

Steam Turbogenerator STG-201-TG-01A

Operating principles — trainee document

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Steam Turbogenerator STG-201-TG-01A — Operating Principles

Document for trainees using the simulator. It does not describe the web page (buttons, panels, mimic diagrams): it explains why the process behaves as it does and on which control logic the model is built, so that the trainee understands the physical phenomenon and the protection strategy, not just the sequence of commands to press.

The document grows chapter by chapter, one per simulated system. It starts with the lubrication oil system, because it is the first system that must be ready before any other part of the machine can turn.

1. Lubrication oil system (MOP-01A/B, ACC-201, H-201)

1.1 Why lubrication is critical

Turbine and generator bearings are oil-film bearings, not rolling-element bearings: between shaft and support there is never direct contact, only a pressurised film of oil that separates the surfaces and carries the load. If that film is missing — even for a few seconds, even at low speed — metal touches metal and the damage is immediate and irreversible.

Two consequences follow from this, and they drive the whole logic of the system:

- lubrication must be confirmed **before** the shaft starts turning, not after;
- it must stay guaranteed even during a shutdown or a trip, because the rotor keeps turning under its own inertia (free coastdown) well beyond the point where steam admission stops — a window in which electrical power to the pumps may no longer even be available.

The first point is enforced with start permissives; the second with a pressure reserve independent of the pumps, the accumulator.

1.2 Fluid path

Oil tank (level LIT-201, temperature TIT-201, heater H-201) → lubrication pumps MOP-01A / MOP-01B → discharge pressure to the header (PIT-202) → coolers E-201A/B → duplex filters F-201A/B (pressure drop

measured by PDSH-201) → distribution header to the bearings (PIT-201, backed also by accumulator ACC-201) → turbine and generator bearings → return to the tank.

Every value shown on the panel for these components is the result of this path, calculated step by step, not a hand-set number: if a pump stops, a filter fouls, or the tank temperature drops, the effect propagates along the chain exactly as above, with its own response times.

1.3 Duty/standby pumps and automatic start

The two pumps are not identical in role: one is duty, the other standby. It is the operator who decides which of the two starts as duty, by starting it manually; the other stays stopped until needed.

The automatic start of the standby pump is a safety interlock independent of the operator's choice: it fires when oil pressure drops below the alarm threshold (PSL-203, 1.5 barg) **and** at the same time the unit is already on-grid or above 50% of nominal speed. Below that speed threshold the interlock does not act: at that stage the machine is not yet turning significantly, and low pressure is more likely a normal start-up transient than a dangerous condition. Past that threshold, however, a pressure loss is an event to correct at once, which is why the interlock acts without waiting for the operator, starting whichever pump is not already running — not necessarily the “duty” one.

1.4 Expected discharge pressure

The header pressure (PIT-202, internal variable oilPd) tracks a reference of 3.4 barg with one pump running, 3.15 barg with both — a model tuning value, not the result of a full pump-curve / system-curve hydraulic calculation — with a response time of 2.5 s.

1.5 Duplex filters: the pressure drop is not only a maintenance matter

The differential pressure across the duplex filters (PDSH-201) is watched by an alarm at 0.9 bar, but filter fouling is **not by itself** a trip cause. The important teaching point is different: the pressure that actually reaches the bearings is the discharge pressure **minus** this pressure drop. A badly fouled filter can therefore push bearing pressure below the trip threshold (1.0 barg) even with the duty pump working perfectly — the low oil pressure trip is therefore not a symptom only of a pump fault, it can also be reached from filters alone. A filter ΔP alarm should therefore be treated as a real trip precursor, not just a maintenance notice to postpone.

In the model the simulatable filter fault affects, together, with the same cause, both the filter ΔP and the oil temperature leaving the coolers: this is a deliberate choice, to represent that a worsening of oil condition (fouling, ageing) tends to show up on several symptoms at once, not as two unrelated faults.

1.6 Tank heater H-201: why viscosity matters

Oil that is too cold is oil that is too viscous: it flows worse, and reaches the bearings later and with less flow. For this reason start-up requires a minimum oil temperature after the coolers (25 °C) as a precondition — see §1.9.

The heater is fully automatic in the model, with hysteresis on tank temperature: it switches on below 30 °C, off above 45 °C. The panel offers no manual heater control: the trainee should not look for one.

1.7 N2 accumulator ACC-201: the reserve for the coastdown

During a trip, especially with a loss of auxiliary electrical power, the pumps can stop while the rotor keeps turning on its own inertia for a long time. The accumulator is the pressure reserve that covers exactly this window: a volume of oil held under pressure by a nitrogen cushion, ready to sustain lubrication even with no pumps running.

