ALCAP GROUP

ALCAP EDUCATIONAL RESEARCH DOCUMENT | POWER QUALITY

Inverter-Driven Voltage Rise and Transformer Tap Adjustment

Why commercial-site voltage rises during solar export, when a tap change is justified, and how to avoid creating undervoltage in other operating modes

Grid-connected inverters do not simply impose a new voltage on a commercial installation. They inject current into a network with resistance and reactance. When real power reverses direction through the site transformer and cables, the normal voltage drop can reverse into a voltage rise.

A transformer tap change can lower the internal voltage envelope, but it also lowers voltage when PV production is low or absent. The correct decision therefore depends on measurements, time-series power-flow analysis, equipment limits, inverter controls, transformer nameplate data and distributor approval.

THE CENTRAL DECISION

Adjust the transformer only when the full operating envelope shows that the candidate tap keeps every relevant bus acceptable during maximum import, minimum load, maximum export, inverter-off, generator and abnormal network conditions. A high inverter-terminal reading alone is not sufficient evidence.

Prepared for South African commercial and industrial energy users

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01 | EXECUTIVE FINDINGS

What commercial sites need to know

Voltage rise is predictable, measurable and usually manageable, but a transformer tap change must be treated as one option within a coordinated voltage-control study.

- A grid-following inverter raises its terminal voltage indirectly by exporting current through network impedance; it does not independently set the public-grid voltage.
- The highest voltage may occur at the inverter terminals while the transformer LV bus remains acceptable. That pattern points toward internal feeder impedance rather than an incorrect transformer tap.
- A high voltage already present at the point of common coupling (PCC) with the inverters off is primarily a source-voltage or network-regulation issue that should be discussed with the distributor.
- A tap adjustment shifts the whole site voltage envelope. It can reduce daytime overvoltage while reducing motor starting margin, increasing current for constant-power loads and creating undervoltage at remote loads after sunset.
- Common HV-side tap terminology is easy to misread. Selecting a higher HV-rated tap often lowers the LV output for the same incoming HV, but the transformer nameplate and manufacturer instructions always govern.[8,9]
- Smart-inverter Volt-VAR, power-factor and Volt-Watt functions can help regulate voltage, but their settings require the distributor's approval and must be coordinated with site equipment and grid requirements.[2,3,4]

> **DO NOT CONFUSE THREE DIFFERENT LIMITS**
>
> The site's preferred design band, the public-network voltage-quality compatibility limits, and an inverter's protection or ride-through envelope are not the same thing. Passing an inverter trip threshold does not prove that the steady-state installation voltage is well designed.

Why this matters at commercial sites

Commercial installations combine long LV cable runs, large rooftop or carport PV systems, multiple parallel inverters, changing production loads, power-factor correction equipment, standby generation and privately owned MV/LV transformers. These conditions create several distinct voltage-control points and can make a single spot measurement misleading. South African SSEG installations must also comply with the applicable distributor process and utility-interface requirements.[5,6,7]

02 | THE ELECTRICAL MECHANISM

Why inverter export elevates local voltage

The direction and magnitude of real and reactive power, together with the resistance and reactance between the inverter and the upstream source, determine the local voltage change.

Under normal import, current flows from the transformer toward the loads and produces a voltage drop along the transformer and cable impedance. When PV production exceeds the coincident load downstream of a point, net current reverses. The same impedance then produces a voltage rise toward the inverter. U.S. DOE and NREL studies describe this reversal and show why higher PV export can push a remote generation bus above its upstream source voltage.[1,2]

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Conceptually: local voltage change is proportional to R x P + X x Q
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Here R and X represent the effective resistance and reactance back to the regulating source; P is real power and Q is reactive power using a stated sign convention. For LV commercial feeders, resistance and active-power export often dominate. On MV networks and transformer paths, reactance and reactive-power behaviour become more influential. A full three-phase model is required where there is phase imbalance, multiple connection points or interacting voltage controls.

