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1. Introduction

[illegible] (PSE), [illegible] [1,2] [illegible] (MIDO) [3–6] [illegible]

[illegible]

2. Batch properties of FCCU

[illegible]

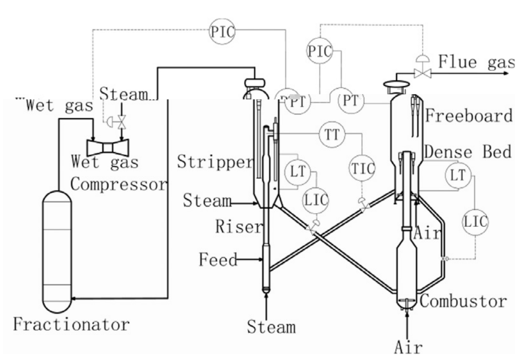

Fig. 1. S[illegible] FCCU [illegible]

[illegible] MD [illegible] FCCU [illegible] CO [illegible] CO_2 [illegible] CO_2 [illegible] FCCU [illegible] CO_2 [illegible] FCCU, CO_2 [illegible] CO_2 [illegible] FCCU, [illegible] CO_2 [illegible] 8 [illegible] 2.

3. Hybrid parametric dynamic optimization

3.1. Mathematical formulation of hybrid parametric dynamic optimization

[illegible] (DAEs):

$$\dot{x}_d = f_d\left(t, x_d(t), x_a(t), u(t), \bar{u}\right) \quad (1a)$$

$$0 = f_a\left(t, x_d(t), x_a(t), u(t), \bar{u}\right) \quad (1b)$$

[illegible] $x_d(t) \in R^{n_d}/x_a(t) \in R^{n_a}$ [illegible]; $u(t)/\bar{u}$ [illegible] $x_d(t_0)$ [illegible] $\bar{u}$ [illegible]

[illegible]

$$J(u(t), \bar{u}) = \int_{t_0}^{t_f} \left(-r(t, x_d(t), x_a(t), u, \bar{u}) + c_1(t, x_d(t), x_a(t), u, \bar{u})\right)dt + c_2(\bar{u}) \quad (2)$$

[illegible] J [illegible] $r\left(t, x_d(t), x_a(t), u, \bar{u}\right)$ [illegible] $c_1\left(t, x_d(t), x_a(t), u, \bar{u}\right)$ [illegible] $c_2(\bar{u})$ [illegible] t_0. [illegible] $\tilde{x}(t)$ [illegible] J. [illegible]

$$\tilde{x} = -r + c_1 \quad (3)$$

[illegible]

$$\tilde{x}(t_0) = 0 \quad (4)$$

[illegible] $x_d(t)$. [illegible] J [illegible]:

$$\min_{u(t),\bar{u}} J\left(x(t_f), \bar{u}\right) = \tilde{x}(t_f) + c_2(\bar{u}) \quad (5)$$

[illegible] $x(t) = (x_d(t)^T, x_a(t)^T)^T$.

[illegible]

$$x^{lb} \le x(t) \le x^{ub} \quad (6a)$$

$$u^{lb} \le u(t) \le u^{ub} \quad (6b)$$

[illegible] $x^{lb} = ((x_d^{lb})^T, (x_a^{lb})^T)^T$, $x^{ub} = ((x_d^{ub})^T, (x_a^{ub})^T)^T$, x_d^{lb} [illegible] x_d^{ub} [illegible]; x_a^{lb} [illegible] x_a^{ub} [illegible]; u^{lb} [illegible] u^{ub} [illegible] MD [illegible] $\bar{u}$ [illegible]

$$\bar{u}^{lb} \le \bar{u} \le \bar{u}^{ub} \quad (7)$$

[illegible] $\bar{u}^{lb}$ [illegible] $\bar{u}^{ub}$ [illegible]

$$x^{flb} \le x(t_f) \le x^{fub} \quad (8)$$

[illegible] $x^{flb} = ((x_d^{flb})^T, (x_a^{flb})^T)^T$, $x^{fub} = ((x_d^{fub})^T, (x_a^{fub})^T)^T$, x_d^{flb} [illegible] x_d^{fub} [illegible]; x_a^{flb} [illegible] x_a^{fub} [illegible]

[illegible] $u(t)$ [illegible] $\bar{u}$ [illegible] Eq. (5), [illegible] Eqs. (1), (6), (7) [illegible] (8). [illegible] (P1).

