APPENDIX

A. DN model constraints

1) MGT operational constraints

$$P_{n,\min}^{\mathrm{CG}} \le P_{n,t}^{\mathrm{CG}} \le P_{n,\max}^{\mathrm{CG}}, \forall n \in \mathrm{N_G} \tag{A1}$$

$$-\mathrm{V} \le P_{n,t}^{\mathrm{CG}} - P_{n,t-1}^{\mathrm{CG}} \le \mathrm{V} \tag{A2}$$

Where: $P_{n,\max}^{\mathrm{CG}}$ 、 $P_{n,\min}^{\mathrm{CG}}$ is the upper and lower limit of MGT active output; V is the MGT climb rate limit.

2) Currents constraints

In this paper, we use linearized distribution network current constraints [41] and ignore network losses:

$$P_{uv,t} = P_{v,t} + P_{vw,t} \tag{A3}$$

$$Q_{uv,t} = Q_{v,t} + Q_{vw,t} \tag{A4}$$

$$U_{u,t} - U_{v,t} = \frac{P_{uv,t} r_{uv} + Q_{uv,t} x_{uv}}{\overline{U}} \tag{A5}$$

$$U_{j,\min} \le U_{j,t} \le U_{j,\max} \tag{A6}$$

$$P_{v,t} = P_{v,t}^{\mathrm{L}} + \sum_{i\in \mathrm{M}} P_{i,t}^{\mathrm{MG}} + P_t^{\mathrm{sell}} - P_t^{\mathrm{buy}} - \sum_{n\in \mathrm{N_G}} P_{n,v,t}^{\mathrm{CG}} \tag{A7}$$

$$Q_{v,t} = Q_{v,t}^{\mathrm{L}} - Q_{v,t}^{\mathrm{TR}} \tag{A8}$$

Where: u is the start node in the DN with node j as the end node and w is the end node with j as the start node. $P_{v,t}$ 、 $Q_{v,t}$ represent the v-node injected active and reactive power values, respectively; $P_{uv,t}/P_{vw,t}$ 、 $Q_{uv,t}/Q_{vw,t}$ represent the active and reactive current values of the branch uv/vw; r_{uv} 、 x_{uv} are the resistance and reactance values of the branch uv; $U_{u,t}$ 、 $U_{v,t}$ are the voltage values at nodes u and v at moment t. $\overline{U}$ is the nodal voltage rating; $U_{j,\max}$ 、 $U_{j,\min}$ is the upper and lower limits of the node voltage; $Q_{v,t}^{\mathrm{TR}}$ is the reactive power injected into the distribution grid by the higher grid. Eqs.(A3)-(A4) and (A7) are the power balance constraints of lines and nodes. Since reactive power is usually not required within the microgrid, the supply of reactive power from the distribution grid to the microgrid is not considered.

3) Power exchange constraints

$$-P_{\max}^{\mathrm{grid}} \le P_t^{\mathrm{TN}} \le P_{\max}^{\mathrm{grid}} \tag{A9}$$

$$-P_{\max} \le P_{i,t}^{\mathrm{MG}} \le P_{\max} \tag{A10}$$

$$-Q_{\max}^{\mathrm{grid}} \le Q_{v,t}^{\mathrm{TR}} \le Q_{\max}^{\mathrm{grid}} \tag{A11}$$

Where: $P_{\max}^{\mathrm{grid}}$ 、 $Q_{\max}^{\mathrm{grid}}$ is the maximum value of active and reactive power exchange between the DN and the higher grid; $P_{\max}$ is the maximum value of power exchanged between the distribution network and the microgrid contact line.

B. MG LAARO model derivation

In this paper, we consider the uncertainty of renewable energy output and use the linear affine function (61) to establish the relationship between the adjustable decision variables and the uncertainty variables in the model, so that the adjustment state of each device in the system varies within a certain range from the schedule and robustness is enhanced. For the transformation of inequality constraints (13)-(14), (16)-(17), (20), (26), (29) and equation constraints (15), (30), since the transformation process is similar, the robust pairwise transformation process is listed as an example for inequality constraints (29) and equation constraints (15).