In the model the accumulator pressure tracks three different levels depending on plant state: 180 barg (full charge) when at least one pump is running under normal conditions, 90 barg during a trip (the level drops

because the accumulator is actually discharging), 60 barg as a baseline level if no pump has ever been started. Start-up requires the accumulator already charged to at least 100 barg: it is not enough for the pumps to give pressure, the reserve for the coastdown transient must already be ready *before* steam is admitted.

There is also an independent low accumulator pressure alarm (PSL-202, below 120 barg): it is a monitoring alarm, not a trip. Its drop toward 90 barg during a trip is expected — it is the accumulator's own function — not a fault; a further drop below that level during the transient is instead a signal to watch closely.

1.8 Alarm and trip thresholds — summary

Tag	Meaning	Threshold	Effect
PSL-203	Low oil pressure	1.5 barg	alarm + standby pump auto-start
PIT-203/A/B/C · 2oo3	Very low oil pressure	1.0 barg	turbine trip
PDSH-201	High oil filter ΔP	0.9 bar	alarm (no direct trip)
PSL-202	Low accumulator pressure	120 barg	alarm

1.9 Oil-related start permissives

In the order they are checked before steam admission, the three linked to oil are:

1. at least one lubrication pump running;
2. accumulator charged to at least 100 barg;
3. oil temperature after the coolers at least 25 °C (viscosity precondition, §1.6).

The lubrication permissive is the very first one checked, even before the condenser circulating water one: no other permissive makes sense to check if the shaft cannot yet turn safely.

1.10 Note for the trainee — what the model simplifies

- The low oil pressure trip is labelled on the mimic as “PIT-203/A/B/C · 2oo3” — three independent transmitters voted 2 out of 3, like a real triplicated trip system. In the simulation model the value is calculated from a single pressure measurement, not from three independent measurements voted against each other (unlike bearing vibration, which in the model really does use a 2oo3 vote across several separately simulated sensors). Threshold and trip behaviour are the real ones; what is not reproduced is the possibility of a single transmitter fault with the other two still valid.
- The discharge pressure value (3.4 barg with one pump, 3.15 with two) is a model tuning value, not the result of a complete pump/system hydraulic calculation.
- The simulatable filter fault ties together filter ΔP and cooler outlet temperature, as described in §1.5: this is a modelling choice, not two independent faults available.

2. Generator cooling (GEN-01A, FAN-301A/B, AHX-301A/B, DRY-301)

2.1 Why cooling is critical

The stator windings are insulated with organic materials that age with temperature: every margin above the design limit shortens insulation life non-linearly, and beyond a certain threshold the damage becomes fast. Unlike a bearing, which usually gives warning signs (vibration, noise) before failing completely, a stator insulation failure often gives no warning: hence continuous temperature monitoring and an automatic trip, not just an alarm.

2.2 Cooling circuit: closed-loop air

The generator is not cooled by direct ambient air, but by a **closed** air circuit: hot air that has passed through the stator/rotor enclosure is driven by the two fans FAN-301A/B through the two air-to-water coolers AHX-301A/B, and returns cooled (return air) to close the loop. Being a closed circuit, cooling does not depend on the outside environment once in service, but depends **entirely** on its own fans and coolers: if they all stop, there is no alternative path to get rid of the heat.

2.3 Fans and coolers: why both pairs are needed

The model ties cooling effectiveness to both the fraction of fans in service and the fraction of coolers in service, **multiplied together**: at least one fan **and** at least one cooler are needed for any cooling at all, and full effectiveness requires both pairs running together. This is a different kind of redundancy from the oil pumps (§1.3), where a single duty pump is enough to hold the target pressure: here the two groups (ventilation, heat exchange) are in series with each other, not alternatives — losing all fans zeroes the cooling even with the coolers perfectly effective, and vice versa.

2.4 Link with load

The reference temperatures, both of the air leaving (TE-304) and of the stator (TE-301/302/303, three reading points), rise with stator current — up to 130% of nominal under overload — because it is the current, not active power alone, that determines the Joule losses in the windings. At full load with full cooling the model converges to about 85 °C for the air and 110 °C for the stator: known points from documentation, used to calibrate the relationship between current and cooling effectiveness. The two temperatures chase their own target with different response times — 12 s for the air, 20 s for the stator — because the thermal mass of the copper windings and the laminated core is much greater than that of the circulating air volume: the stator heats and cools more slowly than the air that flows past it.

