound of CRP (kg/s)	Upper bound of CRP (kg/s)
N^d=2	10.19	GT1	1	109
		GT2	0	94
		GT3	0	92
		GT4	0	89
N^d=3	37.93	GT1	1	109
		GT2	0	94
		GT3	0	93
		GT4	0	91

The lengths of the discrete segments of the N10 system and N20 system with different spatial resolution are shown in TABLE II, III, IV, and V.

TABLE II

The length of each discrete segment in N10 system with N^d=2

Pipe	Form node	To node	Lengths (m)	Length of discrete segment (m)
1	1	2	10000	5000
2	2	3	25000	12500
3	2	4	10000	5000

4	4	5	20000	10000
5	5	6	20000	10000
6	6	7	20000	10000
7	4	8	15000	7500
8	8	9	25000	12500
9	8	10	25000	12500

TABLE III
The length of each discrete segment in N10 system with N^d=3

Pipe	Form node	To node	Lengths (m)	Length of discrete segment (m)
1	1	2	10000	3333.33
2	2	3	25000	8333.33
3	2	4	10000	3333.33
4	4	5	20000	6666.67
5	5	6	20000	6666.67
6	6	7	20000	6666.67
7	4	8	15000	5000
8	8	9	25000	8333.33
9	8	10	25000	8333.33

TABLE IV
The length of each discrete segment in N20 system with N^d=2

Pipe	Form node	To node	Lengths (m)	Length of discrete segment (m)
1	1	2	10126	5063
2	2	3	10061	5030.5
3	3	4	9928	4964
4	4	5	10102	5051
5	5	6	10120	5060
6	6	7	10066	5033
7	4	8	10083	5041.5
8	8	9	10080	5040
9	9	10	10004	5002
10	10	11	10061	5030.5
11	11	12	9957	4978.5
12	12	13	10072	5036
13	13	14	9927	4963.5
14	14	15	9980	4990
15	11	16	9930	4965
16	16	17	9941	4970.5
17	17	18	10097	5048.5
18	8	19	10069	5034.5
19	19	20	9988	4994

TABLE V
The length of each discrete segment in N20 system with N^d=3

Pipe	Form node	To node	Lengths (m)	Length of discrete segment (m)
1	1	2	10126	3375.33
2	2	3	10061	3353.67
3	3	4	9928	3309.33
4	4	5	10102	3367.33
5	5	6	10120	3373.33
6	6	7	10066	3355.33
7	4	8	10083	3361
8	8	9	10080	3360
9	9	10	10004	3334.67
10	10	11	10061	3353.67
11	11	12	9957	3319
12	12	13	10072	3357.33
13	13	14	9927	3309
14	14	15	9980	3326.67
15	11	16	9930	3310
16	16	17	9941	3313.67
17	17	18	10097	3365.67
18	8	19	10069	3356.33
19	19	20	9988	3329.33

4) Reliability of the CRP Model with Non-uniform Expansion Percentages

Even with non-uniform expansion percentages, as long as the expanded CRP is validated as secure, the original CRP's safety and conservativeness are assured. Moreover, since the experimental results presented in our manuscript demonstrate that uniform percentage expansion yields secure CRP within certain expansion percentage ranges, non-uniform expansion with sufficiently small percentages would theoretically also result in secure expanded CRP. To further support this, we conducted additional experiments using non-uniform expansion percentages, where the expansion percentages were randomly selected with maximum values 0.5%, 0.75%, or 1%. The results of the experiments with uniform and non-uniform expansion percentages, summarized in TABLE VI and TABLE VII below, confirm that non-uniform expansion produces outcomes consistent with uniform expansion, demonstrating that the assessment of the CRP and its conservativeness remains unaffected.

TABLE VI
Security of the expanded CRP with uniform expansion percentages

System	Percentage of CRP expansion		
	0.5%	0.75%	1%
N10	√	√	×
N20	√	√	×
N40	√	×	×

"√" indicates secure, "×" indicates insecure

TABLE VII
Security of the expanded CRP with non-uniform expansion percentages

System	Percentage of CRP expansion		
	0.5%	0.75%	1%
N10	√	√	×
N20	√	√	×
N40	√	×	×

"√" indicates secure, "×" indicates insecure