1)The affine function is brought into the deterministic model and the max part containing the uncertainty variable constraints is presented and collapsed to obtain:

$$\min_{P_{i,t}^{\mathrm{MG}}, X_i,\ Z^{\mathrm{N}},\ Z^{\mathrm{A}}} \alpha \tag{B1}$$

$$\begin{aligned}
s.t.\ & L_{\mathrm{MG},i}^{*} + \sum_{t\in T}\left(\lambda^{\mathrm{WT}} P_t^{\mathrm{WT,pre}} + \lambda^{\mathrm{PV}} P_t^{\mathrm{PV,pre}}\right) - \sum_{t\in T}\left(\lambda^{\mathrm{WT}} \overline{P}_t^{\mathrm{WT}} + \lambda^{\mathrm{PV}} \overline{P}_t^{\mathrm{PV}}\right) \\
& + \lambda^{\mathrm{EL}} P_{\mathrm{EL}}^{0} + \lambda^{\mathrm{FC}} P_{\mathrm{FC}}^{0} + \lambda^{\mathrm{EB}} P_{\mathrm{EB}}^{0} \\
& + \lambda^{\mathrm{H}} \sum_{t\in \mathrm{T}} \sum_{h\in \mathrm{N_H}} \left(S_{h,t}^{\mathrm{in}} + S_{h,t}^{\mathrm{out}}\right) + \lambda_E \sum_{t\in \mathrm{T}} \sum_{e\in \mathrm{N_E}} \left(P_{\mathrm{d}}^{0} + P_{\mathrm{c}}^{0}\right) \\
& + \max_{\gamma} \left(\sum_{t\in \mathrm{T}} \left(\begin{aligned}
& \left(\begin{aligned} & \lambda^{\mathrm{E}} \sum_{e\in \mathrm{N_E}} \left(P_{\mathrm{c}}^{1} + P_{\mathrm{d}}^{1}\right) + \lambda^{\mathrm{EL}} P_{\mathrm{EL}}^{1} \\ & + \lambda^{\mathrm{FC}} P_{\mathrm{FC}}^{1} + \lambda^{\mathrm{EB}} P_{\mathrm{EB}}^{1} - \lambda^{\mathrm{PV}} \end{aligned} \right) P_t^{\mathrm{PV+}} \\
& + \left(\begin{aligned} & \lambda^{\mathrm{E}} \sum_{e\in \mathrm{N_E}} \left(P_{\mathrm{c}}^{2} + P_{\mathrm{d}}^{2}\right) + \lambda^{\mathrm{EL}} P_{\mathrm{EL}}^{2} \\ & + \lambda^{\mathrm{FC}} P_{\mathrm{FC}}^{2} + \lambda^{\mathrm{EB}} P_{\mathrm{EB}}^{2} + \lambda^{\mathrm{PV}} \end{aligned} \right) P_t^{\mathrm{PV-}} \\
& + \left(\begin{aligned} & \lambda^{\mathrm{E}} \sum_{e\in \mathrm{N_E}} \left(P_{\mathrm{c}}^{3} + P_{\mathrm{d}}^{3}\right) + \lambda^{\mathrm{EL}} P_{\mathrm{EL}}^{3} \\ & + \lambda^{\mathrm{FC}} P_{\mathrm{FC}}^{3} + \lambda^{\mathrm{EB}} P_{\mathrm{EB}}^{3} - \lambda^{\mathrm{WT}} \end{aligned} \right) P_t^{\mathrm{WT+}} \\
& + \left(\begin{aligned} & \lambda^{\mathrm{E}} \sum_{e\in \mathrm{N_E}} \left(P_{\mathrm{c}}^{4} + P_{\mathrm{d}}^{4}\right) + \lambda^{\mathrm{EL}} P_{\mathrm{EL}}^{4} \\ & + \lambda^{\mathrm{FC}} P_{\mathrm{FC}}^{4} + \lambda^{\mathrm{EB}} P_{\mathrm{EB}}^{4} + \lambda^{\mathrm{WT}} \end{aligned} \right) P_t^{\mathrm{WT-}}
\end{aligned} \right) \right) \le \alpha
\end{aligned} \tag{B2}$$

$$0 \le P_{\mathrm{EB}}^{0} + \max_{\gamma} \left(\begin{aligned} & P_{\mathrm{EB}}^{1} P_t^{\mathrm{PV+}} + P_{\mathrm{EB}}^{2} P_{PV,t}^{-} \\ & + P_{\mathrm{EB}}^{3} P_t^{\mathrm{WT+}} + P_{\mathrm{EB}}^{4} P_t^{\mathrm{WT-}} \end{aligned} \right) \le P_{\max}^{\mathrm{EB}} \tag{B3}$$