2.5 Dryer DRY-301: why humidity matters

The closed air circuit must stay dry: humidity favours condensation forming on the windings and speeds up insulation degradation — the same target that cooling protects. DRY-301 monitors circuit humidity (MSH-301). In the model, as with the oil filter fault (§1.5), a cooler fault does not show up as a single isolated symptom: it reduces cooling effectiveness **and** raises humidity together, from the same cause — representing that a cooler losing efficiency often does so also through leakage or a compromised seal, not only through dry fouling.

2.6 Alarm and trip thresholds — summary

Tag	Meaning	Threshold	Effect
TSH-301	High stator temperature	120 °C	alarm
TSHH-301 · 2003	Very high stator temperature	140 °C	turbine trip
MSH-301	High cooling air humidity	60% RH	alarm

Both temperature thresholds are editable in-line from the panel, like every threshold in the simulator.

2.7 Note for the trainee — what the model simplifies

- TE-301/302/303 are shown as three separate reading points (stator phase A/B/C), but in the model they derive from the same calculated stator temperature, with a fixed ± 2 °C spread between them to give a plausible three-point reading: not three independent thermal calculations — the same simplification already noted for the 2003 oil pressure (§1.10).

- Coolers AHX-301A/B are represented as on/off: the model does not represent a service-water temperature or flow on the cooler side, only the effect of their availability on overall cooling effectiveness.
- The “fouled cooler” fault alone, even at full severity and full load, is not enough to reach the stator temperature trip: it reduces effectiveness but stays below threshold. It takes, in addition, the actual loss of a fan or a cooler — consistent with the redundancy described in §2.3, and this is the combination the trip is actually tested with during simulator commissioning.

3 · Steam and turbine

3.1 The steam path

The simulator represents the turbine as a single body, not three separate stages: mechanical power is a function of admitted flow, not of a stage-by-stage pressure distribution. Steam enters from the supply line, passes through the main stop valve MSV-101 and the governor valve CV-201, expands through the turbine and exhausts to the condenser, where the vacuum sustained by the circulating water allows expansion down to the lowest possible backpressure. The three topics that follow — MSV-101, the governor during warm-up, and condenser vacuum — are the three conditions that govern this path before, during and after steam admission.

3.2 MSV-101: the main stop valve

MSV-101 and CV-201 have different, non-interchangeable roles. CV-201 is the **governor** valve: the governor drives it continuously to track a speed or power reference, with a normal stroke time of 4 s. MSV-101 is the **stop** valve: it is either fully open or fully shut, commanded by the operator during line-up (normal stroke time 8 s) and by the protection logic on trip (stroke time 0.3 s — the stroke of a real safety valve, not a manoeuvring stroke).

The reason the trip closes MSV-101 rather than relying on CV-201 is precisely the independence of the two paths: if a fault were to hit the governor valve (for example “valve stuck”, §faults), a trip that relied only on the CV closing would leave steam in the turbine. In the model the trip always commands MSV-101 to fast closure, regardless of what the CV happens to be doing at that moment.

The start permissive requires MSV-101 to be already open (past 95% of stroke) **before** the CV can move: it is the operator's job to open it to pressurise the line, not an automatic sequence. If this has not been done, the panel reports “Valves out of position: open MSV-101 to pressurise the line.” and the START button stays inhibited.

3.3 The governor during warm-up

A steam turbine has thick parts — casing, valves, rotor — that heat up at different rates: the surface in direct contact with steam expands before the core of the metal does. If steam is admitted too fast, that difference in expansion creates thermal stress in the metal and can close running clearances enough to cause rubbing between rotating and stationary parts. The warm-up ramp exists for this reason: to give the metal time to heat up more uniformly before speed and load are increased.

Start-up therefore does not take the turbine from standstill to 3000 rpm on a single ramp: the governor follows three segments in sequence, and the speed reference itself rises on a ramp, not a step — besides the thermal reason, also so as not to impose a huge initial error on the PID.

1. **Warm-up (0 → 1000 rpm, 60 s).** The speed reference rises linearly from 0 to 1000 rpm in 60 s. The CV is held tight in opening while approaching the hold point, so as not to overshoot it: with a wide margin the machine overshoot it by more than 100 rpm before the governor responded, and stayed above it for the whole following hold (at these speeds friction brakes very little).
2. **IDLE hold at 1000 rpm, 120 s.** Once the hold point is reached, the governor holds it for 120 s before moving to acceleration: this is the typical time allowed for the casing's thermal expansion to stabilise before continuing.
3. **Acceleration (1000 → 3000 rpm, 120 s).** The reference rises linearly from 1000 to 3000 rpm in 120 s. At the end, once nominal speed is reached, the governor's integrator is explicitly reset: without this reset, the

last ramp segment leaves the integrator saturated and the machine settles at a value permanently above nominal.