Problem (P1):

$$\min_{u(t),\bar{u}} J\left(x(t_f), \bar{u}\right) \quad (9a)$$

$$\text{s.t. } x_d(t_0) = x_d^0 \quad (9b)$$

$$\dot{x}_d = f_d\left(t, x_d(t), x_a(t), u(t), \bar{u}\right) \quad (9c)$$

$$0 = f_a\left(t, x_d(t), x_a(t), u(t), \bar{u}\right) \quad (9d)$$

$$G_{\bar{u}}(\bar{u}) \le 0 \quad (9e)$$

$$G_u\left(u(t)\right) \le 0 \quad (9f)$$

$$G_p\left(x(t)\right) \le 0 \quad (9g)$$

$$G_e\left(x(t_f)\right) \le 0 \quad (9h)$$

$$G_{\bar{u}}(\bar{u}) = \begin{pmatrix} \bar{u} - \bar{u}^{ub} \\ \bar{u}^{lb} - \bar{u} \end{pmatrix} \quad (9i)$$

$$G_u\left(u(t)\right) = \begin{pmatrix} u(t) - u^{ub} \\ u^{lb} - u(t) \end{pmatrix} \quad (9j)$$

$$G_p\left(x(t)\right) = \begin{pmatrix} x(t) - x^{ub} \\ x^{lb} - x(t) \end{pmatrix} \quad (9k)$$

$$G_e\left(x(t_f)\right) = \begin{pmatrix} x(t_f) - x^{fub} \\ x^{flb} - x(t_f) \end{pmatrix} \quad (9l)$$

[illegible] NLP [illegible]

$u(t) \in D$,

$$u(t) \approx \hat{u}^N(t) = \sum_{i=1}^{N} u_i^N \phi_i^N(t) \quad (10)$$

$\phi_i^N(t)$ $D^N = \{\phi_1^N(t), \phi_2^N(t), \ldots, \phi_N^N(t)\}$, u_i^N $u(t)$ $\phi_i^N(t)$. U L $\phi_i^N(t)$, $\left(\phi_i^N(t) \cap \phi_j^N(t)\right) = 0$ ( ) $\forall i \neq j$. H $< \phi_i^N(t), \phi_j^N(t) > = 0$ $\forall i \neq j$ D_N. t_0, t_f $N \geq 1$ $t_0 < t_1 < t_2 < \ldots < t_N = t_f$, $\phi_i^N(t)$

$$\phi_i^N(t) = \begin{cases} 1, & t_{i-1} \le t \le t_i \\ 0, & \end{cases} \quad (11)$$

B $u(t)$ $\hat{u}_N = ((u_1^N)^T, \ldots, (u_N^N)^T)^T$ NLP. S $y(t)$ y^{ub} y^{lb}, $y^l(t)$ $y^u(t)$ $\dot{y}^l = \left(0, y^{lb} - y(t)\right)$ $\dot{y}^u = \left(0, y(t) - y^{ub}\right)$, $y^l(t_0) = 0$ $y^u(t_0) = 0$, : $y^l(t_f) = 0$ $y^u(t_f) = 0$. $u(t)$, $u(t)$ $\hat{u}_N$. A NLP P (P2).

Problem (P2):

$$J\left(x(t_f), \bar{u}\right) \quad (12)$$

$$MX(t_0) = X_0 \quad (12)$$

$$M\dot{X}(t) = F\left(t, X(t), \hat{u}_N, \bar{u}\right) \quad (12)$$

$$G(\bar{u}, \hat{u}_N, X(t_f)) \le 0 \quad (12)$$

$$M = (\underbrace{1, \ldots, 1}_{3n_d + 2n_a}, \underbrace{0, \ldots, 0}_{n_a}) \quad (12)$$

