paper5

November 2, 2025

[1]:

```python
# ============================================
# Unified ADMM (UC) with selectable Block-2 solver
# Now configured for: N=50 units, T=24 hours
# ============================================

import numpy as np
import cvxpy as cp
import math
import matplotlib.pyplot as plt
from itertools import product

# ===== Optional (only needed for DVQE mode) =====
try:
    from raiselab import DVQE
except Exception:
    DVQE = None

# -------------------------------
# Choose solver (interactive)
# -------------------------------
choice = input("Choose Block-2 solver: [1] Brute force, [2] DVQE (distributed): ").strip()
if choice not in {"1", "2"}:
    raise ValueError("Please enter '1' for Brute force or '2' for DVQE.")
USE_DVQE = (choice == "2")
if USE_DVQE and DVQE is None:
    raise RuntimeError("DVQE package not found. Install/enable raiselab or choose option 1.")

# -------------------------------
# Switches/verbosity
# -------------------------------
USE_BATCH_IN_UPDATES       = True
DEBUG_COMPARE_BATCH_MICRO = False
VERBOSE_BATCH_LOG          = False
ITERPRINT                  = 10
ACCEPT_TOL_BATCH           = 1e-12
```

```python
# --------------------------------
# Grouped Batch-QUBO controls
# (more batches since N=50)
# --------------------------------
K_BATCHES          = 28
HARD_EPS_ENERGY    = 1e-6
HARD_ETA           = 1e-9
HARD_WEIGHTS       = dict(w1=1.0, w2=1.0, w3=1.0, w4=1.0, w5=1.0)

# --------------------------------
# DVQE config (only used if USE_DVQE=True)
# --------------------------------
dvqe_mode = "distributed"
dvqe_depth = 2
dvqe_lr = 0.1
dvqe_max_iters = 100
qpu_qubit_config = [3, 3, 3, 3, 3, 3]  # 6 mini-QPUs (example)

# --------------------------------
# QUBO helpers (unchanged)
# --------------------------------
def solve_qubo_brute_force(Q, q_linear):
    Q = np.asarray(Q, dtype=float)
    q = np.asarray(q_linear, dtype=float).ravel()
    n = q.size
    if Q.shape != (n, n):
        raise ValueError(f"Q must have shape ({n},{n}), got {Q.shape}")
    Q = 0.5 * (Q + Q.T)
    best_z, best_cost = None, float("inf")
    for cand in product([0, 1], repeat=n):
        z = np.fromiter(cand, dtype=float, count=n)
        cost = z @ Q @ z + q @ z
        if cost < best_cost:
            best_cost = cost
            best_z = z.astype(int)
    return best_z, best_cost

def enumerate_energy(Q, c):
    Q = 0.5 * (Q + Q.T)
    out = []
    for cand in product([0, 1], repeat=3):
        z = np.array(cand, dtype=float)
        E = float(z @ Q @ z + c @ z)
        out.append((cand, E))
    return out
```

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def hardness_score(Q, c, eps_energy_scale=1.0, weights=HARD_WEIGHTS):
    spec = enumerate_energy(Q, c)
    Es = sorted([E for _, E in spec])
    Emin = Es[0]
    Delta = Es[1] - Emin if len(Es) > 1 else float('inf')
    epsE = HARD_EPS_ENERGY * eps_energy_scale
    g_eps = sum(1 for E in Es if E <= Emin + epsE)

    Q12, Q23, Q13 = Q[0,1], Q[1,2], Q[0,2]
    prod_sign = np.sign(Q12 * Q23 * Q13)
    frustrated = 1 if prod_sign < 0 else 0

    coup = abs(Q12) + abs(Q23) + abs(Q13)
    field = abs(c[0]) + abs(c[1]) + abs(c[2]) + 1e-16
    r = coup / field

    coeffs = [abs(Q12), abs(Q23), abs(Q13), abs(c[0]), abs(c[1]), abs(c[2])]
    nz = [x for x in coeffs if x > 0]
    if len(nz) == 0:
        dr = 0.0
    else:
        M, m = max(nz), min(nz)
        dr = math.log10(M / m) if M > 0 and m > 0 else 0.0

    w1, w2, w3, w4, w5 = weights["w1"], weights["w2"], weights["w3"], weights["w4"], weights["w5"]
    score = (
        w1 * (1.0 / (Delta + HARD_ETA)) +
        w2 * ((g_eps - 1.0) / 7.0) +
        w3 * (1.0 * frustrated) +
        w4 * (r / (1.0 + r)) +
        w5 * (dr / 4.0)
    )
    return float(score), dict(Delta=Delta, g_eps=g_eps, frustrated=frustrated, r=r, dr=dr)

def build_unit_batches_at_time_t(N, Q_list_t, c_list_t, k_batches=K_BATCHES):
    k_batches = max(1, min(k_batches, N))
    hard_i = np.zeros(N, dtype=float)
    items = []
    for i in range(N):
        Q, c = Q_list_t[i], c_list_t[i]
        scale = (np.sum(np.abs(Q)) + np.sum(np.abs(c)) + 1.0)
        score, _ = hardness_score(Q, c, eps_energy_scale=scale)
        hard_i[i] = score
        items.append((i, score))
    # sort by difficulty and greedy bin-pack to balance hardness
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    items.sort(key=lambda x: x[1], reverse=True)
    batches = [[] for _ in range(k_batches)]
    batch_scores = [0.0 for _ in range(k_batches)]
    for i, score in items:
        b = int(np.argmin(batch_scores))
        batches[b].append(i)
        batch_scores[b] += score
    sizes = [len(b) for b in batches]
    return batches, batch_scores, sizes, hard_i

def micro_qubo_coeffs(qy, qu, qv, y_hat, u_hat, v_hat, y_ref,
                      gamma_c, gamma_ss, gamma_u2y, gamma_v2ny,
                      gamma_y, gamma_u, gamma_v):
    """Return (Q,c) for 3-bit micro-QUBO over [z^y, z^u, z^v]."""
    Q = np.zeros((3,3), dtype=float)  # [y u v]
    c = np.array([qy, qu, qv], dtype=float)

    # anchors
    c[0] += gamma_y * (1 - 2 * y_hat)
    c[1] += gamma_u * (1 - 2 * u_hat) + gamma_u2y
    c[2] += gamma_v * (1 - 2 * v_hat)

    # local (c): (zy - zu + zv - y_ref)^2
    c[0] += gamma_c * (1 - 2 * y_ref)
    c[1] += gamma_c * (1 + 2 * y_ref)
    c[2] += gamma_c * (1 - 2 * y_ref)
    Q[0,1] += -2 * gamma_c; Q[1,0] = Q[0,1]
    Q[0,2] += +2 * gamma_c; Q[2,0] = Q[0,2]
    Q[1,2] += -2 * gamma_c; Q[2,1] = Q[1,2]

