ECE4053 Power System Analysis

ELECTRICAL ENGINEERING · MONASH UNIVERSITY · LEVEL 4

Full guide + ask Sia about ECE4053

SIDE 1/2 DEFINITIONS · FORMULAS · DECISION RULES · COMPARISONS

EXAM REVISION SHEET

S2 2026 · v2 · 2026-10-25

0 · Exam Map

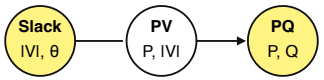
COURSE.JSON · BRIEF

1 Demo 27% | 2 13% | 3 Examination 60%

ASSESSMENT	WEIGHT	SCOPE / FORMAT HELD
1. Demonstration	27%	three group laboratories, 9% each
2. Examination	13%	Weeks 1–5; in person
3. Examination	**60%**	Weeks 1–12; other details unstated

Permitted materials: not confirmed for this offering in the course materials we hold — check the exam instructions on the LMS. `Source: BRIEF.md`

The final rewards **model choice before arithmetic**: classify the network or disturbance, write knowns and unknowns, select the correct balance or connection, compute, then close with a physical check. Never treat numerical convergence as engineering validity.



classify → solve → recover

Bus data decide the state: slack anchors angle and closes losses; PV regulates voltage only within Q limits.

PRIORITY ORDER

SEE	FIRST MOVE	CLOSE WITH
bus network	classify slack/PV/PQ	limits, flows, losses, slack balance
unbalanced fault	draw sequence paths	recover phase current + zone
frequency trace	identify response layer	pickup balance + residual error
voltage deviation	diagnose local Q direction	AC profile + reserve

SIA → *A complete technical answer is model → method → number → physical audit.*

SETUP → CLOSE

PROBLEM	BEFORE NUMBERS	LAST LINE
Power flow	bus data, base, topology, sign	convergence, limits, voltage, loading, slack/loss balance
Dispatch	demand, capacity, bounds, network constraint	outputs sum; active bound; next movable unit; total cost
Fault	common base, sequence paths, grounding/transformer route	phase current; relay quantity, zone and breaker
Frequency	imbalance sign, common base, response layer	pickups sum to disturbance; residual error and reserve
Voltage	local Q direction, device action and limit	AC profile; loading, reserve and side effects

Finish by proving physical closure, not only numerical completion.

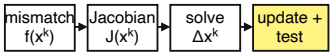
1 · Newton Power Flow

C1 · FINAL METHOD

Slack: |V| and θ fixed; solve P,Q. *PV:* P and |V| fixed; solve θ,Q while Q remains within capability. *PQ:* P,Q fixed; solve θ,|V|. Losses are unknown before solving, so the slack injection must remain free.

ITERATION K

```
evaluate mismatch f(x^k) and Jacobian J(x^k)
solve J(x^k)Δx^k = -f(x^k)
update x^{k+1} = x^k + Δx^k
repeat until chosen mismatch norm < tolerance
```



same-state mismatch + Jacobian

Newton chronology: never mix a mismatch from one state with a Jacobian from another.

SET-UP AND ACCEPTANCE AUDIT

STAGE	WHAT TO WRITE / INSPECT
Data	common base; topology; bus type; specified pair
Model	Y-bus: diagonals collect incident admittances; off-diagonals carry negative coupling
State	unknown angles and PQ voltage magnitudes in an explicit order
Mismatch	row order must match Jacobian rows; keep one injection sign convention
Stop	small chosen mismatch norm, not merely a small correction
Audit	voltages, Q limits, branch loading, slack output and generation = demand + losses

PV Q limit binds: fix Q at the applicable limit, convert PV → PQ, make |V| an unknown, and solve again. Retaining the voltage target would demand unavailable reactive capability.

Flat start uses nominal voltage magnitudes and small or zero angles. If residuals grow, check signs, ordering and row alignment before blaming the initial estimate.

SIA → *Convergence proves only that the stated equations were solved. Engineering acceptance requires the post-solution audit.*

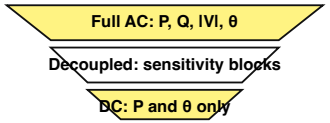
BUS BOOKKEEPING

BUS	FIXED / CONTROLLED	SOLVE / CALCULATE
Slack	|V|, θ	P, Q; closes losses
PV	P, |V|	θ, Q while inside limits
PQ	P, Q	θ, |V|

At a PV bus include active-power mismatch and hold the voltage target only while Q is feasible. If a Q limit binds, fix Q at that bound, add |V| to the state, reclassify as PQ and rebuild the mismatch/Jacobian rows before resolving.