$$X(t) = \begin{pmatrix} x_d(t) \\ x^b(t) \\ x_a(t) \end{pmatrix} \quad (12)$$

$$X_0 = \begin{pmatrix} x_d^0 \\ 0 \\ 0 \end{pmatrix} \quad (12)$$

$$F\left(t, X(t), \hat{u}_N, \bar{u}\right) = \begin{pmatrix} f_d\left(t, x_d(t), x_a(t), \hat{u}_N, \bar{u}^j\right) \\ f_b\left(t, x(t)\right) \\ f_a\left(t, x_d(t), x_a(t), \hat{u}_N, \bar{u}^j\right) \end{pmatrix} \quad (12)$$

$$f_b\left(t, x(t)\right) = \begin{pmatrix} \left(0, x^{lb} - x(t)\right) \\ \left(0, x(t) - x^{ub}\right) \end{pmatrix} \quad (12)$$

$$G(\bar{u}, \hat{u}_N, X(t_f)) = \begin{pmatrix} G_{\bar{u}}(\bar{u}) \\ G'_u(\hat{u}_N) \\ G'_e\left(x^b(t_f)\right) \\ G_e\left(x(t_f)\right) \end{pmatrix} \quad (12)$$

$$G'_u(\hat{u}_N) = \begin{pmatrix} G_u(u_1^N) \\ \vdots \\ G_u(u_N^N) \end{pmatrix} \quad (12)$$

$$G'_e\left(x^b(t_f)\right) = x^b(t_f) \quad (12)$$

3.2. Nonconvex sensitivity-based generalized Benders decomposition

S , GBD- R NSGBD C P 33. I : (1) B (LP) ; (2) ; (3) B

B $\bar{u}$ $\underline{u}$

$$h(\bar{u}, \underline{u}) = \underline{u} - \bar{u} = 0 \quad (13)$$

NSGBD P (P2) :

Problem (P3):

$$(\hat{u}_{N,a}^j | J_a^j) = J\left(x(t_f), \bar{u}_a^j\right) \quad (14)$$

$$MX(t_0) = X_0 \quad (14)$$

$$M\dot{X}(t) = F\left(t, X(t), \hat{u}_N, \bar{u}^j\right) \quad (14)$$

$$G\left(\bar{u}_a^j, \hat{u}_N, X(t_f)\right) \le 0 \quad (14)$$

J_a^j

Problem (P4):

$$(\hat{u}_{N,b}^j, \bar{u}_b^j | \mu_a^j) = J\left(x(t_f), \bar{u}\right) \quad (15)$$

$$MX(t_0) = X_0 \quad (15)$$

$$M\dot{X}(t) = F\left(t, X(t), \hat{u}_N, \bar{u}\right) \quad (15)$$

$$G(\bar{u}, \hat{u}_N, X(t_f)) \le 0 \quad (15)$$

$$h\left(\bar{u}, \underline{u}_a^j\right) = 0 \quad (15)$$

μ_a^j (15).

Problem (P5):

$$(\widehat{\boldsymbol{u}}^{j'}_{N,c}, \overline{\boldsymbol{u}}^{j'}_{c}) = \ \ \ _{\widehat{\boldsymbol{u}}_N, \overline{\boldsymbol{u}}} \parallel \overline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{j}_{t} \parallel^2_A \quad (16)$$

$$. . \ M\boldsymbol{X}(t_0) = \boldsymbol{X}_0 \quad (16)$$

$$M\dot{\boldsymbol{X}}(t) = \boldsymbol{F}\Big(t, \boldsymbol{X}(t), \widehat{\boldsymbol{u}}_N, \overline{\boldsymbol{u}}\Big) \quad (16)$$

$$\boldsymbol{G}\Big(\overline{\boldsymbol{u}}, \widehat{\boldsymbol{u}}_N, \boldsymbol{X}(t_f)\Big) \le \boldsymbol{0} \quad (16)$$

$$\parallel \overline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{j} \parallel^2_A = (\overline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{j})^T A (\overline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{j}) \quad (16)$$

A fi .