    # no simultaneous u+v
    Q[1,2] += gamma_ss; Q[2,1] = Q[1,2]

    # start -> on
    Q[0,1] += -gamma_u2y; Q[1,0] = Q[0,1]

    # shutdown -> off
    Q[0,2] += gamma_v2ny; Q[2,0] = Q[0,2]

    return Q, c

def local_augL_alone(y_it, u_it, v_it, sy_it, su_it, sv_it,
                     lamy_it, lamu_it, lamv_it, zy, zu, zv,
                     rho_y, rho_u, rho_v):
    Ly = lamy_it * (y_it - zy + sy_it) + 0.5 * rho_y * (y_it - zy + sy_it)**2
    Lu = lamu_it * (u_it - zu + su_it) + 0.5 * rho_u * (u_it - zu + su_it)**2
    Lv = lamv_it * (v_it - zv + sv_it) + 0.5 * rho_v * (v_it - zv + sv_it)**2
```

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    return float(Ly + Lu + Lv)

def assemble_batch_qubo(units, Q_list, c_list):
    """Concatenate 3x3 blocks [y,u,v] per unit (no cross couplings)."""
    m = len(units)
    Qb = np.zeros((3*m, 3*m), dtype=float)
    cb = np.zeros(3*m, dtype=float)
    for k, i in enumerate(units):
        Qb[3*k:3*k+3, 3*k:3*k+3] = Q_list[i]
        cb[3*k:3*k+3] = c_list[i]
    return Qb, cb

# -------------------------------
# Problem data (deterministic) - N=50, T=24
# -------------------------------
N = 50
T = 24

rng = np.random.default_rng(11)

# Costs (programmatic patterns for 50 units)
idx = np.arange(N)

# Fixed + linear + mild sinusoidal variation to diversify units
A = 500 + 6.5*idx + 15*np.sin(0.3*idx)                    # fixed cost
B = 20 + (idx % 12) * 0.8                                  # linear gen cost
C = 0.0018 + 0.00002*((idx % 20) + 1)                      # quadratic cost
S = 180 + (idx % 10)*20                                    # startup
H = np.zeros(N)                                            # shutdown (unused here)

# Capacities: cycle Pmin in {20,25,30,35,40}, Pmax = Pmin + 100
Pmin_cycle = np.array([20,25,30,35,40], dtype=float)
Pmin = Pmin_cycle[idx % 5]
Pmax = Pmin + 100.0

# Ramps: cycle {30,35,40,45,50}; SU/RD = RU/RD + 10
RU_cycle = np.array([30,35,40,45,50], dtype=float)
RD_cycle = np.array([30,35,40,45,50], dtype=float)
RU = RU_cycle[idx % 5]
RD = RD_cycle[idx % 5]
SU = RU + 10.0
SD = RD + 10.0

# Min up/down times: alternate 2 / 3
Umin = np.where(idx % 2 == 0, 2, 3).astype(int)
Dmin = np.where(idx % 2 == 1, 2, 3).astype(int)
```

```python
# Demand profile (MW), smooth 24h curve (same as before)
L = np.array([
 900, 950,1000,1050,1100,1150,1200,1250,
1300,1350,1400,1450,1500,1450,1400,1350,
1300,1250,1200,1150,1100,1050,1000, 950], dtype=float)

# Reserve requirements (same as before)
R_up_req = np.array([60,65,70,70,75,80,85,85,90,95,95,100,
                     100,95,90,85,80,75,70,70,65,65,60,60], dtype=float)
R_dn_req = np.array([55,55,60,60,65,65,70,70,75,75,80,80,
                     80,75,75,70,70,65,65,60,60,55,55,55], dtype=float)

delta_tau = 1.0

# -------------------------------
# ADMM runner (unchanged logic)
# -------------------------------
def run_admm(USE_DVQE=False):
    rho_y = rho_u = rho_v = 5.0e6
    beta_y = beta_u = beta_v = 2.0e5
    epsilon = 1e-3
    max_iter = 4000

    # Micro-QUBO penalties (scaled to rho_y)
    gamma_c      = 0.20 * rho_y
    gamma_ss     = 0.10 * rho_y
    gamma_u2y    = 0.05 * rho_y
    gamma_v2ny   = 0.05 * rho_y
    gamma_y = gamma_u = gamma_v = 0.10 * rho_y

    # init
    p0 = np.ones(N)* 40
    y0 = (p0 > 0.0).astype(int)

    y = np.ones((N, T)) * 0.5
    u = np.zeros((N, T))
    v = np.zeros((N, T))
    p = np.tile(L / max(N, 1), (N, 1))
    r_up = np.zeros((N, T))
    r_dn = np.zeros((N, T))

    z_y = np.zeros((N, T), dtype=int)
    z_u = np.zeros((N, T), dtype=int)
    z_v = np.zeros((N, T), dtype=int)
    s_y = np.zeros((N, T))
    s_u = np.zeros((N, T))
    s_v = np.zeros((N, T))
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    lam_y = np.zeros((N, T))
    lam_u = np.zeros((N, T))
    lam_v = np.zeros((N, T))
    primal_residuals = []

    for it in range(max_iter):
        # ========= Block 1: Classical QP =========
        yi  = cp.Variable((N, T))
        ui  = cp.Variable((N, T))
        vi  = cp.Variable((N, T))
        pi  = cp.Variable((N, T))
        rup = cp.Variable((N, T), nonneg=True)
        rdn = cp.Variable((N, T), nonneg=True)

        econ = (
            cp.sum(cp.multiply(A[:, None], yi)) +
            cp.sum(cp.multiply(B[:, None], pi)) +
            cp.sum(cp.multiply(C[:, None], cp.square(pi))) +
            cp.sum(cp.multiply(S[:, None], ui)) +
            cp.sum(cp.multiply(H[:, None], vi))
        )
        pen_y = cp.sum(cp.multiply(lam_y, yi - z_y + s_y)) + (rho_y / 2) * cp.
↪sum_squares(yi - z_y + s_y)
        pen_u = cp.sum(cp.multiply(lam_u, ui - z_u + s_u)) + (rho_u / 2) * cp.
↪sum_squares(ui - z_u + s_u)
        pen_v = cp.sum(cp.multiply(lam_v, vi - z_v + s_v)) + (rho_v / 2) * cp.
↪sum_squares(vi - z_v + s_v)
        objective = cp.Minimize(econ + pen_y + pen_u + pen_v)

        cons = []
        cons += [yi >= 0, yi <= 1, ui >= 0, ui <= 1, vi >= 0, vi <= 1]
        cons += [pi >= 0]
        for t in range(T):
            cons += [cp.sum(pi[:, t]) == L[t]]
        cons += [pi >= cp.multiply(Pmin[:, None], yi)]
        cons += [pi <= cp.multiply(Pmax[:, None], yi)]
        cons += [yi[:, 0] - y0 == ui[:, 0] - vi[:, 0]]
        cons += [ui[:, 0] + vi[:, 0] <= 1]
        for t in range(1, T):
            cons += [yi[:, t] - yi[:, t-1] == ui[:, t] - vi[:, t]]
            cons += [ui[:, t] + vi[:, t] <= 1]
        for i in range(N):
            Ui, Di = int(Umin[i]), int(Dmin[i])
            for t in range(T):
                k_up = max(0, t - Ui + 1)
                k_dn = max(0, t - Di + 1)
```

```
                cons += [cp.sum(ui[i, k_up:t+1]) <= yi[i, t]]
                cons += [cp.sum(vi[i, k_dn:t+1]) <= 1 - yi[i, t]]
        for i in range(N):
            cons += [pi[i, 0] - p0[i] <= RU[i] * y0[i] + SU[i] * ui[i, 0]]
            cons += [p0[i] - pi[i, 0] <= RD[i] * yi[i, 0] + SD[i] * vi[i, 0]]
            for t in range(1, T):
                cons += [pi[i, t] - pi[i, t-1] <= RU[i] * yi[i, t-1] + SU[i] * ui[i, t]]
                cons += [pi[i, t-1] - pi[i, t] <= RD[i] * yi[i, t]   + SD[i] * vi[i, t]]
        cons += [rup <= cp.multiply(Pmax[:, None], yi) - pi]
        cons += [rdn <= pi - cp.multiply(Pmin[:, None], yi)]
        cons += [rup <= RU[:, None] * delta_tau]
        cons += [rdn <= RD[:, None] * delta_tau]