2 · Solver Choice + Dispatch

C2 · COMPARISON



Approximation buys speed by removing questions the model can answer.

METHOD	USE WHEN	BOUNDARY
AC Newton	|V|, Q, losses or limits matter; general transmission study	full nonlinear coupled solve
Decoupled / fast-decoupled	transmission sensitivities support P–θ and Q–|V| separation	can weaken in resistive or stressed networks
DC	rapid P-transfer or contingency screening	|V| near nominal; small angles; negligible R; omits Q and voltage limits
Forward–backward sweep	radial feeder	accumulate downstream, then update voltages outward

Decision rule: if voltage magnitude, reactive limits or losses affect the question, retain an AC model. If only broad active transfers matter and the assumptions are defensible, DC may be adequate. Radial topology is the computational leverage for a feeder sweep.

ECONOMIC OPERATION

Merit order: with constant marginal costs, no congestion and ignored losses, rank available units by increasing marginal cost, apply minimum/maximum limits, and close the generation balance. The **marginal unit** is the unit able to supply the next increment—not necessarily the cheapest unit already full.

SMOOTH LOSSLESS OPTIMUM

```
free units have equal incremental cost: dC_i/dP_i = common value
units at minimum or maximum are not free to move
```

BEFORE COST ARITHMETIC	AFTER DISPATCH
Check available capacity can meet demand plus any stated losses.	Recompute total cost from printed outputs.
Keep on/off commitment separate from output allocation.	Name the active bound and the next movable unit.
Network limits may require a dearer local unit.	Verify ΣP_i closes the required generation.

Average cost = total cost / total output. **Marginal cost** = cost of the next small increment. Do not substitute one for the other.

SIA → *State what the fast method discards; speed without an output boundary is not a method comparison.*

3 · Faults + Protection

C3 · NETWORK FIRST



transform → paths → connect → solve

Symmetrical components make three balanced sets; physical paths still depend on grounding and transformers.

Positive sequence has normal phase order; *negative sequence* has reversed order and signals unbalance; *zero sequence* has three equal in-phase components and needs a neutral or ground return path.

FAULT	SEQUENCE CONNECTION / FIRST CHECK
balanced three-phase	positive network under the standard prefault assumption
line-to-line	positive and negative; no zero-sequence current in the standard connection
single-line-to-ground	positive, negative and zero in series; verify the zero-sequence return path first
double-line-to-ground	requires all relevant sequence paths; redraw the named connection from the course method

Fault workflow: convert all data to one per-unit base → draw generator, line and transformer sequence networks → mark every neutral/grounding impedance → connect for the named fault → solve sequence currents → transform back to phase values.

RELAY CHOOSER

RELAY	COMPARISON	ANSWER MUST NAME
Overcurrent	current magnitude, pickup and time	coordination with adjacent zones
Directional	forward / reverse fault contribution	direction required for selectivity
Distance	apparent impedance against reach	line zone and reach boundary
Differential	current entering vs leaving zone	CT / breaker-defined boundary

A scheme must be reliable, selective, sufficiently sensitive and appropriately fast. Relay name alone is incomplete: state operating quantity, protected zone and isolating breaker.

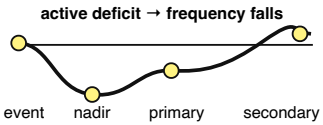
Distributed generation trap: a new source changes fault-current magnitude and direction. Upstream pickup or radial time coordination may no longer hold; trace every source path through every breaker.

SIA → *The decomposition is algebraic; the zero-sequence path is physical. Draw before using a denominator.*

Ground path: zero-sequence current needs a neutral or earth return. Grounded star can admit it; another winding may block transfer, while delta can confine circulation. Mark every neutral and grounding impedance before the denominator.

4 · Frequency Dynamics

C4 · SEPARATE TIMESCALES



Read the trace by layers: inertial slope, nadir, primary arrest and secondary restoration.