In total, $60 + 120 + 120 = 300$ s (5 minutes) of automatic sequence from start to running speed, unless the operator intervenes.

START PAUSE freezes the ramp at the point reached (on either of the two ramp segments) until START is pressed again: useful for observing an intermediate point or simulating a real wait. It is not allowed between 1500 and 1700 rpm — the band where the rotor crosses its critical speeds, where the machine vibrates from crossing a resonance, and the operator must not be able to choose to stop and stay there.

3.4 Condenser vacuum

Condenser vacuum is not only a safety matter (see below): it is the very reason a condensing turbine exhausts under vacuum instead of to atmosphere. The mechanical work extractable from the steam depends on the enthalpy drop between admission and exhaust — the lower the exhaust backpressure, the larger that drop, and so the greater the power obtained from the same admitted steam flow. Vacuum is therefore not an accessory: it is part of the thermodynamic cycle the machine is sized for.

Circulating water pumps CWP-401A/B feed cooling water to the condenser: without at least one running there is no condensation and backpressure rises quickly, which is why the start permissive requires them running even before the oil pumps in the sequence — **before** steam is admitted, not after. The pumps start stopped and must be started by hand.

Vacuum capacity depends on the number of pumps in service: with both running the condenser reaches full vacuum; with one, capacity drops to about 62%; with none, vacuum degrades to atmospheric pressure (1.0 bara), faster the higher the load — at full load total loss takes about 20 s, at no load about 180 s, because more power means more heat to reject to the condenser. With at least one pump running, recovery toward full vacuum is fast, on the order of 15 s.

The thresholds are the same whether the unit is islanded or already on-grid: besides the loss of efficiency, lost vacuum is dangerous for the machine — overheating of the last-stage blading from loss of exhaust steam cooling — regardless of where the power produced is going.

Tag	Meaning	Threshold	Effect
PSL-401	Vacuum falling	0.13 bara	alarm
PSLL-401	Vacuum lost	0.25 bara	turbine trip (MSV-101 closure)
LSLL-401	Low hotwell level	15%	turbine trip
LSL-401	Falling hotwell level	35%	alarm

3.5 Note for the trainee — what the model simplifies

- The turbine is a single body: the pressure distribution across the stages is not represented, only the overall effect of admission and backpressure on power output.
- MSV-101's trip stroke time (0.3 s) represents a spring-operated safety valve; the normal stroke time (8 s) represents the motor-driven actuator used during line-up and controlled shutdown: these are not the same valve seen twice, but two modes of operation of the same valve.
- Circulating water pumps CWP-401A/B are represented as on/off, like the generator cooling fans (§2.3): the model does not represent a service water flow, only the effect of their availability on vacuum capacity.

4. Excitation, synchronization and power regulator

The topics of this chapter have no dedicated mimic: they are electrical and control functions observed on the generator/synchronizer panel, not a process circuit with its own view. For this reason, unlike chapters 1-3, this chapter is not linked to the “?” button of any simulator view — it remains available only here.

4.1 The exciter

A synchronous generator produces voltage at its own terminals only if direct current flows in the rotor: that current creates the magnetic field which, rotating with the shaft, induces the alternating voltage in the stator windings. Without field there is no voltage, and therefore no way to transfer power to the grid, however much the turbine is already supplying mechanically. The exciter (AVR-301, automatic voltage regulator) is what generates and regulates that field current, feeding the field winding with a voltage and current proportional to the desired machine voltage. The field can only be energised once the machine is already carried close to nominal speed (past 95% of 3000 rpm) and with the start sequence already at running speed: exciting a rotor still turning at reduced speed has no physical meaning in the model, which therefore prevents it.

Once energised, machine voltage tracks the AVR reference with a time constant of 0.6 s; if excitation is lost (operator command, or the “AVR-301” fault at sufficient severity), voltage decays to zero with a slower time constant of 1.2 s. The field cannot be de-energised while the unit is on-grid: the 52G breaker must be opened first.

The reactive power (MVar) regulator does not act directly on the number shown on the panel: it acts on the exciter's reference, which is the only real lever for exchanging reactive power once terminal voltage is imposed by the grid. The excitation reference is limited between 10 and 12 kV — the exciter's physical ceiling — so beyond a certain absorption or delivery of reactive power the request can no longer be satisfied and machine voltage stays pinned at the limit.