Problem (P6):

$$(\alpha^{j'}_{d}, \widehat{\boldsymbol{u}}^{j'}_{N,d}, \overline{\boldsymbol{u}}^{j'}_{d} | \boldsymbol{\mu}^{j'}_{b}) = \ \ \ _{\alpha, \widehat{\boldsymbol{u}}_N, \overline{\boldsymbol{u}}} \alpha \quad (17)$$

$$. . \ M\boldsymbol{X}(t_0) = \boldsymbol{X}_0 \quad (17)$$

$$M\dot{\boldsymbol{X}}(t) = \boldsymbol{F}\Big(t, \boldsymbol{X}(t), \widehat{\boldsymbol{u}}_N, \overline{\boldsymbol{u}}\Big) \quad (17)$$

$$\boldsymbol{G}\Big(\overline{\boldsymbol{u}}, \widehat{\boldsymbol{u}}_N, \boldsymbol{X}(t_f)\Big) - \alpha \boldsymbol{e} \le \boldsymbol{0} \quad (17)$$

$$\boldsymbol{h}(\overline{\boldsymbol{u}}, \overline{\boldsymbol{u}}^{j'}_{c}) = \boldsymbol{0} \quad (17)$$

$\boldsymbol{\mu}^{j'}_{b}$ (17) $\boldsymbol{e}$

T $\overline{\boldsymbol{u}}$ (E . (7)) :

$$\boldsymbol{\mu}^{i}_{c} \cdot \Big(\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{ub}\Big) \le 0, i \in K_u \quad (18)$$

$$\boldsymbol{\mu}^{i'}_{d} \cdot \Big(\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{lb}\Big) \le 0, i' \in K_l \quad (18)$$

$\boldsymbol{\mu}^{i}_{c} = (\underbrace{0, ..., 0}_{i-1}, 1, \underbrace{0 ..., 0}_{l-i})$ $\boldsymbol{\mu}^{i'}_{d} = (\underbrace{0, ..., 0}_{i'-1}, -1, \underbrace{0 ..., 0}_{l-i'})$.

Problem (P7):

$$\Big(\eta^{k}_{b}, \underline{\boldsymbol{u}}^{k}_{b} | \boldsymbol{v}^{k}_{a}, \boldsymbol{v}^{k}_{b}, \boldsymbol{v}^{k}_{c}, \boldsymbol{v}^{k}_{d}\Big) = \ \ \ _{\eta, \underline{\boldsymbol{u}}} \eta \quad (19)$$

$$\eta \ge J^{j}_{a} + \boldsymbol{\mu}^{j}_{a} \cdot \Big(\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{j}_{a}\Big), j \in K_{feas} \quad (19)$$

$$\boldsymbol{\mu}^{j'}_{b} \cdot \Big(\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{j'}_{c}\Big) \le 0, j' \in K_{infeas} \quad (19)$$

$$\boldsymbol{\mu}^{i}_{c} \cdot \Big(\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{ub}\Big) \le 0, i \in K_u \quad (19)$$

$$\boldsymbol{\mu}^{i'}_{d} \cdot \Big(\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{lb}\Big) \le 0, i' \in K_l \quad (19)$$

$\boldsymbol{v}^{k}_{a}$, $\boldsymbol{v}^{k}_{b}$, $\boldsymbol{v}^{k}_{c}$ $\boldsymbol{v}^{k}_{d}$ L K_{feas}, K_{infeas}, K_u K_l,

D fi

$$\Xi_a = \{j \in \ : (\boldsymbol{v}^{k}_{a})_j \neq 0\} \quad (20)$$

$$\Xi_b = \{j' \in \ : (\boldsymbol{v}^{k}_{b})_{j'} \neq 0\} \quad (20)$$

$$\Xi_c = \{i \in \ : (\boldsymbol{v}^{k}_{c})_i \neq 0\} \quad (20)$$

$$\Xi_d = \{i' \in \ : (\boldsymbol{v}^{k}_{d})_{i'} \neq 0\} \quad (20)$$

Problem (P8):

$$(\underline{\boldsymbol{u}}^{k}_{c}) = \ \ \ _{\underline{\boldsymbol{u}}} \boldsymbol{\mu}^{k}_{a} \cdot \underline{\boldsymbol{u}} \quad (21)$$

$$\boldsymbol{\mu}^{j'}_{b} \cdot (\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}^{j'}_{c}) \le 0, j' \in K_{infeas} \quad (21)$$

$$\boldsymbol{\mu}^{i}_{c} \cdot (\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}_{u}) \le 0, i \in K_u \quad (21)$$

$$\boldsymbol{\mu}^{i'}_{d} \cdot (\underline{\boldsymbol{u}} - \overline{\boldsymbol{u}}_{l}) \le 0, i' \in K_l \quad (21)$$