        for t in range(T):
            cons += [cp.sum(rup[:, t]) >= R_up_req[t]]
            cons += [cp.sum(rdn[:, t]) >= R_dn_req[t]]

        yi.value, ui.value, vi.value = y, u, v
        pi.value, rup.value, rdn.value = p, r_up, r_dn

        prob = cp.Problem(objective, cons)
        installed = set(cp.installed_solvers())
        status = "unknown"
        if "OSQP" in installed:
            prob.solve(solver=cp.OSQP, eps_abs=1e-8, eps_rel=1e-8,
                       max_iter=1_600_000, polish=True, warm_start=True, verbose=False)
            status = prob.status
        if status not in ("optimal", "optimal_inaccurate") and "SCS" in installed:
            prob.solve(solver=cp.SCS, eps=5e-8, max_iters=2_000_000,
                       warm_start=True, verbose=False)
            status = prob.status

        y   = yi.value
        u   = ui.value
        v   = vi.value
        p   = pi.value
        r_up = rup.value
        r_dn = rdn.value

        # ========= Block 2: K batch-QUBOs per time t =========
        z_y_prev, z_u_prev, z_v_prev = z_y.copy(), z_u.copy(), z_v.copy()

        for t in range(T):
```

```
        qy_vec = -(lam_y[:, t] + rho_y * (y[:, t] + s_y[:, t])) + 0.5 *␣
↪rho_y
        qu_vec = -(lam_u[:, t] + rho_u * (u[:, t] + s_u[:, t])) + 0.5 *␣
↪rho_u
        qv_vec = -(lam_v[:, t] + rho_v * (v[:, t] + s_v[:, t])) + 0.5 *␣
↪rho_v

        Q_list_t, c_list_t = [None]*N, [None]*N
        for i in range(N):
            y_hat, u_hat, v_hat = y[i, t], u[i, t], v[i, t]
            y_ref = (z_y_prev[i, t-1] if t > 0 else (1 if 40 > 0 else 0)) ␣
↪# y0[i] with p0>0
            Q3, c3 = micro_qubo_coeffs(qy_vec[i], qu_vec[i], qv_vec[i],
                                       y_hat, u_hat, v_hat, y_ref,
                                       gamma_c, gamma_ss, gamma_u2y,␣
↪gamma_v2ny,
                                       gamma_y, gamma_u, gamma_v)
            Q_list_t[i] = Q3
            c_list_t[i] = c3

        batches_t, batch_scores_t, batch_sizes_t, hard_i =␣
↪build_unit_batches_at_time_t(
            N, Q_list_t, c_list_t, k_batches=K_BATCHES
        )

        for b, units in enumerate(batches_t):
            n_units = len(units)
            Qb = np.zeros((3*n_units, 3*n_units))
            cb = np.zeros(3*n_units)
            for k, i in enumerate(units):
                Q3, c3 = Q_list_t[i], c_list_t[i]
                idxs = slice(3*k, 3*k+3)
                Qb[idxs, idxs] = Q3
                cb[idxs] = c3

            if USE_DVQE:
                Qb = 0.5 * (Qb + Qb.T)
                zb, _, _ = DVQE(mode=dvqe_mode, Q=Qb, q_linear=cb,␣
↪init_type=2,
                                depth=dvqe_depth, lr=dvqe_lr,␣
↪max_iters=dvqe_max_iters,
                                qpu_qubit_config=qpu_qubit_config,␣
↪rel_tol=1e-6)
                zb = np.asarray(zb, dtype=float).ravel()
                zb = (zb >= 0.5).astype(int)
            else:
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                zb, _ = solve_qubo_brute_force(Qb, cb)
                zb = np.asarray(zb, dtype=int).ravel()

            proposed = []
            for k, i in enumerate(units):
                zy_new, zu_new, zv_new = map(int, zb[3*k:3*k+3])
                proposed.append((i, zy_new, zu_new, zv_new))

            old_al_sum = 0.0
            new_al_sum = 0.0
            for (i, zy_new, zu_new, zv_new) in proposed:
                old_al_sum += local_augL_alone(
                    y[i, t], u[i, t], v[i, t],
                    s_y[i, t], s_u[i, t], s_v[i, t],
                    lam_y[i, t], lam_u[i, t], lam_v[i, t],
                    z_y_prev[i, t], z_u_prev[i, t], z_v_prev[i, t],
                    rho_y, rho_u, rho_v
                )
                new_al_sum += local_augL_alone(
                    y[i, t], u[i, t], v[i, t],
                    s_y[i, t], s_u[i, t], s_v[i, t],
                    lam_y[i, t], lam_u[i, t], lam_v[i, t],
                    zy_new, zu_new, zv_new,
                    rho_y, rho_u, rho_v
                )

            if new_al_sum + ACCEPT_TOL_BATCH <= old_al_sum:
                for (i, zy_new, zu_new, zv_new) in proposed:
                    z_y[i, t], z_u[i, t], z_v[i, t] = zy_new, zu_new, zv_new
            else:
                for (i, _, _, _) in proposed:
                    z_y[i, t], z_u[i, t], z_v[i, t] = z_y_prev[i, t],
↪z_u_prev[i, t], z_v_prev[i, t]

        # ========= Block 3: Prox slacks + projection =========
        s_y = -(lam_y + rho_y * (y - z_y)) / (beta_y + rho_y)
        s_u = -(lam_u + rho_u * (u - z_u)) / (beta_u + rho_u)
        s_v = -(lam_v + rho_v * (v - z_v)) / (beta_v + rho_v)
        s_y = np.maximum(0.0, s_y)
        s_u = np.maximum(0.0, s_u)
        s_v = np.maximum(0.0, s_v)

        # ========= Dual updates =========
        lam_y = lam_y + 0.5 * rho_y * (y - z_y + s_y)
        lam_u = lam_u + 0.5 * rho_u * (u - z_u + s_u)
        lam_v = lam_v + 0.5 * rho_v * (v - z_v + s_v)
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        # ========= Residual / stopping =========
        res = math.sqrt(
            np.linalg.norm((y - z_y + s_y).ravel())**2 +
            np.linalg.norm((u - z_u + s_u).ravel())**2 +
            np.linalg.norm((v - z_v + s_v).ravel())**2
        )
        primal_residuals.append(res)

        if it % ITERPRINT == 0:
            print(f"Iter {it:3d} | status={status:>18s} | residual: {res:.4e}")

        if res < epsilon:
            break

    return {"residuals": primal_residuals, "p": p}

# -------------------------------
# Run per user choice
# -------------------------------
res_brute = None
res_dvqe  = None

if USE_DVQE:
    print("Running ADMM with DVQE (distributed) batch solver...")
    res_dvqe = run_admm(USE_DVQE=True)
else:
    print("Running ADMM with Brute-force batch solver...")
    res_brute = run_admm(USE_DVQE=False)

# -------------------------------
# Plot & Save
# -------------------------------
plt.figure(figsize=(7.2, 4.6))

if res_brute is not None:
    plt.semilogy(
        res_brute["residuals"],
        label="Brute force",
        marker='o',
        markevery=max(1, len(res_brute["residuals"])//12)
    )
if res_dvqe is not None:
    plt.semilogy(
        res_dvqe["residuals"],
        label="DVQE",
        marker='s',
        markevery=max(1, len(res_dvqe["residuals"])//12)
```