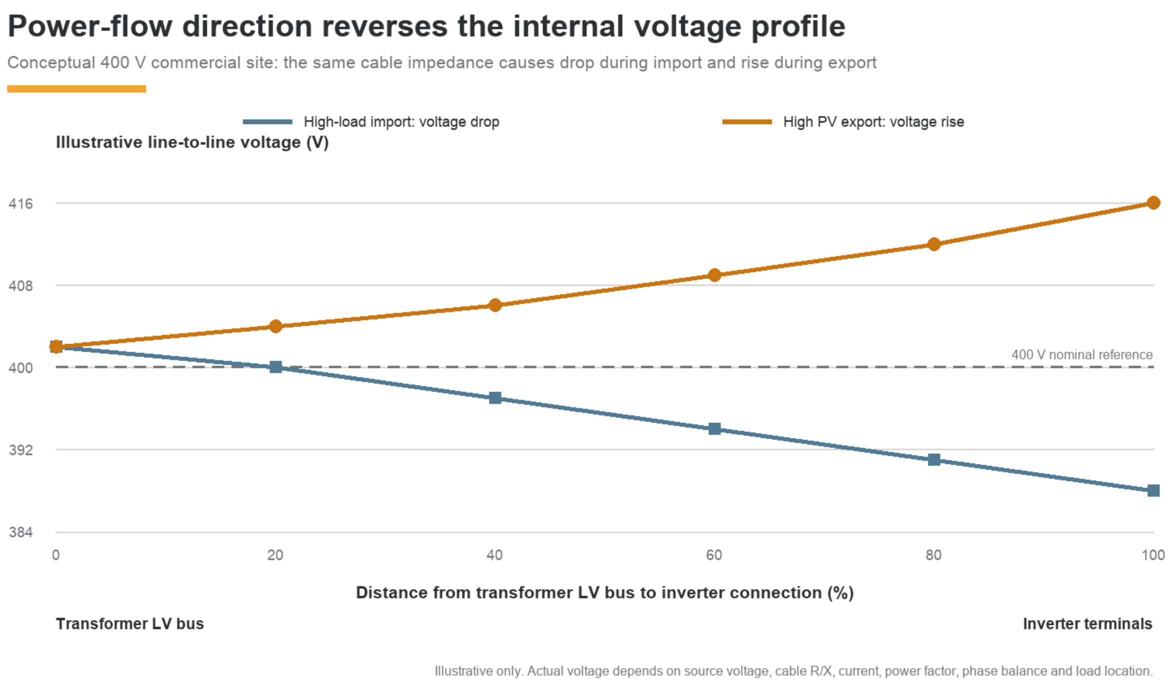

Figure 1: Conceptual internal voltage profiles. Values are illustrative and are not design or compliance limits.

03 | DIAGNOSIS

Find where the voltage is being created

The voltage gradient across the site identifies whether the primary issue is upstream source voltage, transformer ratio, internal feeder impedance, phase imbalance or inverter control.

Observed pattern	Most likely interpretation	First response
PCC high, inverter off	Incoming supply or upstream regulator is already high	Confirm calibrated measurements and engage the distributor before altering privately owned equipment
Transformer LV bus acceptable; inverter terminals high	Internal feeder voltage rise	Review cable length, size, routing, connection point, current, power factor and phase allocation
Transformer LV bus rises materially only during export	Reverse power through transformer and upstream impedance	Time-series study; review tap, inverter controls and export level together
Only one phase high	Unequal single-phase generation/load, neutral issue or phase impedance	Balance phases and inspect conductors and terminations before a three-phase tap change
Short peaks during cloud ramps or switching	Control response, regulator deadband, capacitor switching or event	Use waveform/event logging; a fixed tap may not address the transient cause
High reading only in inverter portal	Possible sensor reference, averaging or calibration difference	Compare with a calibrated analyser at the same terminals and timestamp

Measurements required before making a tap decision

- Record line-to-line and line-to-neutral voltage on all phases at the PCC, transformer LV bus, main board, critical remote loads, PV connection point and inverter terminals.
- Synchronise voltage with current, kW, kvar, power factor, inverter status, export/import direction and major load states.
- Capture maximum-load/no-PV, minimum-load/maximum-PV, cloud ramps, inverter-off, capacitor steps, generator supply and any islanded mode.
- Log long enough to include representative utility-voltage variation, weekdays, weekends, shutdowns and seasonal operating patterns.
- Confirm analyser accuracy, wiring configuration, phase rotation, instrument-transformer ratios and aggregation conventions.

