Voltage-Constrained Hosting Capacity Assessment of Decentralized PV Injection in a Campus Distribution Network

8,436.15 kWp

rooftop PV potential injected at 19 candidate transformers

OpenDSS assessment of a Nigerian university 11 kV network

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Objectives

Why it matters

About 666 million people lacked electricity access in 2022, mostly in sub-Saharan Africa. Unreliable grids push Nigerian institutions towards costly diesel.

Rooftop PV is attractive at 3.5–7.0 kWh/m²/day, but networks built for one-way flow risk voltage rise and reverse power flow when PV is high and demand is low.

Hosting capacity studies of Nigerian campus medium-voltage networks under reduced demand are scarce.

01 · Daytime HC

Model the 11 kV network and find its voltage-constrained HC under simultaneous PV at 19 transformers.

02 · Minimum load

Find the voltage HC at 20%, 30% and 40% demand and check reverse power flow.

03 · First binding limit

Compare voltage, transformer and cable thermal loading.

04 · Sensitivity

Test cable length, source voltage and PV power factor.

Literature review

01

Voltage is reported most

PV that exceeds local load pushes voltage up the feeder, a primary concern in the literature [8][21]. 48% of HC studies use voltage violations [21]. Overvoltage was the first violated limit in 61.5% of 50,000 LV systems [12].

02

But it is not universal

Conductor overload came first in 27.7% of those systems [12]. Thermal loading led in an MV study [27], harmonics can bind alone [16], and reverse flow came first on an Indonesian feeder [15].

03

Method trade-offs

Deterministic sweeps are cheap but conservative. Stochastic and time-series methods need data that are scarce [25][28], so this study uses a deterministic sweep.

Gap: no Nigerian campus MV study identifies the first binding constraint under reduced demand

Methodology

Network

- OpenDSS v11 driven by Python
- 55 transformers, 10 feeders, 290 buses
- 2 × 33/11 kV, 10 MVA; 750 MVA grid, X/R 15
- Tap 0.975 pu for compliant base case

Load

- 8 building types with Ku, Ks, PF
- Connected load = 70% of rating
- Daytime plus minimum load at 20, 30, 40% demand

PV

- 8,436.15 kWp on 120 rooftops
- Injected at 0.4 kV buses of 19 transformers
- Unity PF, 1000 W/m²
- Scaled 10–500% of candidate kWp

Limits checked

- Voltage: 0.94–1.06 pu (400 V), 0.95–1.05 pu (11 kV)
- Transformer loading above 100%
- Cable current above 400 A
- Reverse power flow reported

Network HC = min (voltage HC, transformer thermal HC, cable thermal HC)

Base case: no PV

Daytime load: setting the tap

Tap	Min (pu)	Max (pu)	Status
1.000 nominal	0.92718	0.99017	Non-compliant
0.975	0.95451	0.99024	Compliant

At the nominal tap, 37 of the 290 buses, all at 0.4 kV, fell below 0.94 pu. Lowering the HV tap of both 33/11 kV transformers to 0.975 pu brought every bus within the band.

Minimum load at tap 0.975 pu

Demand	Min (pu)	Max (pu)	Status
20%	0.99828	1.01791	Compliant
30%	0.99738	1.01391	Compliant
40%	0.99645	1.00982	Compliant

Demand is shown as a share of the daytime load, with zero PV.

Tap 0.975 pu is the reference for every PV result and is held fixed in all scenarios

Hosting capacity by constraint

Constraint	Daytime (% of candidate kWp)	40% demand (% of candidate kWp)	30% demand (% of candidate kWp)	20% demand (% of candidate kWp)
Voltage	170 (14,341.5)	101 (8,520.5)	91 (7,676.9)	80 (6,748.9)
Transformer thermal	110 (9,279.8)	94 (7,930.0)	92 (7,761.3)	89 (7,508.2)
Cable thermal	312 (26,320.8)	286 (24,127.4)	281 (23,705.6)	277 (23,368.1)
First to bind	Transformer (110)	Transformer (94)	Voltage (91)	Voltage (80)

170%

Daytime voltage HC: 14,341.5 kWp, 131.5% of the daytime load

133%

Daytime reverse power flow starts at the 33/11 kV transformers

24%

Candidate PV above rating at the transformer that binds first

Minimum load and sensitivity

At 40%, 30% and 20% demand

- Reverse power flow starts at 52%, 39% and 26% of the rooftop potential
- At 100% PV the 33/11 kV transformers export 3.89, 4.97 and 6.05 MW, against a 2.71 MW import at daytime
- Highest transformer loading: 105.8%, 108.9% and 112.1% (87.9% at daytime)
- 18 of 19 candidate transformers export

Daytime sensitivity (% of candidate kWp)

Case	Voltage HC	Transf. HC	First limit
Base case	170	110	Transformer
Cable 1.02 D + 8 m	170	110	Transformer
Source 1.02 pu	130	110	Transformer
Source 0.98 pu	No HC	110	Undervoltage at zero PV
PV absorbing, pf 0.95	137	95	Transformer

Conclusions

01

At daytime load the full 8,436.15 kWp complies. Transformer thermal loading binds first at 110% (9,279.8 kWp), before voltage at 170%.

02

Under minimum load the HC falls to 80–94% (6,748.9–7,930.0 kWp). Voltage binds first at 30% and 20% demand, and 3.9–6.0 MW is exported at 100% PV.

03

Cable length had no effect. +2% source voltage cuts voltage HC from 170% to 130%. PV absorbing at pf 0.95 brings thermal (95%) and undervoltage (137%) limits forward.

Limitations: no measured validation, assumed loads and minimum-load multipliers, LV network not modelled.

References

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Numbers match the reference list in the paper.

Thank you

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