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    )

ax = plt.gca()
ax.spines['top'].set_visible(False)
ax.spines['right'].set_visible(False)
plt.grid(True, which="both", linestyle="--", linewidth=0.6)
plt.xlabel("Iteration", fontsize=14)
plt.ylabel("Primal residual (log)", fontsize=14)
plt.title("ADMM Convergence (Deterministic UC, Batched QUBOs, N=50)",␣
↪fontsize=15)
plt.xticks(fontsize=12)
plt.yticks(fontsize=12)
plt.legend(frameon=False, fontsize=12)

plt.tight_layout()
plt.savefig("admm_convergence.jpg", dpi=600, bbox_inches="tight")
plt.show()
print('Saved figure: "admm_convergence.jpg"')

# -------------------------------
# LaTeX dispatch table printer
# -------------------------------
def print_dispatch_table(p, L):
    # show 10 spread-out units across 50
    units_to_show = [1, 4, 8, 10, 13, 19, 24, 32, 41, 49]  #␣
↪2,5,9,11,14,20,25,33,42,50
    hours_to_show = range(6)  # first six hours

    print("\n\\begin{table}[!t]")
    print("\\scriptsize")
    print("\\setlength{\\tabcolsep}{3pt}")
    print("\\renewcommand{\\arraystretch}{1.2}")
    print("\\captionsetup{font={footnotesize}}")
    print("\\caption{Partial Dispatch for UC ($N{=}50$, $T{=}24$). Ten␣
↪representative units over first six hours.}")
    print("\\centering")
    print("\\begin{tabular}{c|cccccccccc|c|c}")
    print("\\hline")
    print("\\multirow{2}{*}{\\textbf{t}} "
          "& \\multicolumn{10}{c|}{\\textbf{Unit Dispatch $p_i$ (MW)}} "
          "& \\multirow{2}{*}{$\\sum_i p_{i,t}$} "
          "& \\multirow{2}{*}{$L_t$} \\\\ \\cline{2-11}")
    print("& $p_2$ & $p_5$ & $p_{9}$ & $p_{11}$ & $p_{14}$ & $p_{20}$ &␣
↪$p_{25}$ & $p_{33}$ & $p_{42}$ & $p_{50}$ & & \\\\ \\hline")

    for t in hours_to_show:
        vals = [f"{p[i, t]:.1f}" for i in units_to_show]
```

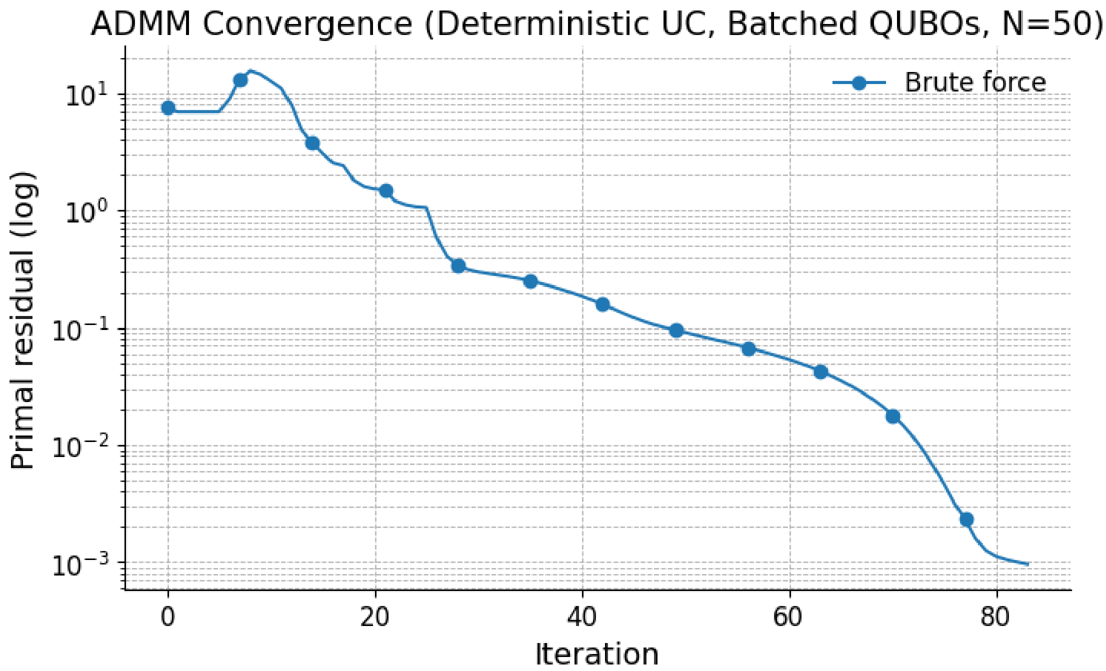
```python
        total_gen = f"{np.sum(p[:, t]):.1f}"
        demand = f"{L[t]:.1f}"
        row = " & ".join([str(t+1)] + vals + [total_gen, demand])
        print(row + " \\\\ \\hline")

    print("\\end{tabular}")
    print("\\label{tab:dispatch_medium_N50}")
    print("\\end{table}\n")

# Print table for whichever run we just did
if res_brute is not None:
    print("\n% === LaTeX table for Brute-force run (N=50) ===")
    print_dispatch_table(res_brute["p"], L)
if res_dvqe is not None:
    print("\n% === LaTeX table for DVQE run (N=50) ===")
    print_dispatch_table(res_dvqe["p"], L)
```

```
Choose Block-2 solver: [1] Brute force, [2] DVQE (distributed):  1

Running ADMM with Brute-force batch solver…
Iter   0 | status=           optimal | residual: 7.5383e+00
Iter  10 | status=           optimal | residual: 1.2569e+01
Iter  20 | status=           optimal | residual: 1.5214e+00
Iter  30 | status=           optimal | residual: 2.9933e-01
Iter  40 | status=           optimal | residual: 1.8540e-01
Iter  50 | status=           optimal | residual: 9.1122e-02
Iter  60 | status=           optimal | residual: 5.3470e-02
Iter  70 | status=           optimal | residual: 1.7995e-02
Iter  80 | status=           optimal | residual: 1.1237e-03
```