04 | TRANSFORMER TAP EFFECT

What a tap change actually changes

Transformer taps change the effective turns ratio. The resulting LV shift depends on which winding is tapped, how the positions are labelled and the actual incoming voltage.

Many commercial MV/LV transformers use taps on the HV winding, commonly in discrete steps such as 2.5%. For a fixed incoming HV, selecting a higher HV-rated tap generally uses more effective primary turns and therefore lowers the LV output. Schneider Electric cautions that the physical tap position must not be confused with its effect on secondary voltage; the nameplate is the authoritative instruction.[8,9,10]

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V_LV,new approximately equals V_LV,old x (old HV tap rating / new HV tap rating)
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Example: an 11 kV / 400 V transformer is on the 11,000 V tap and its LV bus measures 422 V under a repeatable condition. A candidate 11,275 V tap would produce an estimated 422 x 11,000 / 11,275 = 411.7 V under the same condition - a reduction of about 2.44%, not exactly 2.50% of the original measured voltage. Regulation, loading and source movement will change the real result.

TAP DIRECTION WARNING

Never issue an instruction such as 'move the tap up' or 'select minus 2.5%' without the transformer nameplate, winding diagram and manufacturer convention. Those phrases can describe either the physical selector position, the rated primary tap voltage or the intended LV effect.

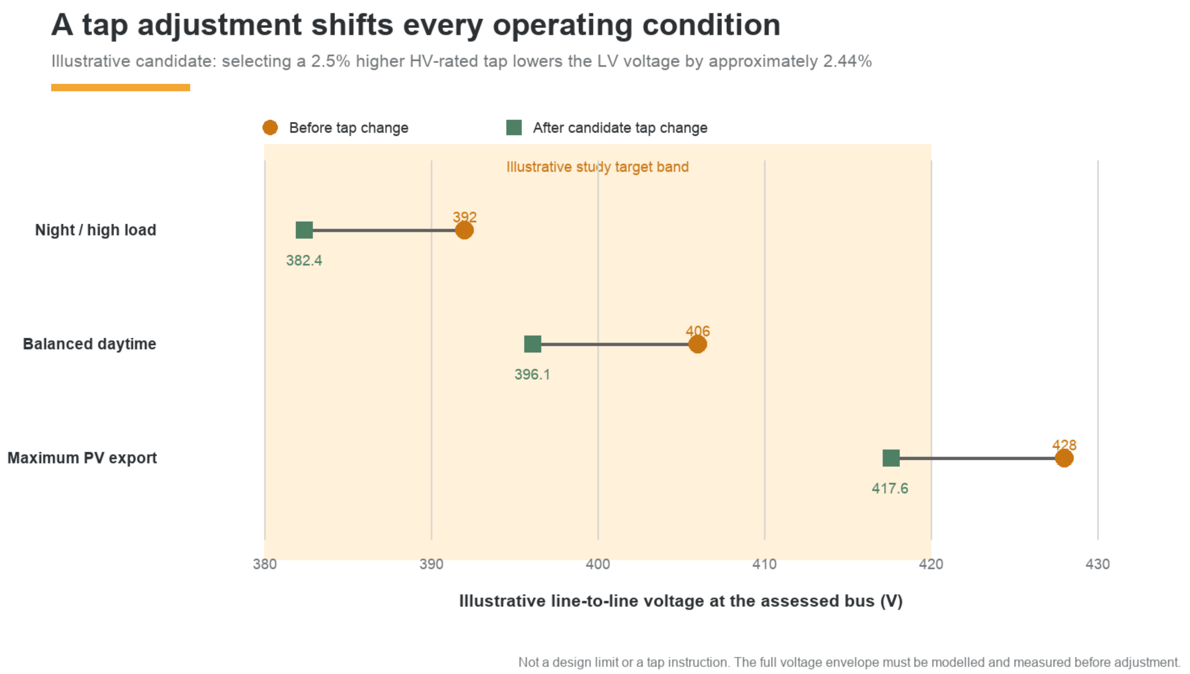

Figure 2: An illustrative candidate tap shift applied to three operating conditions. The study must include every critical bus, not only the inverter terminals.

05 | WORKED COMMERCIAL-SITE EXAMPLE

Why a successful daytime correction can still fail

This simplified example shows why the remote-load minimum and the inverter-terminal maximum must be checked together.