T :

$$\mathrm{LBD} > \mathrm{UBD} \quad (22)$$

$$\mathrm{UBD} - \mathrm{LBD} < \varepsilon_1 \quad (22)$$

T :

$$\parallel \boldsymbol{\mu}^{k}_{a} / J^{k}_{a} \parallel_B \le \varepsilon_2 \quad (23)$$

$$\parallel \underline{\boldsymbol{u}}^{k}_{b} - \underline{\boldsymbol{u}}^{k}_{c} \parallel_B \le \varepsilon_3 \quad (23)$$

Algorithm 1: NSGBD with CVP for Problem (P1)

Step 1. D t_0,t_f $t_0 < t_1 < t_2 < \ldots < t_N = t_f$ $\boldsymbol{u}(t)$ $\widehat{\boldsymbol{u}}_N$. F $\overline{\boldsymbol{u}}^{1}_{t}$ E . (7); $j = 1$, $j' = 1$, $K_{feas} = \emptyset$, $K_{infeas} = \emptyset$, $LBD = -\infty$; γ, ε_1, ε_2 ε_3.

Step 2. S P (P3) $\overline{\boldsymbol{u}}_a = \overline{\boldsymbol{u}}^{j}_{t}$. O - :

(1). P (P3) $\widehat{\boldsymbol{u}}^{j}_{N,a}$ J^{j}_{a}; - P (P4) $\underline{\boldsymbol{u}}^{j}_{a} = \overline{\boldsymbol{u}}^{j}_{a}$ $\overline{\boldsymbol{u}}^{j}_{a}$ $\widehat{\boldsymbol{u}}^{j}_{N,a}$ $\boldsymbol{\mu}^{j}_{a}$. UBD = J^{j}_{a}; O :

①. LBD > UBD. $\boldsymbol{\mu}^{l}_{a} = \gamma \boldsymbol{\mu}^{l}_{a}$, $l \in \Xi_a$.

②. UBD − LBD < ε_1. O :

(a). $|\Xi_b| + |\Xi_c| + |\Xi_d| = 0$ ($\overline{\boldsymbol{u}}^{j}_{a}$). I E . (23) - fi ($\widehat{\boldsymbol{u}}^{j}_{N,a}$, $\overline{\boldsymbol{u}}^{j}_{a}$), $\boldsymbol{\mu}^{l}_{a} = \gamma \boldsymbol{\mu}^{l}_{a}$, $l \in \Xi_a$.

(b). $|\Xi_b| + |\Xi_c| + |\Xi_d| \neq 0$ ($\overline{\boldsymbol{u}}^{j}_{a}$). S P (P8) $\overline{\boldsymbol{u}}^{j}_{a}$ $\underline{\boldsymbol{u}}^{j}_{c}$. I E . (23) fi ($\underline{\boldsymbol{u}}^{j}_{b} = \overline{\boldsymbol{u}}^{j}_{a}$), ($\widehat{\boldsymbol{u}}^{j}_{N,a}$, $\overline{\boldsymbol{u}}^{j}_{a}$).

③. O .

$K_{feas} = \{K_{feas}, j\}$; $j = j + 1$.

(2). P P (P3) . S P (P5) $\overline{\boldsymbol{u}}^{j}_{t}$ ($\widehat{\boldsymbol{u}}^{j'}_{N,c}$, $\overline{\boldsymbol{u}}^{j'}_{c}$). S P (P6) $\overline{\boldsymbol{u}}^{j'}_{c}$ ($\widehat{\boldsymbol{u}}^{j'}_{N,c}$, $\overline{\boldsymbol{u}}^{j'}_{c}$) $\alpha = 0$ $\boldsymbol{\mu}^{j'}_{b}$. K_{infeas} = K_{infeas},j' . $\overline{\boldsymbol{u}}^{j}_{t} = \overline{\boldsymbol{u}}^{j'}_{c}$, $j' = j' + 1$. R S 2.