```
Saved figure: "admm_convergence.jpg"

% === LaTeX table for Brute-force run (N=50) ===

\begin{table}[!t]
\scriptsize
\setlength{\tabcolsep}{3pt}
\renewcommand{\arraystretch}{1.2}
\captionsetup{font={footnotesize}}
\caption{Partial Dispatch for UC ($N{=}50$, $T{=}24$). Ten representative units
over first six hours.}
\centering
\begin{tabular}{c|cccccccccc|c|c}
\hline
\multirow{2}{*}{\textbf{t}} & \multicolumn{10}{c|}{\textbf{Unit Dispatch $p_i$
(MW)}} & \multirow{2}{*}{$\sum_i p_{i,t}$} & \multirow{2}{*}{$L_t$} \\
\cline{2-11}
& $p_2$ & $p_5$ & $p_{9}$ & $p_{11}$ & $p_{14}$ & $p_{20}$ & $p_{25}$ & $p_{33}$
& $p_{42}$ & $p_{50}$ & & \\ \hline
1 & 0.0 & 66.7 & 17.9 & -0.0 & 0.0 & 51.5 & 66.8 & 0.0 & 0.0 & 52.8 & 900.0 &
900.0 \\ \hline
2 & 0.0 & 66.7 & 41.0 & -0.0 & 0.0 & 44.1 & 66.8 & 0.0 & 0.0 & 52.8 & 950.0 &
950.0 \\ \hline
3 & 24.8 & 42.9 & 17.9 & 0.0 & 27.9 & 19.6 & 66.8 & 0.0 & 13.8 & 68.4 & 1000.0 &
1000.0 \\ \hline
```

```
4 & 49.7 & 19.1 & 19.0 & -0.0 & 51.4 & 19.6 & 66.8 & 15.8 & 16.9 & 53.4 & 1050.0
& 1050.0 \\ \hline
5 & 52.0 & 19.1 & 19.0 & 0.0 & 46.0 & 19.6 & 66.8 & 17.7 & 16.9 & 47.9 & 1100.0
& 1100.0 \\ \hline
6 & 39.1 & 19.1 & 19.0 & 0.0 & 34.6 & 19.6 & 66.8 & 17.7 & 16.9 & 36.0 & 1150.0
& 1150.0 \\ \hline
\end{tabular}
\label{tab:dispatch_medium_N50}
\end{table}
```

[ ]:

```python
# ============================================
# Unified ADMM (UC) with selectable Block-2 solver
# Now configured for: N=50 units, T=24 hours
# ============================================

import numpy as np
import cvxpy as cp
import math
import matplotlib.pyplot as plt
from itertools import product

# ===== Optional (only needed for DVQE mode) =====
try:
    from raiselab import DVQE
except Exception:
    DVQE = None

# -------------------------------
# Choose solver (interactive)
# -------------------------------
choice = input("Choose Block-2 solver: [1] Brute force, [2] DVQE (distributed):␣
↪").strip()
if choice not in {"1", "2"}:
    raise ValueError("Please enter '1' for Brute force or '2' for DVQE.")
USE_DVQE = (choice == "2")
if USE_DVQE and DVQE is None:
    raise RuntimeError("DVQE package not found. Install/enable raiselab or␣
↪choose option 1.")

# -------------------------------
# Switches/verbosity
# -------------------------------
USE_BATCH_IN_UPDATES      = True
DEBUG_COMPARE_BATCH_MICRO = False
VERBOSE_BATCH_LOG         = False
ITERPRINT                 = 10
```

```
ACCEPT_TOL_BATCH          = 1e-12

# -------------------------------
# Grouped Batch-QUBO controls
# (more batches since N=50)
# -------------------------------
K_BATCHES           = 28
HARD_EPS_ENERGY     = 1e-6
HARD_ETA            = 1e-9
HARD_WEIGHTS        = dict(w1=1.0, w2=1.0, w3=1.0, w4=1.0, w5=1.0)

# -------------------------------
# DVQE config (only used if USE_DVQE=True)
# -------------------------------
dvqe_mode = "distributed"
dvqe_depth = 2
dvqe_lr = 0.1
dvqe_max_iters = 100
qpu_qubit_config = [3, 3, 3, 3, 3, 3]  # 6 mini-QPUs (example)

# -------------------------------
# QUBO helpers (unchanged)
# -------------------------------
def solve_qubo_brute_force(Q, q_linear):
    Q = np.asarray(Q, dtype=float)
    q = np.asarray(q_linear, dtype=float).ravel()
    n = q.size
    if Q.shape != (n, n):
        raise ValueError(f"Q must have shape ({n},{n}), got {Q.shape}")
    Q = 0.5 * (Q + Q.T)
    best_z, best_cost = None, float("inf")
    for cand in product([0, 1], repeat=n):
        z = np.fromiter(cand, dtype=float, count=n)
        cost = z @ Q @ z + q @ z
        if cost < best_cost:
            best_cost = cost
            best_z = z.astype(int)
    return best_z, best_cost

def enumerate_energy(Q, c):
    Q = 0.5 * (Q + Q.T)
    out = []
    for cand in product([0, 1], repeat=3):
        z = np.array(cand, dtype=float)
        E = float(z @ Q @ z + c @ z)
        out.append((cand, E))
    return out
```

```python
def hardness_score(Q, c, eps_energy_scale=1.0, weights=HARD_WEIGHTS):
    spec = enumerate_energy(Q, c)
    Es = sorted([E for _, E in spec])
    Emin = Es[0]
    Delta = Es[1] - Emin if len(Es) > 1 else float('inf')
    epsE = HARD_EPS_ENERGY * eps_energy_scale
    g_eps = sum(1 for E in Es if E <= Emin + epsE)

    Q12, Q23, Q13 = Q[0,1], Q[1,2], Q[0,2]
    prod_sign = np.sign(Q12 * Q23 * Q13)
    frustrated = 1 if prod_sign < 0 else 0

    coup = abs(Q12) + abs(Q23) + abs(Q13)
    field = abs(c[0]) + abs(c[1]) + abs(c[2]) + 1e-16
    r = coup / field

    coeffs = [abs(Q12), abs(Q23), abs(Q13), abs(c[0]), abs(c[1]), abs(c[2])]
    nz = [x for x in coeffs if x > 0]
    if len(nz) == 0:
        dr = 0.0
    else:
        M, m = max(nz), min(nz)
        dr = math.log10(M / m) if M > 0 and m > 0 else 0.0

    w1, w2, w3, w4, w5 = weights["w1"], weights["w2"], weights["w3"], 
 ↪weights["w4"], weights["w5"]
    score = (
        w1 * (1.0 / (Delta + HARD_ETA)) +
        w2 * ((g_eps - 1.0) / 7.0) +
        w3 * (1.0 * frustrated) +
        w4 * (r / (1.0 + r)) +
        w5 * (dr / 4.0)
    )
    return float(score), dict(Delta=Delta, g_eps=g_eps, frustrated=frustrated, 
 ↪r=r, dr=dr)

def build_unit_batches_at_time_t(N, Q_list_t, c_list_t, k_batches=K_BATCHES):
    k_batches = max(1, min(k_batches, N))
    hard_i = np.zeros(N, dtype=float)
    items = []
    for i in range(N):
        Q, c = Q_list_t[i], c_list_t[i]
        scale = (np.sum(np.abs(Q)) + np.sum(np.abs(c)) + 1.0)
        score, _ = hardness_score(Q, c, eps_energy_scale=scale)
        hard_i[i] = score
        items.append((i, score))
```

