Supplemental File for Physics-Informed Recurrent Network for Gas Pipeline Network Parameters Identification

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I. Parameters of Numerical Tests

In our numerical tests, the IEEE RTS96 One Area 24 bus power system and 24 pipe benchmark gas system are used as the gas-electricity integrated optimal dispatch test case. The parameters of GTs, P2Gs and compressors in the gas network and generators, wind turbines and photovoltaics in the power system are listed in the following tables.

TABLE I
PARAMETERS OF GTS AND P2GS

Type of Units	Bus in power system	Node in gas system	Total capacity (MW)	Energy efficiency
GTs	6	8	60	0.75
GTs	13	12	80	0.77
GTs	19	18	70	0.72
GTs	25	24	60	0.69
P2Gs	4	6	8	0.48
P2Gs	9	13	7	0.44
P2Gs	3	19	9	0.50
P2Gs	22	25	6	0.54

TABLE II
PARAMETERS OF COMPRESSORS

Compressors	Pipeline in gas system	Maximum additional gas pressure (MPa)	Locating distance from the head node (km)
COMP1	P1	0.1	2
COMP2	P8	0.05	5
COMP3	P3	0.03	1
COMP4	P14	0.04	3
COMP5	P20	0.06	1

TABLE III
PARAMETERS OF GENERATORS IN THE POWER SYSTEM

Type of unites	Bus in power system	Total capacity (MW)
Coal generators	2	100
Wind turbines	4	65
Wind turbines	18	80
Wind turbines	21	55
Photovoltaics	16	50
Photovoltaics	22	70

II. Mathematical Model of Gas-electricity Integrated Optimal Dispatch

A. Models of gas system

According to the parameter identification results, the state-space model of the gas pipeline network is as follows:

$$\boldsymbol{h}_t = \boldsymbol{J}^{(1)}\boldsymbol{S}\boldsymbol{h}_{t-1} + \boldsymbol{J}^{(2)}\boldsymbol{u}_t \tag{1}$$

where the matrices $\boldsymbol{J}^{(1)}$ and $\boldsymbol{J}^{(2)}$ can be obtained by the parameter identification model. $\boldsymbol{u}_t$ denotes the control variable vector, collecting all the controllable gas pressure and gas mass flow injection of nodes.

The gas wells (GWs) provide natural gas for the whole gas system with the upper and lower gas injection and gas pressure bounds.

$$\underline{f}_k^{\text{gw}} \le f_{k,t}^{\text{gw}} \le \overline{f}_k^{\text{gw}} \tag{2a}$$

$$\underline{\pi}_k^{\text{gw}} \le \pi_{k,t}^{\text{gw}} \le \overline{\pi}_k^{\text{gw}} \tag{2b}$$

where $\pi_{k,t}^{\text{gw}}$ and $f_{k,t}^{\text{gw}}$ denote the gas pressure and gas mass flow of gas well k at time t, respectively.

The compressors also have the maximum and minimum pressure booster limits.

$$\Delta\underline{\pi}_k \le \Delta\pi_{k,t} \le \Delta\overline{\pi}_k \tag{3}$$

where $\Delta\pi_{k,t}$ denotes the boosted gas pressure of compressor k at time t.

The gas turbines (GTs) transform the natural gas into electricity with the efficiency η_k^{gt}. Both their gas input and the electricity output have the upper and lower bounds.

$$p_{k,t}^{\text{gt}} = \eta_k^{\text{gt}} f_{k,t}^{\text{gt}} q_L \tag{4a}$$

$$\underline{f}_k^{\text{gt}} \le f_{k,t}^{\text{gt}} \le \overline{f}_k^{\text{gt}} \tag{4b}$$

where $p_{k,t}^{\text{gt}}$ and $f_{k,t}^{\text{gt}}$ denote the generation power and gas mass flow of gas turbine k at time t, respectively. η_k^{gt} denotes the efficiency of gas-power transformation. q_L denotes the low heat value of natural gas.

The power-to-gas devices (P2Gs) transform the electricity into natural gas with the efficiency η_k^{p2g}. Both their electricity input and gas output have the upper and lower bounds.

$$f_{k,t}^{\text{p2g}} = \eta_k^{\text{p2g}} p_{k,t}^{\text{p2g}} / q_L \tag{5a}$$

$$\underline{f}_k^{\mathrm{p2g}} \le f_{k,t}^{\mathrm{p2g}} \le \overline{f}_k^{\mathrm{p2g}} \tag{5b}$$

where $f_{k,t}^{\mathrm{p2g}}$ and $p_{k,t}^{\mathrm{p2g}}$ denote the generated gas mass flow and power consumption of P2G k at time t, respectively.