Consider a privately owned 11 kV / 400 V transformer supplying a commercial site with a large PV plant. The values below are illustrative. They are not based on an ALCAP client site and are not compliance limits. A power-flow model would also include transformer impedance, cable R/X, phase balance, reactive power, temperature and upstream voltage variation.

Operating mode	LV bus before	Remote load before	PV bus before	LV bus after	Remote load after	PV bus after
Maximum load / no PV	404.0 V	388.0 V	392.0 V	394.1 V	378.5 V	382.4 V
Balanced daytime	410.0 V	398.0 V	406.0 V	400.0 V	388.3 V	396.1 V
Maximum PV export	414.0 V	410.0 V	428.0 V	403.9 V	400.0 V	417.6 V

Interpretation

- The candidate tap improves the maximum-export PV bus from 428.0 V to approximately 417.6 V.
- The same adjustment reduces the remote load to approximately 378.5 V during maximum import. Whether that is acceptable depends on the agreed design band, applicable standards, load starting performance and measured source variability.
- If the remote load is unacceptable, the site should first reduce the voltage gradient - for example through feeder reinforcement, connection-point changes or inverter voltage support - instead of forcing the whole LV system downward.
- The final tap should be selected from an envelope study, not by rounding a single high reading to the nearest tap step.

For an on-load tap changer (OLTC), the study must also examine controller setpoint, deadband, line-drop compensation, reverse-power behaviour, time delay and interactions with inverter Volt-VAR control. An OLTC is a control system, not merely a remotely movable selector.

06 | DECISION METHOD

When is a tap change justified?

A tap change is justified only when it addresses the dominant cause and leaves adequate voltage margin for every credible operating state.

1. Confirm the correct nominal voltage, PCC, applicable distributor rules, internal equipment ratings and the voltage criterion being assessed.
2. Validate time-synchronised measurements at the utility/PCC, transformer, critical loads and inverter terminals.
3. Separate upstream source voltage from transformer ratio and internal feeder voltage rise.
4. Build and validate a three-phase power-flow model using actual transformer and cable data.
5. Model the present tap across maximum import, minimum load, maximum export, inverter-off, generator, islanded and abnormal phase conditions.
6. Test lower-cost or more targeted remedies: phase balancing, cable reinforcement, connection-point changes, approved inverter Volt-VAR/power-factor settings and export control.
7. Evaluate each available nameplate tap and identify the option with adequate upper and lower margins at all assessed buses.
8. Obtain owner, distributor and manufacturer approvals as applicable; issue a controlled switching, safety and commissioning plan.
9. After the change, repeat measurements under comparable operating conditions and update the as-built record.