```python
    # sort by difficulty and greedy bin-pack to balance hardness
    items.sort(key=lambda x: x[1], reverse=True)
    batches = [[] for _ in range(k_batches)]
    batch_scores = [0.0 for _ in range(k_batches)]
    for i, score in items:
        b = int(np.argmin(batch_scores))
        batches[b].append(i)
        batch_scores[b] += score
    sizes = [len(b) for b in batches]
    return batches, batch_scores, sizes, hard_i

def micro_qubo_coeffs(qy, qu, qv, y_hat, u_hat, v_hat, y_ref,
                      gamma_c, gamma_ss, gamma_u2y, gamma_v2ny,
                      gamma_y, gamma_u, gamma_v):
    """Return (Q,c) for 3-bit micro-QUBO over [z^y, z^u, z^v]."""
    Q = np.zeros((3,3), dtype=float)  # [y u v]
    c = np.array([qy, qu, qv], dtype=float)

    # anchors
    c[0] += gamma_y * (1 - 2 * y_hat)
    c[1] += gamma_u * (1 - 2 * u_hat) + gamma_u2y
    c[2] += gamma_v * (1 - 2 * v_hat)

    # local (c): (zy - zu + zv - y_ref)^2
    c[0] += gamma_c * (1 - 2 * y_ref)
    c[1] += gamma_c * (1 + 2 * y_ref)
    c[2] += gamma_c * (1 - 2 * y_ref)
    Q[0,1] += -2 * gamma_c; Q[1,0] = Q[0,1]
    Q[0,2] += +2 * gamma_c; Q[2,0] = Q[0,2]
    Q[1,2] += -2 * gamma_c; Q[2,1] = Q[1,2]

    # no simultaneous u+v
    Q[1,2] += gamma_ss; Q[2,1] = Q[1,2]

    # start -> on
    Q[0,1] += -gamma_u2y; Q[1,0] = Q[0,1]

    # shutdown -> off
    Q[0,2] += gamma_v2ny; Q[2,0] = Q[0,2]

    return Q, c

def local_augL_alone(y_it, u_it, v_it, sy_it, su_it, sv_it,
                     lamy_it, lamu_it, lamv_it, zy, zu, zv,
                     rho_y, rho_u, rho_v):
    Ly = lamy_it * (y_it - zy + sy_it) + 0.5 * rho_y * (y_it - zy + sy_it)**2
    Lu = lamu_it * (u_it - zu + su_it) + 0.5 * rho_u * (u_it - zu + su_it)**2
```

```
    Lv = lamv_it * (v_it - zv + sv_it) + 0.5 * rho_v * (v_it - zv + sv_it)**2
    return float(Ly + Lu + Lv)

def assemble_batch_qubo(units, Q_list, c_list):
    """Concatenate 3x3 blocks [y,u,v] per unit (no cross couplings)."""
    m = len(units)
    Qb = np.zeros((3*m, 3*m), dtype=float)
    cb = np.zeros(3*m, dtype=float)
    for k, i in enumerate(units):
        Qb[3*k:3*k+3, 3*k:3*k+3] = Q_list[i]
        cb[3*k:3*k+3] = c_list[i]
    return Qb, cb

# -------------------------------
# Problem data (deterministic) - N=50, T=24
# -------------------------------
N = 50
T = 24

rng = np.random.default_rng(11)

# Costs (programmatic patterns for 50 units)
idx = np.arange(N)

# Fixed + linear + mild sinusoidal variation to diversify units
A = 500 + 6.5*idx + 15*np.sin(0.3*idx)                    # fixed cost
B = 20 + (idx % 12) * 0.8                                 # linear gen cost
C = 0.0018 + 0.00002*((idx % 20) + 1)                     # quadratic cost
S = 180 + (idx % 10)*20                                   # startup
H = np.zeros(N)                                           # shutdown (unused here)

# Capacities: cycle Pmin in {20,25,30,35,40}, Pmax = Pmin + 100
Pmin_cycle = np.array([20,25,30,35,40], dtype=float)
Pmin = Pmin_cycle[idx % 5]
Pmax = Pmin + 100.0

# Ramps: cycle {30,35,40,45,50}; SU/RD = RU/RD + 10
RU_cycle = np.array([30,35,40,45,50], dtype=float)
RD_cycle = np.array([30,35,40,45,50], dtype=float)
RU = RU_cycle[idx % 5]
RD = RD_cycle[idx % 5]
SU = RU + 10.0
SD = RD + 10.0

# Min up/down times: alternate 2 / 3
Umin = np.where(idx % 2 == 0, 2, 3).astype(int)
Dmin = np.where(idx % 2 == 1, 2, 3).astype(int)
```

```
# Demand profile (MW), smooth 24h curve (same as before)
L = np.array([
 900, 950,1000,1050,1100,1150,1200,1250,
1300,1350,1400,1450,1500,1450,1400,1350,
1300,1250,1200,1150,1100,1050,1000, 950], dtype=float)

# Reserve requirements (same as before)
R_up_req = np.array([60,65,70,70,75,80,85,85,90,95,95,100,
                     100,95,90,85,80,75,70,70,65,65,60,60], dtype=float)
R_dn_req = np.array([55,55,60,60,65,65,70,70,75,75,80,80,
                     80,75,75,70,70,65,65,60,60,55,55,55], dtype=float)

delta_tau = 1.0

# -------------------------------
# ADMM runner (unchanged logic)
# -------------------------------
def run_admm(USE_DVQE=False):
    rho_y = rho_u = rho_v = 5.0e6
    beta_y = beta_u = beta_v = 2.0e5
    epsilon = 1e-3
    max_iter = 4000

    # Micro-QUBO penalties (scaled to rho_y)
    gamma_c      = 0.20 * rho_y
    gamma_ss     = 0.10 * rho_y
    gamma_u2y    = 0.05 * rho_y
    gamma_v2ny   = 0.05 * rho_y
    gamma_y = gamma_u = gamma_v = 0.10 * rho_y

    # init
    p0 = np.ones(N)* 40
    y0 = (p0 > 0.0).astype(int)

    y = np.ones((N, T)) * 0.5
    u = np.zeros((N, T))
    v = np.zeros((N, T))
    p = np.tile(L / max(N, 1), (N, 1))
    r_up = np.zeros((N, T))
    r_dn = np.zeros((N, T))

    z_y = np.zeros((N, T), dtype=int)
    z_u = np.zeros((N, T), dtype=int)
    z_v = np.zeros((N, T), dtype=int)
    s_y = np.zeros((N, T))
    s_u = np.zeros((N, T))
```

