Secondary Injection Testing

Theory and Method — Protection Relay Commissioning (OMICRON Test Universe / CMC 256plus, 353, 356)

1. Core Theory

A protection relay never sees primary power system quantities directly — it sees scaled-down secondary signals from current transformers (CTs, typically 5A or 1A secondary) and voltage transformers (VTs, typically 63.5V phase-neutral or 110/120V phase-phase). Secondary injection testing bypasses the CTs/VTs entirely: the CMC's current and voltage amplifiers connect straight to the relay's CT and VT input terminals, replacing the real transformers. The relay cannot tell the difference — it just sees a voltage/current waveform on its input terminals and reacts exactly per its programmed settings. This is what lets you prove a setting (pickup, angle, time delay, restraint slope, directionality) without needing real fault current on the primary system, without de-energising a live busbar for a destructive test, and without any risk to the CTs/VTs themselves.

Because the injected signal lands after the CT/VT, everything the relay's internal algorithm does with ratio compensation, vector-group correction, zero-sequence filtering and so on is exercised exactly as it would be in service — the test only replaces the transducer, not the relay's logic.

2. Secondary vs. Primary Injection

Aspect	Secondary Injection	Primary Injection
Where signal enters	Relay's CT/VT terminals directly	Actual primary conductor / busbar
Equipment needed	CMC test set only	High-current primary injection set, heavy leads
What it proves	Relay settings, logic, timing, output contacts	Everything above + CT/VT ratio, polarity, wiring, burden
Typical use	Routine commissioning, periodic testing, setting changes	New installation, CT/VT ratio verification, wiring checks
Outage / risk	Relay isolated from trip circuit or trip circuit blocked	Often needs the primary circuit de-energised and earthed
Time & cost	Fast, low cost, one engineer	Slow, expensive, heavy equipment, more personnel

In practice, commissioning uses both: primary injection (or CT ratio/polarity checks via a simpler primary current injection kit) confirms the transducer chain is correct, then secondary injection via Test Universe proves every protection function's settings and logic in detail.

3. Electrical Quantities and Scaling

- **CT secondary:** 1A or 5A nominal. The relay's current settings (pickup, differential slope points) are usually entered in secondary amps or in per-unit of CT secondary — confirm which before calculating the injection value.
- **VT secondary:** 63.5V (phase-neutral, from a 110V phase-phase VT) or 110/120V (phase-phase) are the common secondary standards. Always check the relay's nameplate/setting file for which reference (phase-neutral vs phase-phase) its voltage settings are entered against.
- **CT/VT ratio compensation:** differential and distance functions apply CT ratio (and sometimes VT ratio) compensation internally — when injecting secondary values you are testing against the relay's as-programmed ratio, so if the ratio setting is wrong the test will "pass" against a wrong reference. Cross-check the ratio setting against the CT/VT nameplate before testing.
- **Angle reference:** Test Universe lets you fix a reference phasor (commonly VA at 0°) and define every other channel's magnitude and angle relative to it — this is how directional, power, and impedance tests set up realistic pre-fault and fault phasor diagrams.

- **Symmetrical components:** State Sequencer can accept inputs directly as positive/negative/zero sequence (I1/I2/I0, V1/V2/V0) instead of phase quantities — useful for unbalance and earth-fault functions (46, 59N, 67N, 64REF) without hand-calculating phase values.

4. Physical Test Set Connections

- **Current outputs:** CMC current amplifier channels (IA, IB, IC, optionally IN) connect directly to the relay's CT secondary input terminals — CT circuit at the relay must be isolated/shorted from the live CT first if the relay is still connected to the plant CT, to avoid back-feeding the amplifier into a live CT circuit or leaving a CT secondary open.
- **Voltage outputs:** CMC voltage amplifier channels (VA, VB, VC, VN) connect to the relay's VT secondary input terminals — the relay's VT fuses/MCB should normally be racked out or isolated first so the injected voltage doesn't feed back into the station VT circuit.
- **Binary inputs (to the relay):** CMC binary outputs can simulate breaker auxiliary contacts (52a/52b), other relay outputs, or SCADA commands feeding into the relay under test — used for schemes like breaker failure initiation, synchronism-check permissives, or blocking logic.
- **Binary outputs (from the relay):** the relay's trip/alarm contacts wire back into CMC binary inputs — this is how Test Universe captures operate time: the State Sequencer timer starts at the fault-state transition and stops the instant the monitored binary input changes state.
- **Trip circuit isolation:** unless breaker operation is intentionally part of the test, the actual trip coil circuit is normally isolated (test switches/links pulled) so the CMC sees the trip contact close without actually operating the circuit breaker.
- **Multi-set / GPS sync:** functions needing more than one CMC's worth of channels (busbar differential across many feeders, synchronism check with two independent voltage sources) use multiple CMC356 units synchronised via GPS or a sync cable so all injected phasors share one absolute time reference.

5. Signal Generation Methods in Test Universe

QuickCMC — manual, steady-state signal generator. You set fixed magnitude/angle/frequency on each channel and switch it on/off by hand. Best for quick sanity checks: confirming wiring, confirming the relay reads the expected value on its local HMI/metering, or manually walking a value up to pickup while watching an LED or SCADA point.