$$\begin{aligned}
& \max_{\gamma} \left\{ \begin{aligned} & \left(\eta_e^{\mathrm{cha}} P_{\mathrm{c}}^{1} + P_{\mathrm{d}}^{1}/\eta_e^{\mathrm{dis}}\right) P_t^{\mathrm{PV+}} + \left(\eta_e^{\mathrm{cha}} P_{\mathrm{c}}^{2} + P_{\mathrm{d}}^{2}/\eta_e^{\mathrm{dis}}\right) P_t^{\mathrm{PV-}} \\ & + \left(\eta_e^{\mathrm{cha}} P_{\mathrm{c}}^{3} + P_{\mathrm{d}}^{3}/\eta_e^{\mathrm{dis}}\right) P_t^{\mathrm{WT+}} + \left(\eta_e^{\mathrm{cha}} P_{\mathrm{c}}^{4} + P_{\mathrm{d}}^{4}/\eta_e^{\mathrm{dis}}\right) P_t^{\mathrm{WT-}} \end{aligned} \right\} \\
& = E_{e,t+1} - E_{e,t} - \eta_e^{\mathrm{cha}} P_{\mathrm{c}}^{0} + P_{\mathrm{d}}^{0}/\eta_e^{\mathrm{dis}}
\end{aligned} \tag{B4}$$

$$\begin{aligned}
& \max_{\gamma} \left\{ \begin{aligned}
& \left(P_{\mathrm{WT}}^{1} + P_{\mathrm{PV}}^{1} + \sum_{\mathrm{e}\in \mathrm{N_E}} \left(P_{\mathrm{d}}^{1} - P_{\mathrm{c}}^{1}\right) + \sum_{\mathrm{h}\in \mathrm{N_H}} \left(P_{\mathrm{FC}}^{1} - P_{EL}^{1}\right) - \sum_{\mathrm{b}\in \mathrm{N_B}} \left(P_{\mathrm{EB}}^{1}\right)\right) P_t^{\mathrm{PV}+} \\
& + \left(P_{\mathrm{WT}}^{2} + P_{\mathrm{PV}}^{2} + \sum_{\mathrm{e}\in \mathrm{N_E}} \left(P_{\mathrm{d}}^{2} - P_{\mathrm{c}}^{2}\right) + \sum_{\mathrm{h}\in \mathrm{N_H}} \left(P_{\mathrm{FC}}^{2} - P_{\mathrm{EL}}^{2}\right) - \sum_{\mathrm{b}\in \mathrm{N_B}} \left(P_{\mathrm{EB}}^{2}\right)\right) P_t^{\mathrm{PV}-} \\
& + \left(P_{\mathrm{WT}}^{3} + P_{\mathrm{PV}}^{3} + \sum_{\mathrm{e}\in \mathrm{N_E}} \left(P_{\mathrm{d}}^{3} - P_{\mathrm{c}}^{3}\right) + \sum_{\mathrm{h}\in \mathrm{N_H}} \left(P_{\mathrm{FC}}^{3} - P_{\mathrm{EL}}^{3}\right) - \sum_{\mathrm{b}\in \mathrm{N_B}} \left(P_{\mathrm{EB}}^{3}\right)\right) P_t^{\mathrm{WT}+} \\
& + \left(P_{\mathrm{WT}}^{4} + P_{\mathrm{PV}}^{4} + \sum_{\mathrm{e}\in \mathrm{N_E}} \left(P_{\mathrm{d}}^{4} - P_{\mathrm{c}}^{4}\right) + \sum_{\mathrm{h}\in \mathrm{N_H}} \left(P_{\mathrm{FC}}^{4} - P_{\mathrm{EL}}^{4}\right) - \sum_{\mathrm{b}\in \mathrm{N_B}} \left(P_{\mathrm{EB}}^{4}\right)\right) P_t^{\mathrm{WT}-}
\end{aligned} \right\} \\
& = P_t^{\mathrm{L}} - P_{i,t}^{\mathrm{MG}} - P_{\mathrm{WT}}^{0} - P_{\mathrm{PV}}^{0} - \sum_{\mathrm{e}\in \mathrm{N_E}} \left(P_{\mathrm{d}}^{0} - P_{\mathrm{c}}^{0}\right) - \sum_{\mathrm{h}\in \mathrm{N_H}} \left(P_{\mathrm{FC}}^{0} - P_{\mathrm{EL}}^{0}\right) + \sum_{\mathrm{b}\in \mathrm{N_B}} P_{\mathrm{EB}}^{0}
\end{aligned} \tag{B5}$$

Where: α is the auxiliary variable.