```
    s_v = np.zeros((N, T))

    lam_y = np.zeros((N, T))
    lam_u = np.zeros((N, T))
    lam_v = np.zeros((N, T))
    primal_residuals = []

    for it in range(max_iter):
        # ========= Block 1: Classical QP =========
        yi  = cp.Variable((N, T))
        ui  = cp.Variable((N, T))
        vi  = cp.Variable((N, T))
        pi  = cp.Variable((N, T))
        rup = cp.Variable((N, T), nonneg=True)
        rdn = cp.Variable((N, T), nonneg=True)

        econ = (
            cp.sum(cp.multiply(A[:, None], yi)) +
            cp.sum(cp.multiply(B[:, None], pi)) +
            cp.sum(cp.multiply(C[:, None], cp.square(pi))) +
            cp.sum(cp.multiply(S[:, None], ui)) +
            cp.sum(cp.multiply(H[:, None], vi))
        )
        pen_y = cp.sum(cp.multiply(lam_y, yi - z_y + s_y)) + (rho_y / 2) * cp.
↪sum_squares(yi - z_y + s_y)
        pen_u = cp.sum(cp.multiply(lam_u, ui - z_u + s_u)) + (rho_u / 2) * cp.
↪sum_squares(ui - z_u + s_u)
        pen_v = cp.sum(cp.multiply(lam_v, vi - z_v + s_v)) + (rho_v / 2) * cp.
↪sum_squares(vi - z_v + s_v)
        objective = cp.Minimize(econ + pen_y + pen_u + pen_v)

        cons = []
        cons += [yi >= 0, yi <= 1, ui >= 0, ui <= 1, vi >= 0, vi <= 1]
        cons += [pi >= 0]
        for t in range(T):
            cons += [cp.sum(pi[:, t]) == L[t]]
        cons += [pi >= cp.multiply(Pmin[:, None], yi)]
        cons += [pi <= cp.multiply(Pmax[:, None], yi)]
        cons += [yi[:, 0] - y0 == ui[:, 0] - vi[:, 0]]
        cons += [ui[:, 0] + vi[:, 0] <= 1]
        for t in range(1, T):
            cons += [yi[:, t] - yi[:, t-1] == ui[:, t] - vi[:, t]]
            cons += [ui[:, t] + vi[:, t] <= 1]
        for i in range(N):
            Ui, Di = int(Umin[i]), int(Dmin[i])
            for t in range(T):
                k_up = max(0, t - Ui + 1)
```

```
                k_dn = max(0, t - Di + 1)
                cons += [cp.sum(ui[i, k_up:t+1]) <= yi[i, t]]
                cons += [cp.sum(vi[i, k_dn:t+1]) <= 1 - yi[i, t]]
        for i in range(N):
            cons += [pi[i, 0] - p0[i] <= RU[i] * y0[i] + SU[i] * ui[i, 0]]
            cons += [p0[i] - pi[i, 0] <= RD[i] * yi[i, 0] + SD[i] * vi[i, 0]]
            for t in range(1, T):
                cons += [pi[i, t] - pi[i, t-1] <= RU[i] * yi[i, t-1] + SU[i] *␣
↪ui[i, t]]
                cons += [pi[i, t-1] - pi[i, t] <= RD[i] * yi[i, t]   + SD[i] *␣
↪vi[i, t]]
        cons += [rup <= cp.multiply(Pmax[:, None], yi) - pi]
        cons += [rdn <= pi - cp.multiply(Pmin[:, None], yi)]
        cons += [rup <= RU[:, None] * delta_tau]
        cons += [rdn <= RD[:, None] * delta_tau]
        for t in range(T):
            cons += [cp.sum(rup[:, t]) >= R_up_req[t]]
            cons += [cp.sum(rdn[:, t]) >= R_dn_req[t]]

        yi.value, ui.value, vi.value = y, u, v
        pi.value, rup.value, rdn.value = p, r_up, r_dn

        prob = cp.Problem(objective, cons)
        installed = set(cp.installed_solvers())
        status = "unknown"
        if "OSQP" in installed:
            prob.solve(solver=cp.OSQP, eps_abs=1e-8, eps_rel=1e-8,
                       max_iter=1_600_000, polish=True, warm_start=True,␣
↪verbose=False)
            status = prob.status
        if status not in ("optimal", "optimal_inaccurate") and "SCS" in␣
↪installed:
            prob.solve(solver=cp.SCS, eps=5e-8, max_iters=2_000_000,
                       warm_start=True, verbose=False)
            status = prob.status

        y   = yi.value
        u   = ui.value
        v   = vi.value
        p   = pi.value
        r_up = rup.value
        r_dn = rdn.value

        # ========= Block 2: K batch-QUBOs per time t =========
        z_y_prev, z_u_prev, z_v_prev = z_y.copy(), z_u.copy(), z_v.copy()

        for t in range(T):
```

```
        qy_vec = -(lam_y[:, t] + rho_y * (y[:, t] + s_y[:, t])) + 0.5 *␣
↪rho_y
        qu_vec = -(lam_u[:, t] + rho_u * (u[:, t] + s_u[:, t])) + 0.5 *␣
↪rho_u
        qv_vec = -(lam_v[:, t] + rho_v * (v[:, t] + s_v[:, t])) + 0.5 *␣
↪rho_v

        Q_list_t, c_list_t = [None]*N, [None]*N
        for i in range(N):
            y_hat, u_hat, v_hat = y[i, t], u[i, t], v[i, t]
            y_ref = (z_y_prev[i, t-1] if t > 0 else (1 if 40 > 0 else 0)) ␣
↪# y0[i] with p0>0
            Q3, c3 = micro_qubo_coeffs(qy_vec[i], qu_vec[i], qv_vec[i],
                                       y_hat, u_hat, v_hat, y_ref,
                                       gamma_c, gamma_ss, gamma_u2y,␣
↪gamma_v2ny,
                                       gamma_y, gamma_u, gamma_v)
            Q_list_t[i] = Q3
            c_list_t[i] = c3

        batches_t, batch_scores_t, batch_sizes_t, hard_i =␣
↪build_unit_batches_at_time_t(
            N, Q_list_t, c_list_t, k_batches=K_BATCHES
        )

        for b, units in enumerate(batches_t):
            n_units = len(units)
            Qb = np.zeros((3*n_units, 3*n_units))
            cb = np.zeros(3*n_units)
            for k, i in enumerate(units):
                Q3, c3 = Q_list_t[i], c_list_t[i]
                idxs = slice(3*k, 3*k+3)
                Qb[idxs, idxs] = Q3
                cb[idxs] = c3

            if USE_DVQE:
                Qb = 0.5 * (Qb + Qb.T)
                zb, _, _ = DVQE(mode=dvqe_mode, Q=Qb, q_linear=cb,␣
↪init_type=2,
                                depth=dvqe_depth, lr=dvqe_lr,␣
↪max_iters=dvqe_max_iters,
                                qpu_qubit_config=qpu_qubit_config,␣
↪rel_tol=1e-6)
                zb = np.asarray(zb, dtype=float).ravel()
                zb = (zb >= 0.5).astype(int)
            else:
```