Ramping — automatically and slowly increases (or decreases) one parameter (current, voltage, frequency, impedance angle, V/Hz ratio) at a controlled rate until a monitored binary output changes state (pickup/dropoff). Test Universe records the exact injected value at the moment of state change — this is the standard method for proving a pickup/dropoff setting to a tight tolerance, since a ramp catches the exact threshold rather than testing only above and below it in discrete steps.

State Sequencer — the main tool for anything with timing, transients, or multiple phases of a test. You define a sequence of states (e.g. Pre-Fault → Fault → Post-Trip), each with its own fixed V/I magnitude, angle and frequency per channel, a duration, and one or more trigger conditions that end the state early (a binary input changing, an analog value crossing a threshold, elapsed time). Timers attached to binary inputs measure operate time between any two events — this is how pickup time, trip time, reset time and breaker-failure timer margins are all captured in one automated run.

Advanced Differential / Advanced Distance / Overcurrent modules — purpose-built wizards layered on top of State Sequencer logic: you enter the relay's actual setting values (slope breakpoints, CT ratio, mho circle parameters, IDMT curve and TMS) once, and the module auto-generates the correct series of injection points and expected results, rather than you hand-building every State Sequencer state yourself.

Harmonics — individual states can have harmonic content (2nd, 3rd, 5th, etc.) added on top of the fundamental on any channel, expressed as a percentage of fundamental magnitude and its own phase angle — used for inrush restraint (2nd harmonic), overexcitation restraint (5th harmonic), and 100% stator earth fault schemes (3rd harmonic ratio/undervoltage).

6. General Test Procedure (applies across all 20 functions)

- **Step 1 — Prepare:** isolate the relay's trip output(s) from the physical breaker trip coil (unless intentionally testing through to the breaker), isolate the CT/VT secondary circuits from the live plant, and record the settings under test from the relay's setting file.
- **Step 2 — Connect:** wire CMC current/voltage outputs to the relay's CT/VT terminals per the relay's own terminal diagram, and wire the relevant trip/alarm output contacts back to CMC binary inputs.
- **Step 3 — Pre-fault state:** inject realistic normal-load or no-load values first (e.g. balanced nominal voltage, zero or light load current) and confirm the relay's local metering agrees, before moving into the fault state — this also confirms wiring polarity is correct before you trust any subsequent result.
- **Step 4 — Apply the test condition:** either a ramp to find a threshold, or a State Sequencer fault state to prove operate time, or a sweep of several points to trace a characteristic (slope, curve, circle).
- **Step 5 — Capture:** record the measured pickup/operate value and the operate time against the expected setting value and its published tolerance (many relay manufacturers state ±5% for pickup and ±2–5% or a fixed number of milliseconds for timing).
- **Step 6 — Reset / post-trip:** return to a safe state, confirm the relay resets and any latched targets/LEDs behave as expected, and confirm alarms or lockouts clear or hold per their design.
- **Step 7 — Record:** log the result against the test report (Function / setting / measured value / operate time / Pass-Fail / remarks), matching the 20-function test report template already generated for this job.

7. Common Pitfalls

- **CT/VT polarity reversed:** the single most common secondary injection error — differential, directional, and power functions will give exactly inverted or nonsensical results if a current or voltage channel is reverse-wired. Always verify polarity in the pre-fault state before trusting a fault-state result.
- **Wrong reference (phase-neutral vs phase-phase, primary vs secondary):** entering a phase-phase setting value as if it were phase-neutral (or vice-versa) gives a 1.73× error; entering a secondary setting as primary (or vice-versa) gives a CT/VT-ratio-sized error.
- **Leaving a CT secondary open-circuit:** if the relay's CT input is still connected to a live plant CT while you connect the CMC in parallel without properly isolating, an open CT secondary can generate a dangerous high voltage — always isolate/short the live CT circuit before connecting test equipment.
- **Angle reference confusion:** forgetting that Test Universe angles are relative to the chosen reference channel (commonly VA at 0°) leads to directional and power-based tests (32R/32O, 67, 40) being set up with the wrong V-I angle and producing a false pass or fail.
- **Ratio/vector-group compensation not matching the plant:** for transformer differential (87T/87GT), if the relay's programmed vector group or CT ratio compensation doesn't match the actual transformer nameplate, a through-fault stability test can falsely pass or fail depending on which way the error points.
- **Timer not attached to the right binary input:** a State Sequencer timer measuring from the wrong trigger (e.g. state-start instead of an actual fault-detected binary) silently reports an operate time that includes extra ramp-up or settling time, making a healthy relay look slow.
- **Trip circuit not isolated when it should be:** forgetting to isolate the physical trip coil before a full-current fault-state test can trip a live breaker unintentionally if the relay under test is still connected to it.

8. Correlating Test Results to the Commissioning Report

Every result captured above maps directly onto the 20-row test report matrix already produced for this job: Function / ANSI code / Test Universe module used / method summary / setting value / measured pickup or operate value / operate time / Pass-Fail / remarks. Test Universe itself can export a PDF test report per State Sequencer/Ramping run directly from the software, which can be attached as supporting evidence behind each row of the summary report

for the client and for future periodic-test comparison.