2)Using dyadic theory, introduce dyadic variables, to transform the inequality constraints:

$$
\begin{cases}
P_{\mathrm{EB}}^{0}+\omega_{\mathrm{EB}}^{1}\widehat{P}_{t}^{\mathrm{PV+}}+\omega_{\mathrm{EB}}^{2}\widehat{P}_{t}^{\mathrm{PV-}}+\omega_{\mathrm{EB}}^{3}\widehat{P}_{t}^{\mathrm{WT+}} \\
+\omega_{\mathrm{EB}}^{4}\widehat{P}_{t}^{\mathrm{WT-}}+4\psi^{\mathrm{EB}}\cdot\mu\le P_{\max}^{\mathrm{EB}} \\
P_{\mathrm{EB}}^{0}+\omega_{\mathrm{EB}}^{5}\widehat{P}_{t}^{\mathrm{PV+}}+\omega_{\mathrm{EB}}^{6}\widehat{P}_{t}^{\mathrm{PV-}}+\omega_{\mathrm{EB}}^{7}\widehat{P}_{t}^{\mathrm{WT+}} \\
+\omega_{\mathrm{EB}}^{8}\widehat{P}_{t}^{\mathrm{WT-}}+4\psi^{\mathrm{EB}}\cdot\mu\ge 0 \\
\omega_{\mathrm{EB}}^{1}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{PV+}}}\ge P_{\mathrm{EB}}^{1},\omega_{\mathrm{EB}}^{2}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{PV-}}}\ge P_{\mathrm{EB}}^{2}, \\
\omega_{\mathrm{EB}}^{3}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{WT+}}}\ge P_{\mathrm{EB}}^{3},\omega_{\mathrm{EB}}^{4}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{WT-}}}\ge P_{\mathrm{EB}}^{4} \\
\omega_{\mathrm{EB}}^{5}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{PV+}}}\ge -P_{\mathrm{EB}}^{1},\omega_{\mathrm{EB}}^{6}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{PV-}}}\ge -P_{\mathrm{EB}}^{2}, \\
\omega_{\mathrm{EB}}^{7}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{WT+}}}\ge -P_{\mathrm{EB}}^{3},\omega_{\mathrm{EB}}^{8}+\dfrac{\psi^{\mathrm{EB}}}{\widehat{P}_{t}^{\mathrm{WT-}}}\ge -P_{\mathrm{EB}}^{4}
\end{cases}
\tag{B6}
$$

Constraint transformations are performed to ensure that the battery storage capacity as well as the electric power balance constraints are satisfied in both the minimum and maximum case directions on the uncertainty set; The variable $E_{e,t+1}{}'\in\left[E_{\min},E_{\max}\right]$ is also introduced to indicate that the maximum case SoC value stays within the battery capacity range. The dyadic variable ω_e,ψ^e is introduced for conversion:

$$
\begin{cases}
\omega_e^1\widehat{P}_t^{\mathrm{PV+}}+\omega_e^2\widehat{P}_t^{\mathrm{PV-}}+\omega_e^3\widehat{P}_t^{\mathrm{WT+}}+\omega_e^4\widehat{P}_{WT,t}^{-}+4\psi^e\cdot\mu \\
\le E_{e,t+1}{}'-E_{e,t}-\eta_{\mathrm{e}}^{\mathrm{cha}}P_{\mathrm{c}}^{0}+P_{\mathrm{d}}^{0}/\eta_{\mathrm{e}}^{\mathrm{dis}} \\
\omega_e^5\widehat{P}_t^{\mathrm{PV+}}+\omega_e^6\widehat{P}_t^{\mathrm{PV+}}+\omega_e^7\widehat{P}_t^{\mathrm{WT+}}+\omega_e^8\widehat{P}_t^{\mathrm{WT-}}+4\psi^e\cdot\mu \\
\ge E_{e,t+1}-E_{e,t}-\eta_{\mathrm{e}}^{\mathrm{cha}}P_{\mathrm{c}}^{0}+P_{\mathrm{d}}^{0}/\eta_{\mathrm{e}}^{\mathrm{dis}} \\
\omega_e^1+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{PV+}}}\ge\eta_e^{\mathrm{cha}}P_{\mathrm{d}}^{1}+P_{\mathrm{d}}^{1}/\eta_e^{\mathrm{dis}},\omega_e^2+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{PV-}}}\ge\eta_e^{\mathrm{cha}}P_{\mathrm{c}}^{2}+P_{\mathrm{d}}^{2}/\eta_e^{\mathrm{dis}} \\
\omega_e^3+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{WT+}}}\ge\eta_e^{\mathrm{cha}}P_{\mathrm{c}}^{3}+P_{\mathrm{d}}^{3}/\eta_e^{\mathrm{dis}},\omega_e^4+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{WT-}}}\ge\eta_e^{\mathrm{cha}}P_{\mathrm{c}}^{4}+P_{\mathrm{d}}^{4}/\eta_e^{\mathrm{dis}} \\
\omega_e^5+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{PV+}}}\ge-\left(\eta_e^{\mathrm{cha}}P_{\mathrm{c}}^{1}+P_{\mathrm{d}}^{1}/\eta_e^{\mathrm{dis}}\right), \\
\omega_e^6+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{PV-}}}\ge-\left(\eta_e^{\mathrm{cha}}P_{\mathrm{c}}^{2}+P_{\mathrm{d}}^{2}/\eta_e^{\mathrm{dis}}\right), \\
\omega_e^7+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{WT+}}}\ge-\left(\eta_e^{\mathrm{cha}}P_{\mathrm{c}}^{3}+P_{\mathrm{d}}^{3}/\eta_e^{\mathrm{dis}}\right), \\
\omega_e^8+\dfrac{\psi^e}{\widehat{P}_t^{\mathrm{WT-}}}\ge-\left(\eta_e^{\mathrm{cha}}P_{c}^{4}+P_{d}^{4}/\eta_e^{\mathrm{dis}}\right)
\end{cases}
\tag{B7}
$$