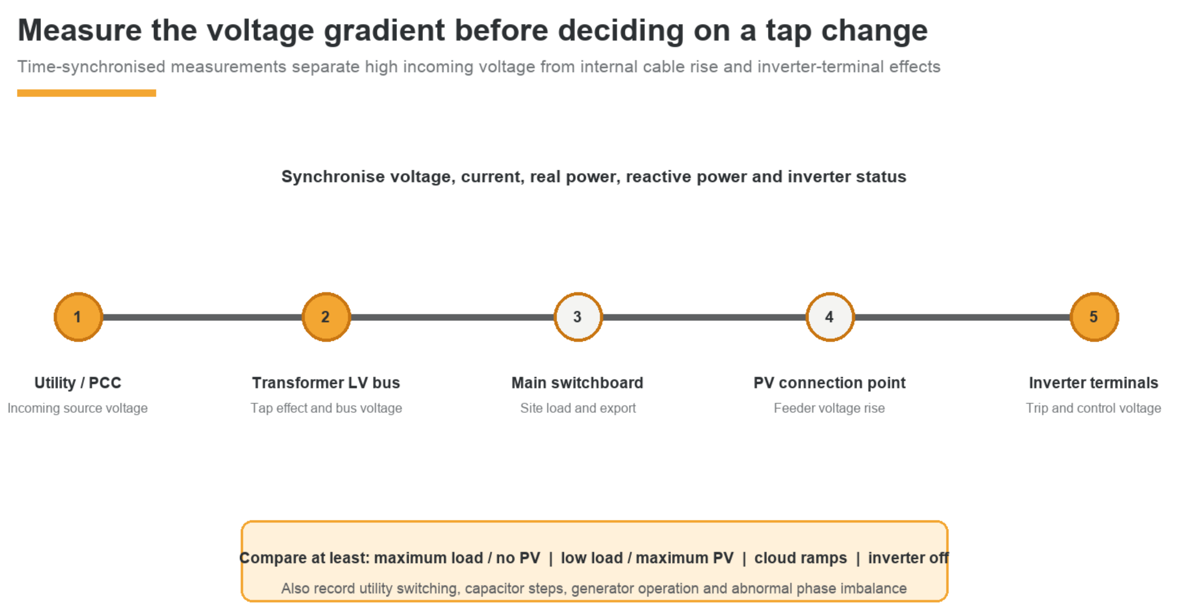

Figure 3: Minimum measurement locations for separating source voltage, transformer ratio and internal voltage rise.

07 | MITIGATION HIERARCHY

Consider targeted remedies before lowering the whole site

The best remedy depends on where the voltage rise occurs and whether the problem is steady-state, phase-specific or event-driven.

Option	Best fit	Primary benefit	Key constraint
Distributor/source-voltage review	PCC is already high with PV off	May correct the cause without reducing customer-side voltage margin	Requires distributor evidence and approval
Increase feeder conductor size or add parallel paths	Transformer bus is acceptable; inverter terminal is high	Directly reduces internal voltage rise and losses	Cost, route, protection and termination capacity
Move PV connection closer to transformer/main bus	Long dedicated PV feeder	Reduces impedance traversed by export current	Switchboard ratings, fault level and protection study
Balance phases	One phase rises more than others	Improves voltage unbalance and neutral loading	Only applicable to movable single-phase generation or loads
Volt-VAR / approved power-factor control	Reactive power materially affects bus voltage	Dynamic local response without changing transformer ratio	Inverter kVA headroom, losses, distributor settings and interactions
Volt-Watt or export limiting	Overvoltage occurs only at high export	Directly reduces the active-power driver	Energy curtailment and contractual constraints
Transformer tap adjustment	Whole LV envelope is high with adequate low-side margin	Simple and durable where correctly selected	Shifts every operating mode; may require shutdown
Transformer/network upgrade	Voltage rise, thermal loading and impedance remain excessive	Creates structural capacity and hosting margin	Capital cost, outage, approvals and protection redesign

CONTROL COORDINATION MATTERS

Inverter Volt-VAR, capacitor banks, OLTCs, generator AVR controls and utility voltage regulators can oppose one another or hunt if their setpoints, deadbands and delays are not coordinated. NREL guidance recommends location-specific settings based on feeder resistance, reactance, topology and loading.[2,3]

08 | EQUIPMENT AND OPERATIONAL RISK

What can go wrong if the tap is set too low

Solving inverter overvoltage by lowering the transformer can transfer the problem to motors, controls and remote loads.

Equipment	Risk from excessive voltage reduction	Verification
Induction motors and fixed-speed compressors	Starting and pull-out torque reduce approximately with voltage squared; loaded motors may draw more current and run hotter	Record start voltage, current, acceleration time, trips and motor-terminal voltage
VSDs, UPSs and constant-power electronic loads	Lower input voltage requires higher current for the same kW, reducing rectifier, cable and thermal margin	Check minimum input voltage, DC-bus alarms, bypass limits and current ratings
Contactors, relays and control transformers	Dropout, chatter, nuisance reset or unreliable operation during motor starts and dips	Check coil/control voltage at the actual device during worst case
Lighting and small power	Reduced light output, higher current in constant-power supplies or nuisance shutdown	Confirm manufacturer ranges and remote-end voltage
Protection and metering	Changed current, voltage and power-flow conditions can affect settings, pickup margins and directional elements	Review protection coordination and instrument-transformer data
Inverters and batteries	Low-voltage limits may be reached during import, charging, generator supply or islanded operation	Test every operating mode and approved ride-through setting
Transformer	An incorrect tap can alter volts-per-turn, excitation and thermal performance	Use nameplate/manufacturer instructions and confirm actual HV and frequency

A tap change may still be the right answer

Where the entire LV system is consistently high, the incoming HV is close to the tap's rated voltage, the maximum-import case retains adequate margin, and targeted feeder or inverter measures do not address the dominant cause, a correctly selected tap can be the simplest durable solution. The decision should be documented as an engineering change with before-and-after evidence.