Step 3. S P (P7) η^{j}_{b}, $\underline{\boldsymbol{u}}^{j}_{b}$, $\boldsymbol{v}^{j}_{a}$, $\boldsymbol{v}^{j}_{b}$, $\boldsymbol{v}^{j}_{c}$ $\boldsymbol{v}^{j}_{d}$; LBD = η^{j}_{b}, $\overline{\boldsymbol{u}}^{j}_{t} = \underline{\boldsymbol{u}}^{j}_{b}$. R S 2.

Remark 1. T fl NSGBD 13 F . 2. P (P3) (P4) fi $\overline{\boldsymbol{u}}^{j}_{a}$ - B . T P (P3) fi - P (P4) P (P3). P (P5) (P6) $\overline{\boldsymbol{u}}^{j}_{t}$ $\overline{\boldsymbol{u}}^{j'}_{c}$ $\overline{\boldsymbol{u}}$ $\boldsymbol{\mu}^{j'}_{b}$, $\overline{\boldsymbol{u}}$. P (P5) fi . P - (P6) P (P5) $\alpha = 0$. P (P7) LP . Ξ_a B . A B Ξ_a γ LBD . Ξ_b, Ξ_c Ξ_d

[illegible] K_{infeas}, K_u [illegible] K_l, [illegible] Eq. (22) [illegible] LBD, [illegible] Eq. (23) [illegible] (23) [illegible] P [illegible] (P8) [illegible] Eq. (23), [illegible] T [illegible] NSGBD [illegible] B [illegible] S [illegible] 2 [illegible] A [illegible] 1.

Remark 2. T [illegible] NSGBD [illegible]: 1) μ_a^j [illegible] ([illegible]) [illegible] 13 [illegible] $\overline{u}$; 2) [illegible] 38 [illegible] NSGBD, [illegible].

3.3. Novel implementation framework of optimal solution

A [illegible] C P, [illegible] M [illegible] T [illegible]

T [illegible]

NCO

4. Hybrid parametric dynamic optimization of FCCU

4.1. Mathematical formulation of FCCU

A L . 7, fl CO

$u(t)$ $T_{ra\ sp}(t)$, $\bar{u}$ fl V CO M_{pro}. T CO 8 h = 480 2 h = 120 . F

$$J\left(T_{ra\ sp}(t),\{V_i\}_{i=1}^{4},M_{pro}\right)=\int_0^{480}\left(-\omega_{1d}F_d\left(t,T_{ra\ sp}(t),\{V_i\}_{i=1}^{4},M_{pro}\right)-\omega_{1n}F_n\left(t,T_{ra\ sp}(t),\{V_i\}_{i=1}^{4},M_{pro}\right)\right)dt+\sum_{i=1}^{4}\int_{120(i-1)}^{120i}f(V_i)dt+\omega_3M_{pro} \tag{25}$$

ω_{1d}, ω_{1n} ω_3 CO; F_d F_n; f $\{V_i\}_{i=1}^{4}$. T FCCU L . 7. H $T_{ra\ sp}(t)$ M_{pro} $\{V_i\}_{i=1}^{4}$ E. (25), fi . N . T

T V V

$$J\left(T_{ra\ sp}(t),V(t),M_{pro}\right)=\int_0^{480}\left(-\omega_{1d}F_d\left(t,T_{ra\ sp}(t),V(t),M_{pro}\right)-\omega_{1n}F_n\left(t,T_{ra\ sp}(t),V(t),M_{pro}\right)+f\left(V(t)\right)\right)dt+\omega_3M_{pro} \tag{26}$$

C CO (M_{pro} = 4), A T 1. T L . 7.

T NSGBD PROMS/ OPT MATLAB LP . M 16 . N C 3, NSGBD C P.

4.2. Case 1: Combustion air as a continuous operation whereas CO promoter as a batch operation

I M_{pro} $T_{ra\ sp}$ V, L . 7, C P . H 32 NLP . U NSGBD , L T 2. U ε_1=1, ε_2= 0.1 ε_2= 0.1, NSGBD 5 .