The above transformations convert max conditions containing uncertain variables into deterministic min-term constraints through robust pairing, yielding an easy-to-handle MILP reconstruction formulation that is efficiently and directly solved by an off-the-shelf Gurobi optimization package.

C. File Formats for Graphics

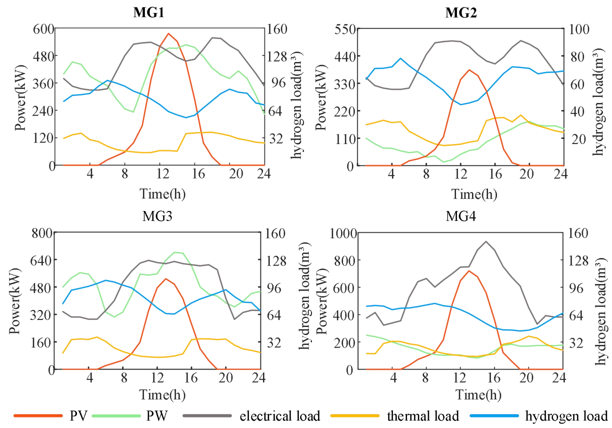

Fig.C1. Convergence curve of cost

TABLE I

COMPARISON OF RUNNING COSTS OF DIFFERENT SOLUTIONS

Typology	Time period	Electricity price/(yuan /(kW·h))
Valley hours	1:00-6:00、23:00-24:00	0.45
Flat hours	13:00-17:00	0.73
Peak hours	7:00-12:00、18:00-22:00	1.21

TABLE II

OTHER PARAMETERS OF THE MODEL

parameters	value	parameters	value
T/(h)	24	Δt/(h)	1
N_G	4	$P_{\max}^{\mathrm{cha/dis}}$/(kW)	200
V/(kW)	200	$P_{\max}^{\mathrm{FC/EL}}$/(kW)	450
$P_{\max}^{\mathrm{grid}}$/(kW)	2000	$P_{\max}^{\mathrm{EB}}$/(kW)	500
$P_{\max}$/(kW)	600	$\lambda^{\mathrm{PV/WT}}$/(yuan /kW·h)	0.1
$\eta_{\mathrm{e}}^{\mathrm{cha}}/\eta_{\mathrm{e}}^{\mathrm{dis}}$	0.95	λ^{E}/(yuan /kW·h)	0.011
$\eta_{\mathrm{h}}^{\mathrm{in}}/\eta_{\mathrm{h}}^{\mathrm{out}}$	0.8/0.65	λ^{H}/(yuan /kW·h)	0.018
$\eta_{\mathrm{h}}^{\mathrm{EL}}/\eta_{\mathrm{h}}^{\mathrm{FC}}/\eta_{\mathrm{b}}^{\mathrm{EB}}$	0.352/0.45/0.9	λ^{EL}/(yuan /kW·h)	0.0628
$[E_{\min},E_{\max}]$ /(kW·h)	[40,360]	λ^{FC}/(yuan /kW·h)	0.0625
$[S_{\min},S_{\max}]$/(m³)	[150,1350]	λ^{EB}/(yuan /kW·h)	0.063