4.2 Synchronism

Before closing the generator breaker 52G, three conditions must be satisfied at the same time:

Quantity	Tolerance
Δf (frequency mismatch)	< 0.1 Hz
$\Delta \phi$ (phase mismatch)	< 10°
ΔV (voltage mismatch)	< 5%

These three tolerances exist because closing a breaker across two misaligned voltages amounts to abruptly connecting two sources that do not coincide: the instantaneous difference discharges as a large inrush current, with an impulsive torque on the shaft, on the coupling and on the windings — larger the further apart frequency, phase and amplitude are. Staying inside the tolerances in the table limits that transient to a value the machine can tolerate without damage.

In **manual** mode the operator acts on the two references — speed (speed changer) and voltage (AVR) — watching the synchroscope, and closes the 52G themselves once the three conditions are verified. In **auto-matic** mode, with the synchronizer enabled, the model does the same work by itself: it corrects the voltage reference toward nominal when ΔV exceeds 0.2%, and when the frequency mismatch is already small but phase is still outside the window, it slowly slews the speed reference (± 0.015 Hz, about 8°/s) to advance phase through the acceptance window — a controlled slew, not an instantaneous chase. The three conditions must stay satisfied together for a short confirmation time (0.6 s), not for a single instant, before the 52G closes by itself: this avoids latching onto an isolated transient.

At the instant of closing, the real residual phase mismatch (within the $\pm 10^\circ$ window, but not necessarily zero) becomes the initial load angle: it is the small but real torque impact of a closure that is not perfectly in phase — not an idealised lock-in at a balance already zeroed. Immediately after closing, the unit automatically picks up a minimum load (2 MW): left at zero reference, it would draw its own losses from the grid instead of delivering them, motoring (see reverse power protection below).

After the 52G closes, the concept of “phase mismatch” between the two voltages no longer exists — the two nodes are now electrically the same node — and the quantity that matters is the **load angle δ** : the phase displacement between the machine's internal e.m.f. and the grid voltage, which shifts with the real speed mismatch

(electromechanical equation of motion) until the transmitted electrical power equals the mechanical power in. It is small at low load and grows with load; if excitation collapses (loss of field) the maximum transmissible power collapses with it and the angle can move past the point beyond which no equilibrium exists any more — the machine loses synchronism (see §4.3).

4.3 The power regulator

After synchronization, the governor changes function: from a speed regulator (which no longer makes sense to impose — it is the grid that holds frequency) it becomes a **power** regulator.

- In **manual** mode, the power reference (MW) is translated directly into a governor valve opening command, with no correction for the power actually achieved: it is an open-loop command, consistent with the real use of manual mode as a direct operator intervention.
- In **automatic** mode, a PI regulator tracks the error between reference power and actually measured power, with integral action and proportional correction.

In both modes governor valve opening stays limited to a reduced maximum (15%) for a short period right after the 52G closes, during synchronization: this prevents the regulator from suddenly pushing a large load onto a unit that has just been paralleled.

The “unstable governor” fault superimposes an oscillation on the valve opening **command**, not on the reference the regulator tracks: it represents a regulator that hunts on its own, not a machine poorly tracking a correct reference — it shows up as a continuous back-and-forth of the governor valve, independent of the load actually requested.

Reverse power protection. If the unit stays on-grid and excited but terminal power becomes negative beyond a minimum threshold (typically because the stop valve is closed without first unloading and opening the breaker), after a short delay the 52G opens by itself and the unit returns to speed control. This is not a trip: no protection alarm, no RESET needed — it is the equivalent of a real 32 relay, automatic and silent.

Loss of synchronism (protection 78). This is the limiting case in which synchronism, once reached, is lost again: if the mechanical power to be transmitted exceeds the maximum transmissible through the synchronous reactance at the available e.m.f. — typically from a loss of excitation, which collapses that e.m.f. — an equilibrium load angle no longer exists and δ slips continuously instead of oscillating around a fixed point. If this condition lasts more than half a second with the unit still on-grid, the trip fires.

4.4 Note for the trainee — what the model simplifies

- The machine’s internal e.m.f. is approximated with the excitation voltage itself (which has its own response time constant), not calculated from a complete equivalent circuit with leakage reactance and stator resistance.
- The reactive power regulator acts with a single equivalent gain toward excitation; it does not represent the generator’s capability curve (the stator, rotor and stability limits that in a real machine bound the operating area on a P-Q diagram), only a summary delivery limit on MVar and on the exciter’s voltage ceiling.
- Automatic phase search reuses the same gesture — a small offset of the speed reference — that a real operator would use to slowly slew phase until lock-in: it is not an algorithm computing the optimal closing instant, but the same empirical logic used in the control room.