T fi . T $M_{pro}^{1.1}=2$ $M_{pro}^{1.2}=4$. T 5 $J^5-LBD^5\leq 1$ $\|\mu^5/J^5\|\leq 5\times10^{-3}$ ( ), M_{pro}^{j} . C $M_{pro}^{5}=3.1864$, J^5 = 1655.2¥. T 5 F . 4.

A F . 4 4, fl CO L . 7. A F . 4 4, O_2 fl . H NCO- fl . H . A . 7, fl O_2 fl .

D fi $L=\{k\in N:\mu^k<0\}$, $R=\{k\in N:\mu^k>0\}$, $M_{pro}^{k}<M_{pro}^{*}$ $k\in L$ $M_{pro}^{k}>M_{pro}^{*}$ $k\in R$. H

$$M_{pro}^{*}\in\left(\max_{k\in L}M_{pro}^{k},\min_{k\in R}M_{pro}^{k}\right)=(3.1864,3.3440) \tag{27}$$

B S 3.3, NCO- T 3.

A fi T 3, M_{pro} = 3.1864 M_{pro} = 3.3440, NCO- . B T 3, M_{pro} 3.344, 3.45 . T $M_{pro}=3.4kg$ J = 2732.3¥

495.4

Case 2: Combusti

14

SGBD

). ND

D. A C P

16

4,

5,

T 6.

NSGBD

2^5=

1.

Table 4

P ... .

I	4.4	5	6	7	8	9	10
M_{pro}( )	2.5865	2.4590	2.7855	2.8738	2.8890	3.2639	3.3223
μ_M	8.9744	−21.541	27.047	25.754	20.927	53.115	58.887
V_1(^{3}/)	49.034	49.061	49.064	49.064	49.065	49.068	49.068
μ_{V1}	−3480.3	−3515.4	−3471.9	−3479.8	−3490.8	−3480.0	−3468.3
V_2(^{3}/)	48.952	48.977	48.978	48.979	48.979	48.980	48.981
μ_{V2}	−3456.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V10V 1 Tf 2.3841 0 T8.9							

:

$$M^*_{pro} \in (\quad _{k \in P} M^k_{pro}, M^{10}_{pro}) = (2.5865, 3.3223) \quad (28)$$

$$V^*_1 \in (V^{10}_1, \quad _{k \in N_1} V^k_1) = (49.068, 49.072) \quad ^3/ \quad (28)$$

$$V^*_2 \in (V^{10}_2, \quad _{k \in N_2} V^k_2) = (48.981, 48.983) \quad ^3/ \quad (28)$$

$$V^*_3 \in (V^{10}_3, \quad _{k \in N_3} V^k_3) = (48.931, 48.932) \quad ^3/ \quad (28)$$

$$V^*_4 \in (V^{10}_4, \quad _{k \in N_4} V^k_4) = (48.896, 48.897) \quad ^3/ \quad (28)$$

T ... NCO- ... T 7.

A ... fi ... T 7, ... $(M^{10}_{pro}, V^{10}_1, V^{10}_2, V^{10}_3, V^{10}_4)$, ... NSGBD ... NCO- ... . B ... T 7, ... : $M_{pro} \in (3.3223, 3.3223)$, $V_1 \in (49.076, 49.080)$ ^{3}/ , $V_2 \in (48.988, 48.992)$ ^{3}/ , $V_3 \in (48.938, 48.942)$ ^{3}/ , $V_4 \in (48.904, 48.908)$ ^{3}/ . T ... $M_{pro} = 3.3223$, $V_1 = 49.078$ ^{3}/ , $V_2 = 48.990$ ^{3}/ , $V_3 = 48.940$ ^{3}/ , $V_4 = 48.906$ ^{3}/ $J = 1890.4$¥, ... NCO- ... F . 5. A

... F . 5 , ... NCO- ... . T ... fl ... 2 ... 8 , ... fi ... 0.5 ... (... F . 5). M ... .

F C 3 4, ... NCO- ... , ... T 8. C ... C 2 1 4 3, ... T ...

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