09 | IMPLEMENTATION AND COMMISSIONING

Controlled execution checklist

Tap adjustment is high-risk electrical work. The following list defines governance and verification, not a switching instruction.

1. Confirm transformer ownership and the authority required from the distributor, landlord, insurer, manufacturer and appointed competent person.
2. Obtain the transformer nameplate, tap schedule, winding diagram, manual, maintenance history, oil or dry-type condition information and present tap record.
3. Determine whether the device is de-energized/off-circuit, off-load or on-load. Standard DETC positions must be changed only under the manufacturer's specified de-energized and lockout conditions.[10]
4. Issue an approved method statement, isolation and lockout/tagout plan, prove-dead procedure, earthing requirements and site outage/operational plan.
5. Record phase voltages, currents, kW, kvar, power factor, transformer temperatures and inverter states immediately before the change under a defined condition.
6. Verify the intended LV effect from the actual nameplate tap ratings; do not rely on physical direction or plus/minus shorthand.
7. After adjustment, verify selector/link position on every required phase, mechanical indication, interlocks, clearances, earthing, covers and test results before energisation.
8. Energise and load under the approved procedure; check phase sequence, no-load/load voltage, unbalance, sound, current, temperature and protection indications.
9. Repeat the time-series power-quality assessment across maximum export and maximum import; confirm inverter, motor, UPS, control and generator performance.
10. Update the single-line diagram, transformer data sheet, tap register, protection file, commissioning report and future operating instructions.

ALCAP RECOMMENDATION

Treat a tap change as the final controlled output of a voltage-envelope study. The handover should state the original and final tap ratings, measured before/after voltages, assessed operating modes, remaining margins, inverter-control settings and conditions that would trigger a re-study.

10 | CONCLUSION

The correct objective is voltage margin, not merely stopping trips

A commercial site needs an acceptable voltage envelope at every important bus and in every credible operating mode.

Inverter-driven voltage rise is a consequence of export current flowing through transformer and cable impedance. The resulting gradient may be small at the PCC, larger at the transformer LV bus and largest at a remote inverter. That pattern must be measured before choosing a remedy.

A transformer tap adjustment is appropriate when it corrects the dominant system-wide voltage bias and the full study demonstrates adequate lower-voltage margin. It is not an automatic response to a high inverter reading. Where the rise is concentrated along an internal feeder, cable reinforcement, connection-point changes, phase balancing, approved inverter voltage support or export management may solve the cause more precisely.

For planned PV or battery projects, the voltage-envelope study should be completed during design using the as-built network data, then validated during commissioning. For existing sites, measurements should capture both maximum export and maximum import before any transformer setting is changed.

NEXT STEP

Contact ALCAP to arrange a measurement-led assessment covering the PCC, transformer, critical loads and inverter terminals; time-series voltage and power logging; transformer tap evaluation; and verification of the selected mitigation.

This document provides general educational information and is not a tap-setting instruction, switching procedure, electrical design or substitute for a site-specific assessment by authorised and suitably qualified persons. Apply the latest distributor requirements, standards, equipment manuals and safety rules.

REFERENCES

Technical sources and further reading

1. U.S. Department of Energy - Distributed Photovoltaic Systems Design and Technology Requirements.
2. NREL - Advanced Inverter Technology for High Penetration Levels of PV Generation in Distribution Systems.
3. NREL - Overview of IEEE 1547-2018 Voltage and Reactive Power Control.
4. IEEE - IEEE Std 1547-2018, Interconnection and Interoperability of Distributed Energy Resources.
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6. NERSA - NRS 048-2:2025, Electricity Supply Quality and Compatibility Levels.
7. Eskom - Small-Scale Embedded Generators.
8. Schneider Electric - What are voltage adjustment taps on transformers?.
9. Schneider Electric - Effect of tap selection on transformer secondary output.
10. Schneider Electric - Medium-voltage transformer taps and de-energized tap changers.
11. NREL - High-Penetration Photovoltaic Integration Handbook for Distribution Engineers.

Reference numbering in the text points to this list. Standards and distributor requirements may be revised; confirm the current applicable edition and connection agreement for the specific site.