```
                zb, _ = solve_qubo_brute_force(Qb, cb)
                zb = np.asarray(zb, dtype=int).ravel()

            proposed = []
            for k, i in enumerate(units):
                zy_new, zu_new, zv_new = map(int, zb[3*k:3*k+3])
                proposed.append((i, zy_new, zu_new, zv_new))

            old_al_sum = 0.0
            new_al_sum = 0.0
            for (i, zy_new, zu_new, zv_new) in proposed:
                old_al_sum += local_augL_alone(
                    y[i, t], u[i, t], v[i, t],
                    s_y[i, t], s_u[i, t], s_v[i, t],
                    lam_y[i, t], lam_u[i, t], lam_v[i, t],
                    z_y_prev[i, t], z_u_prev[i, t], z_v_prev[i, t],
                    rho_y, rho_u, rho_v
                )
                new_al_sum += local_augL_alone(
                    y[i, t], u[i, t], v[i, t],
                    s_y[i, t], s_u[i, t], s_v[i, t],
                    lam_y[i, t], lam_u[i, t], lam_v[i, t],
                    zy_new, zu_new, zv_new,
                    rho_y, rho_u, rho_v
                )

            if new_al_sum + ACCEPT_TOL_BATCH <= old_al_sum:
                for (i, zy_new, zu_new, zv_new) in proposed:
                    z_y[i, t], z_u[i, t], z_v[i, t] = zy_new, zu_new, zv_new
            else:
                for (i, _, _, _) in proposed:
                    z_y[i, t], z_u[i, t], z_v[i, t] = z_y_prev[i, t],␣
↪z_u_prev[i, t], z_v_prev[i, t]

    # ========= Block 3: Prox slacks + projection =========
    s_y = -(lam_y + rho_y * (y - z_y)) / (beta_y + rho_y)
    s_u = -(lam_u + rho_u * (u - z_u)) / (beta_u + rho_u)
    s_v = -(lam_v + rho_v * (v - z_v)) / (beta_v + rho_v)
    s_y = np.maximum(0.0, s_y)
    s_u = np.maximum(0.0, s_u)
    s_v = np.maximum(0.0, s_v)

    # ========= Dual updates =========
    lam_y = lam_y + 0.5 * rho_y * (y - z_y + s_y)
    lam_u = lam_u + 0.5 * rho_u * (u - z_u + s_u)
    lam_v = lam_v + 0.5 * rho_v * (v - z_v + s_v)
```

```python
        # ========= Residual / stopping =========
        res = math.sqrt(
            np.linalg.norm((y - z_y + s_y).ravel())**2 +
            np.linalg.norm((u - z_u + s_u).ravel())**2 +
            np.linalg.norm((v - z_v + s_v).ravel())**2
        )
        primal_residuals.append(res)

        if it % ITERPRINT == 0:
            print(f"Iter {it:3d} | status={status:>18s} | residual: {res:.4e}")

        if res < epsilon:
            break

    return {"residuals": primal_residuals, "p": p}

# -------------------------------
# Run per user choice
# -------------------------------
res_brute = None
res_dvqe  = None

if USE_DVQE:
    print("Running ADMM with DVQE (distributed) batch solver...")
    res_dvqe = run_admm(USE_DVQE=True)
else:
    print("Running ADMM with Brute-force batch solver...")
    res_brute = run_admm(USE_DVQE=False)

# -------------------------------
# Plot & Save
# -------------------------------
plt.figure(figsize=(7.2, 4.6))

if res_brute is not None:
    plt.semilogy(
        res_brute["residuals"],
        label="Brute force",
        marker='o',
        markevery=max(1, len(res_brute["residuals"])//12)
    )
if res_dvqe is not None:
    plt.semilogy(
        res_dvqe["residuals"],
        label="DVQE",
        marker='s',
        markevery=max(1, len(res_dvqe["residuals"])//12)
```

```
    )

ax = plt.gca()
ax.spines['top'].set_visible(False)
ax.spines['right'].set_visible(False)
plt.grid(True, which="both", linestyle="--", linewidth=0.6)
plt.xlabel("Iteration", fontsize=14)
plt.ylabel("Primal residual (log)", fontsize=14)
plt.title("ADMM Convergence (Deterministic UC, Batched QUBOs, N=50)",␣
 ↪fontsize=15)
plt.xticks(fontsize=12)
plt.yticks(fontsize=12)
plt.legend(frameon=False, fontsize=12)

plt.tight_layout()
plt.savefig("admm_convergence.jpg", dpi=600, bbox_inches="tight")
plt.show()
print('Saved figure: "admm_convergence.jpg"')

# -------------------------------
# LaTeX dispatch table printer
# -------------------------------
def print_dispatch_table(p, L):
    # show 10 spread-out units across 50
    units_to_show = [1, 4, 8, 10, 13, 19, 24, 32, 41, 49]  #␣
 ↪2,5,9,11,14,20,25,33,42,50
    hours_to_show = range(6)  # first six hours

    print("\n\\begin{table}[!t]")
    print("\\scriptsize")
    print("\\setlength{\\tabcolsep}{3pt}")
    print("\\renewcommand{\\arraystretch}{1.2}")
    print("\\captionsetup{font={footnotesize}}")
    print("\\caption{Partial Dispatch for UC ($N{=}50$, $T{=}24$). Ten␣
 ↪representative units over first six hours.}")
    print("\\centering")
    print("\\begin{tabular}{c|cccccccccc|c|c}")
    print("\\hline")
    print("\\multirow{2}{*}{\\textbf{t}} "
          "& \\multicolumn{10}{c|}{\\textbf{Unit Dispatch $p_i$ (MW)}} "
          "& \\multirow{2}{*}{$\\sum_i p_{i,t}$} "
          "& \\multirow{2}{*}{$L_t$} \\\\ \\cline{2-11}")
    print("& $p_2$ & $p_5$ & $p_{9}$ & $p_{11}$ & $p_{14}$ & $p_{20}$ &␣
 ↪$p_{25}$ & $p_{33}$ & $p_{42}$ & $p_{50}$ & & \\\\ \\hline")

    for t in hours_to_show:
        vals = [f"{p[i, t]:.1f}" for i in units_to_show]
```

```
        total_gen = f"{np.sum(p[:, t]):.1f}"
        demand = f"{L[t]:.1f}"
        row = " & ".join([str(t+1)] + vals + [total_gen, demand])
        print(row + " \\\\ \\hline")

    print("\\end{tabular}")
    print("\\label{tab:dispatch_medium_N50}")
    print("\\end{table}\n")

# Print table for whichever run we just did
if res_brute is not None:
    print("\n% === LaTeX table for Brute-force run (N=50) ===")
    print_dispatch_table(res_brute["p"], L)
if res_dvqe is not None:
    print("\n% === LaTeX table for DVQE run (N=50) ===")
    print_dispatch_table(res_dvqe["p"], L)
```

```
Choose Block-2 solver: [1] Brute force, [2] DVQE (distributed):  2

Running ADMM with DVQE (distributed) batch solver…
```

[ ]:

```

```