FEATURE	DOMINANT INFLUENCE	WHAT IT DOES NOT PROVE
initial RoCoF	disturbance size and aggregate inertia	final allocation or restoration
nadir	inertia plus speed/amount of primary or fast response	steady frequency
primary equilibrium	droop sharing + load damping if included	nominal frequency restored
secondary restoration	reference movement using area control error	unlimited reserve

When electrical demand exceeds mechanical input, rotors decelerate and frequency falls. Greater aggregate inertia reduces the magnitude of the initial slope for the same imbalance; it buys time but neither restores frequency nor chooses the eventual sharing.

INVERSE-DROOP SHARING · COMMON BASE

```
ΔP = -Δf Σ(1/R_i)   [damping ignored]
ΔP_i = -Δf/R_i
check ΣΔP_i = disturbance
```

All units see essentially one area frequency deviation. Smaller R means more pickup for that same deviation, after every slope has been converted to the same power base. Add load damping only when given and keep its contribution distinct from controlled generation.

Why primary leaves error: frequency deviation is the signal sustaining added governor output. If frequency returned to nominal without a reference change, the added primary response would disappear. Secondary control moves references so output remains while frequency and scheduled interchange are restored.

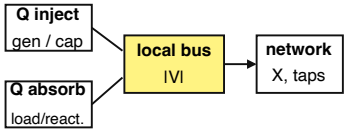
Fast response / virtual inertia: can shape the trajectory but is limited by converter power, stored energy and control settings. Do not describe it as an unlimited replacement for synchronous inertia.

SIA → *For every trace label the feature, dominant mechanism, direction and response layer still outstanding.*

Trace audit: frequency-sensitive load gives natural relief, not governor pickup; keep damping separate when given. Primary control changes mechanical power and arrests the fall. Secondary moves references to restore frequency and interchange.

5 · Voltage + Reactive Power

C5 · LOCAL DIAGNOSIS



Q direction is local; the AC network determines sensitivity, paths and side effects.

Direction rule: local reactive deficit tends to depress voltage; local excess tends to raise it. This is a diagnosis, not an exact voltage calculation: line reactance, neighbouring voltages, taps and device limits determine the response.

DEVICE	PRIMARY ACTION	LIMIT / SECOND EFFECT
Generator excitation	supply or absorb Q; regulate terminal voltage	capability curve and reactive reserve
Capacitor bank	inject Q; support low voltage	steps; fixed-susceptance output falls with voltage
Shunt reactor	absorb Q; control high voltage	can deepen a low-voltage event
Static compensator	fast, continuous regulation	current / equipment rating
Tap changer	change ratio; redistribute voltage and Q	does not create a new Q source; shifts stress

DIAGNOSIS → ACTION → VERIFICATION

LOW |V|	check local inductive demand, generator/compensator limits, transfer and tap; add or release feasible Q injection
HIGH |V|	check light loading and excess injection; absorb Q or revise switching/taps
PV AT Q LIMIT	fix Q; convert to PQ; resolve with |V| unknown
ALWAYS	rerun AC power flow; inspect all voltages, reactive outputs, branch loading and reserve

Control layers: primary = immediate local automatic loop (for example excitation); secondary = coordinated regional setpoints and reserve restoration; slower scheduling positions taps, shunts and generator targets. Name measured variable and actuator.

Do not swap balances: frequency points first to system-wide active-power imbalance; local voltage points first to reactive balance and network sensitivity.

SIA → *A local MVAr balance proves capacity feasibility, not the restored voltage. Only the full AC solution validates the profile.*

Locality: reactive transfer drops voltage across network X, so distant Q support may be inefficient and worsen loading. Prefer feasible nearby support; state its limit and second effect, then rerun AC power flow for neighbouring buses, branch loading and reserve.

ECE4053 Power System Analysis · Self-Test Drills

ELECTRICAL ENGINEERING · MONASH UNIVERSITY · LEVEL 4

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SIDE 2/2 FIVE WORKED MINI-EXAMPLES · IF X → DO Y · CLASSIC TRAPS · EXAM-MORNING PLAN

EXAM REVISION SHEET

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6 · Drill 1 – Newton Corrections

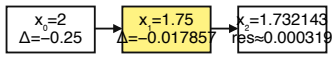
C1 WORKED EXAMPLE

Given: solve $f(x)=x^2-3$ from $x_0=2.0000$ using two Newton corrections.