For the consideration of security, the gas pressures of gas pipelines also have upper and lower bounds. For any $l \in \mathcal{L}$

$$\underline{\pi}_l \le \pi_{i,t} \le \overline{\pi}_l, \forall i \in \mathcal{S}_l \tag{6}$$

where $\pi_{i,t}$ denotes the gas pressure of gas pipeline at the discrete computation point i at time t. $\mathcal{L}$ denotes the index set of pipelines. $\mathcal{S}_l$ denotes the index set of discrete computation point of pipeline l.

The gas injection at nodes can be described as the net injection of all the units. For any $n \in \mathcal{N}$

$$f_{n,t}^{\mathrm{inj}} = \sum_{k\in\mathcal{D}_n^{\mathrm{gw}}} f_{k,t}^{\mathrm{gw}} + \sum_{k\in\mathcal{D}_n^{\mathrm{p2g}}} f_{k,t}^{\mathrm{p2g}} - \sum_{k\in\mathcal{D}_n^{\mathrm{gt}}} f_{k,t}^{\mathrm{gt}} - f_{n,t}^{\mathrm{ld}} \tag{7}$$

where $\mathcal{D}_n^{\mathrm{gw}}$, $\mathcal{D}_n^{\mathrm{p2g}}$, and $\mathcal{D}_n^{\mathrm{gt}}$ denote the index sets of gas sources, P2Gs, and GTs that directly linked to node n, respectively. $f_{n,t}^{\mathrm{ld}}$ denotes the mass flow rate of gas load at node n at time t. $\mathcal{N}$ denotes the index set of all pipeline nodes.

B. Models of power system

In the power system, there are some units such as GTs, P2Gs, generators (GENs), wind turbines (WTs) and photovoltaics (PVs). Each type of unit has its specific active and reactive power flexibility range and can be express as a polygon. For any $s = \{\mathrm{gt,p2g,gen,wt,pv}\}$ and any $k \in \mathcal{K}^{\mathrm{s}}$

$$\underline{p}_k^s \le p_{k,t}^s \le \overline{p}_k^s \tag{8}$$

$$\underline{q}_k^s \le q_{k,t}^s \le \overline{q}_k^s \tag{9}$$

where $\mathcal{K}^{\mathrm{s}}$ denotes the index sets of unit s in the power system. $p_{k,t}^s$ and $q_{k,t}^s$ denote the active and reactive output power of k-th unit s at time t.

The ramp rate constraints should of coal generators should also be considered as follows:

$$-r_k^{\mathrm{gen}} \le p_{k,t}^{\mathrm{gen}} - p_{k,t-1}^{\mathrm{gen}} \le r_k^{\mathrm{gen}} \tag{10}$$

where r_k^{gen} denotes the ramp rates.

The network constraints of the power system restrict the active and reactive output power among all the units. Based on the linearized power flow model, the network constraints can be expressed in the compact form as follows:

$$\boldsymbol{A}_t^{\mathrm{ps}} \boldsymbol{x}_t \le \boldsymbol{b}_t^{\mathrm{ps}} \tag{11}$$

where $\boldsymbol{A}_t^{\mathrm{ps}}$ and $\boldsymbol{b}_t^{\mathrm{ps}}$ are constant parameters representing the network constraints of the power system; $\boldsymbol{x}_t$ is a vector collects the active and reactive output power of all units at time t, that is

$$\boldsymbol{x}_t := \left[\cdots, p_{k,t}^s, \cdots, q_{k,t}^s, \cdots\right]^\top, \forall s, \forall k \in \mathcal{K}^{\mathrm{s}} \tag{12}$$

C. Objective function

The objective of optimal dispatch of integrated gas-electricity system is minimizing the total cost of these two systems.

$$\min \sum_{t\in\mathcal{T}} \left(\sum_{i\in\mathcal{K}^{\mathrm{gen}}} C_i^{\mathrm{gen}} + \sum_{j\in\mathcal{D}^{\mathrm{gt}}} C_j^{\mathrm{gt}} \right) \cdot \Delta t \tag{13a}$$

$$C_i^{\mathrm{gen}} = a_i^{\mathrm{gen}} \left(p_{i,t}^{\mathrm{gen}}\right)^2 + b_i^{\mathrm{gen}} p_{i,t}^{\mathrm{gen}} + c_i^{\mathrm{gen}} \tag{13b}$$

$$C_j^{\mathrm{gt}} = \lambda_j^{\mathrm{gt}} f_{j,t}^{\mathrm{gt}} \tag{13c}$$

where C_i^{gen} and C_j^{gt} denote the fuel cost of i-th generator and j-th GT, respectively; a_i^{gen}, b_i^{gen} and c_i^{gen} are coefficients of cost function of i-th generator. λ_j^{gt} are cost of natural gas of j-th GT. Since the renewable generators such as wind turbines and photovoltaics do not need to consume fuel, their costs are set to 0.