RULE

$f'(x)=2x \quad \cdot \quad \Delta x=-f/f' \quad \cdot \quad x^+=x+\Delta x$

ROW	X	F(X)	F′(X)	ΔX / UPDATE
0	2.0000	1	4	$-0.2500 \rightarrow x_1=1.7500$
1	1.7500	0.0625	3.5	$-0.017857 \rightarrow x_2=1.732143$
check	1.732143	residual ≈ 0.000319		



evaluate → correct → update

Answer path to the end: two corrections and a substituted residual check.

Answer: $x_2=1.732143$; the residual is about 0.000319.

IF YOU SEE X → DO Y

RESIDUAL GROWS	check sign convention, variable/row order and same-state J/f
PV EXCEEDS Q LIMIT	fix Q; PV→PQ; add |V| to unknowns; resolve
SOLVER CONVERGES	still audit voltage, Q, loading, losses and slack
SOFTWARE DIFFERS	match base, topology, bus types and tolerance first

REBUILD THE FULL NETWORK METHOD

STEP	VISIBLE WORKING
1 Classify	for every bus print the two specified quantities and the two to recover
2 Assemble	use one base and topology; Y-bus diagonal collects incident admittances, off-diagonal is negative coupling
3 Initialise	state vector in a fixed order; flat start only as the initial estimate
4 Evaluate	specified minus calculated injections using one sign convention
5 Correct	form J at the same state, solve the linear system, update once
6 Reclassify	check PV reactive output against both capability limits
7 Accept	voltage, branch flow, slack injection and generation = demand + losses

Answer sentence: "The iteration converged to the stated tolerance; bus types remain valid / bus ___ changes to PQ; the slack and loss balance is plausible / requires correction."

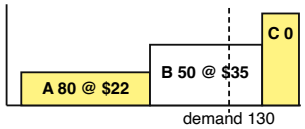
SIA → *Keep each mismatch and derivative on the same iteration row.*

Precision trap: carry enough decimals for the residual to fall for the right reason. Stop on the chosen mismatch norm, not a small correction; substitute the final state and report the audit.

7 · Drill 2 – Merit Dispatch

C2 WORKED EXAMPLE

Given: A costs $22/MWh up to 80 MW; B $35/MWh up to 70 MW; C $58/MWh up to 60 MW. Meet 130 MW; losses ignored.



Demand cuts unit B: A is full; B is the next movable and therefore marginal unit.

1. Rank A → B → C by ascending marginal cost.
2. Dispatch A at 80 MW maximum; 50 MW remains.
3. Dispatch B at 50 MW; C at 0 MW.
4. Balance: 80+50=130 MW.
5. Cost: 80×22 + 50×35 = **$3,510/h**.
6. B can still increase, so marginal cost = **$35/MWh**.

Answer: P_A=80 MW, P_B=50 MW, P_C=0; cost $3,510/h; B is marginal.

METHOD CHOOSER

IF THE QUESTION NEEDS…	CHOOSE / SAY
P, Q, |V|, losses, Q limits	full AC Newton reference model
faster AC on suitable transmission grid	decoupled / fast-decoupled; state sensitivity assumptions
rapid P and θ screening only	DC; state omitted voltage/Q detail
radial distribution voltages	forward–backward sweep
constant marginal costs	merit order + bounds + balance
smooth free units	equal incremental cost; exclude bound units

Classic traps: cheapest-full unit is not automatically marginal; average cost is not marginal cost; total committed capacity must be feasible before optimisation; network constraints can force a dearer local dispatch.

DISPATCH AUDIT AFTER EACH BOUND

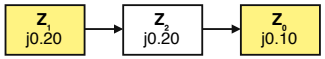
FEASIBLE?	Σ available maximum must cover demand plus any stated losses; on/off commitment defines the feasible set.
BALANCED?	Print every unit output and verify their sum before calculating cost.
OPTIMAL?	For constant costs fill cheaper available output first; for smooth curves equalise incremental costs among free units.
CONSTRAINED?	A unit at minimum/maximum cannot take the next transfer; a network limit can make dearer local output necessary.
INTERPRETED?	Name the binding constraint, marginal unit, total cost and marginal cost separately.

Average versus marginal: total cost divided by total output describes the fleet average; the cost of the next increment is set at the current operating boundary.

8 · Drill 3 – Ground Fault

C3 WORKED EXAMPLE

Given: V_1=1.00 pu; Z_1=j0.20 pu; Z_2=j0.20 pu; Z_0=j0.10 pu; bolted phase-a-to-ground fault.



SLG: equal sequence currents

For this bolted SLG case the three sequence networks are in series.

SERIES DENOMINATOR

$Z_1+Z_2+Z_0+3Zf = j0.20+j0.20+j0.10 = j0.50$ pu

$I_1=I_2=I_0 = 1/(j0.50) = -j2.00$ pu

$I_a=I_0+I_1+I_2 = -j6.00$ pu

Answer: $I_a=-j6.00$ pu = $6.00\angle -90°$ pu. Report magnitude and angle; verify the voltage/impedance relationship.

PROTECTION JUDGEMENT CARDS

LARGE CURRENT ONLY?	overcurrent: pickup + time coordination
CONTRIBUTION CAN REVERSE?	directional element: forward/reverse discrimination
FAULT LOCATION ALONG LINE?	distance: apparent impedance + reach zone
INTERNAL EQUIPMENT ZONE?	differential: boundary-current comparison
NEW DISTRIBUTED SOURCE?	redraw every source path; recheck magnitude, direction and coordination

FAULT TRAPS

- Writing a ground-fault denominator before proving a zero-sequence path.
- Ignoring transformer winding and grounding in Z_0.
- Mixing per-unit bases between sequence networks.
- Stopping at sequence current without phase recovery.
- Saying "relay trips" without operating quantity, zone and breaker.

SEQUENCE RECALL FROM FIRST PRINCIPLES

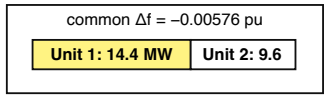
SET	PHYSICAL READING	NETWORK QUESTION
Positive	balanced normal abc rotation; ordinary transfer component	prefault source and positive-sequence path?
Negative	balanced reversed acb rotation; created by unbalance	negative-sequence impedance to the fault?
Zero	three equal in-phase currents	neutral/ground return? grounded star, delta circulation or blocked transfer?

Protection close: "Relay ___ measures ___ against ___, covers the zone bounded by ___, and commands breaker ___; adjacent healthy equipment remains energised if coordination is selective."

9 · Drill 4 – Droop Sharing

C4 WORKED EXAMPLE

Given: common 100 MW base; R_1=0.04, R_2=0.06 pu frequency per pu power; load rises 24 MW; damping ignored.



14.4 + 9.6 = 24 MW

One shared frequency deviation; pickup is apportioned by inverse droop on a common base.

1. Convert disturbance: 24/100 = 0.24 pu.
2. Aggregate inverse droop: 1/0.04 + 1/0.06 = 25 + 16.6667 = **41.6667**.
3. Δf = −0.24/41.6667 = **−0.00576 pu**.
4. $\Delta P_1=-\Delta f/R_1$=0.144 pu=**14.4 MW**.
5. $\Delta P_2=-\Delta f/R_2$=0.096 pu=**9.6 MW**.
6. Check 14.4+9.6=24 MW; primary equilibrium still has frequency error.

Answer: common deviation −0.00576 pu; pickups 14.4 MW and 9.6 MW. Secondary control is still required.

TRACE DECODER

IF YOU SEE…	SAY / CALCULATE
steeper initial fall	larger deficit or less aggregate inertia; RoCoF is a slope
lower nadir	inspect speed/amount of response as well as inertia
primary plateau below nominal	droop has arrested/shared but not restored
return to nominal + interchange	secondary / AGC reference movement
battery or virtual inertia	state power, energy and control-setting limits

Classic traps: combine droops only after common-base conversion; equal percentage droop on unequal bases does not imply equal MW; damping is not governor pickup; nadir is not RoCoF.

LAYER-BY-LAYER RECALL

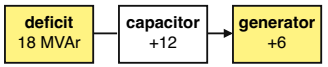
LAYER	SIGNAL / ACTION	BOUNDARY
Inertial	stored kinetic energy limits initial RoCoF	does not restore or allocate steady output
Load damping	frequency-sensitive demand changes naturally	keep separate from controlled generation
Primary	governors / fast controls arrest and share	droop equilibrium retains an offset
Secondary	area control error moves participating references	restores frequency and scheduled interchange
Virtual inertia	controlled converter response shapes early trajectory	limited by power, energy and settings

Direction check: demand above mechanical input → machines decelerate → frequency falls. Use this before inserting any sign.

10 · Drill 5 – Local Q Support

C5 WORKED EXAMPLE

Given: a new inductive load adds 18 MVAr at a 0.94 pu bus. A capacitor can supply 12 MVAr; a generator has 10 MVAr spare capability. Screen a feasible allocation.



4 MVAr generator reserve remains

Capacity screen: local injection closes 18 MVAr; AC power flow still decides voltage adequacy.

1. Identify the added inductive demand as an **18 MVAr local deficit**.
2. Switch the capacitor: +12 MVAr; 6 MVAr remains.
3. Request +6 MVAr from the generator; this is within 10 MVAr spare.
4. Check 12+6=18 MVAr; generator reserve = 10−6=**4 MVAr**.
5. Rerun AC power flow for the bus and neighbouring profile.

Answer: capacitor 12 MVAr + generator 6 MVAr; 4 MVAr generator capability remains. No exact restored voltage can be claimed from this local screen.

VOLTAGE DECISION CARDS

LOW VOLTAGE	seek local Q deficiency, high transfer, exhausted source or unfavourable tap; inject/release Q if feasible
HIGH VOLTAGE	seek light load or excess Q; absorb with reactor or adjust switching/tap
CAPACITOR PROPOSED	supports low voltage, but discrete and gives less Q as voltage falls for fixed susceptance
TAP PROPOSED	redistributes voltage/Q; does not create reactive power
GENERATOR AT LIMIT	PV→PQ and resolve; voltage target is no longer enforceable

Classic traps: prescribing capacitors for high voltage; treating a local MVAr balance as an exact voltage result; ignoring neighbouring violations; forgetting remaining reserve; confusing local voltage control with system-wide frequency response.

CONTROL HORIZON CHECK

PRIMARY	local automatic regulator acts at the device/bus; name measured voltage and actuator.
SECONDARY	coordinates zonal setpoints, improves the regional profile and restores reactive reserve.
SLOWER SCHEDULING	positions taps, shunts and generator targets for expected conditions.
AFTER ANY LAYER	inspect all bus voltages, Q outputs, branch loading and remaining reserve—not the target bus alone.

Recommendation sentence: "Because |V| is low/high and local Q is deficient/excessive, use ___ to inject/absorb/redistribute Q within ___ limit, then verify the complete AC profile and reserve."

11 · Fast Recall + Morning Plan

ALL CHAPTERS

f low active deficit	**f high** active surplus
V low local Q deficit	**V high** local Q excess

diagnose balance before controller

Two axes, two remedies: active balance ↔ frequency; local reactive balance ↔ voltage.

CLASSIC TRAP TABLE

TEMPTING SHORTCUT	CORRECTION
small mismatch = valid state	audit limits, loading, losses and slack balance
hold PV voltage beyond Q limit	fix Q, convert to PQ, resolve
DC method for voltage/Q question	use AC because DC omits those outputs
cheapest unit sets marginal cost	ask which non-bound unit can move next
ground fault formula by memory	prove Z_0 path and connection first
relay label only	quantity + characteristic + zone + breaker
inertia restores frequency	it changes initial slope; secondary restores
equal droop means equal MW	convert to a common power base
capacitor cures any voltage issue	it injects Q and can worsen high voltage
local Q closure fixes |V| exactly	rerun full AC profile

90-SECOND METHOD WRITE-UP

1. **Classify:** bus types, topology, fault, response layer or Q direction.
2. **Base/sign:** common per-unit/MW base; injection convention; units.
3. **Model:** required outputs and assumptions; draw sequence/control path where relevant.
4. **Calculate:** show mismatch/connection/balance before substituting.
5. **Check:** residual, ΣP, phase recovery, pickup sum or MVAr reserve.
6. **Conclude:** direction, feasibility, binding limit and next verification.

EXAM-MORNING PLAN

BEFORE LEAVING	check personal timetable and current LMS exam instructions; do not infer conditions from prior offerings
RECALL FROM BLANK	bus table; Newton chronology; solver boundaries; three sequence sets; response timeline; Q direction
RECOMPUTE	one row each from the five drills: Newton Δ, dispatch balance, SLG denominator, droop sum, Q reserve
DURING READING	circle required output, base, assumption, limit and physical check before arithmetic
FINAL MINUTE	units / pu, signs, four-decimal request, feasibility, direction, limit, balance