Increasing PV Hosting Capacity with Optimal Inverter Dispatch (OID)

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Outline

- Solar PV related operational challenges in distribution networks
- Voltage regulation with PV inverters
- OID problem formulation
- Fairness of PV curtailment
Solar PV systems in Australia

This September total Installed Solar PV Capacity Reached 10GW

Monthly Installations by Size Category

Source: APVI, 2018
Operational Challenges
High Solar PV Penetration poses new challenges for distribution network operators

PV Hosting Capacity Limits due to:

- Overvoltage
- Reverse power flow
- Line current limits
- Transformer capacity limits

Technology Solutions

- Voltage regulators, capacitor banks, network reinforcement
- Energy storage
- Inverter reactive power support control
Voltage Regulation using Inverters
From local to central inverter control

- Legacy inverters
- Voltage regulation with active power (Volt/Watt)
- Voltage regulation with reactive power (Volt/VAr)

• Optimal Inverter Dispatch (OID)
OID Problem Formulation

Multi-objective optimisation problem

\[
\min_{V, P_c, Q_c} \quad c_\rho \rho(V) + c_\varphi \varphi(P_c, Q_c) + c_\theta \theta(V) \\
\text{subject to} \quad 0 \leq P_{c,n} \leq P_{av,n} \\
Q_{c,n}^2 + (P_{av,n} - P_{c,n})^2 \leq S_n^2 \\
|Q_{c,n}| \leq \tan(\Phi) \cdot (P_{av,n} - P_{c,n})
\]

- Power balance constraints
- Voltage limit constraint
- Line capacity constraint
- Transformer capacity constraint
Case Study
Low voltage residential area

Analysis Framework
- Incremental increase in solar PV capacity
- Recording network conditions at peak solar
- Finding inverter operational setpoints

Evaluation Criteria
1. PV hosting capacity
2. Line losses
3. Distribution of curtailment
Changes in Installed PV Capacity

+ 9.4kW solar PV with OID before curtailment occurs

Transformer Capacity Limits

PV output – load ratio

Active Power [kW]

77.5kW

100

150

0

2

4

6

8

10

S_{capacity}

P_{capacity}

S_{actual}

P_{actual}

Active Power [kW]

68.1kW

100

150

0

2

4

6

8

10

Volt/VAr

Power Curtainment $P_c$

Reactive Power $Q_c$

Injected Power

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Household Individual Curtailment

@ 6.1:1 PV/load ratio

@ 8.2:1 PV/load ratio

@ 10.4:1 PV/load ratio

@ 6.1:1 PV/load ratio

@ 8.2:1 PV/load ratio

@ 10.4:1 PV/load ratio

Power Curtailment [kW]

House

Total Curtailment

OID

V/Var

OID

V/Var

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OID Problem Formulation with fairness objective

Multi-objective optimisation problem

\[
\min_{V, P_c, Q_c} \begin{array}{c}
  c_{\rho} \rho(V) + c_{\phi} \varphi(P_c, Q_c) + c_{\theta} \vartheta(V) + c_{k} k(P_c/P_{av}) \\
  \text{Line losses} & \text{PV curtailment} & \text{Voltage deviations} & \text{Curtailment Variance}
\end{array}
\]

subject to

• Inverter constraints
• Power balance constraints
• Voltage limit constraint
• Line capacity constraint
• Transformer capacity constraint
Curtailment with fairness objective

Fairness element can be weighted based on the PV capacity and the operator’s preferences
Fairness element can be weighted based on the PV capacity and the operator’s preferences.
Summary

• Case study showed 13% more solar PV installed with OID compared to Volt/VAr control without energy curtailment.
• Introducing a **fairness component** reduces the maximum curtailment by any individual customer

Future Work

• Integrating OID into the distribution networks operational model including cost-benefit analysis
Thank You!

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Changes in Installed PV Capacity

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Transformer Capacity Limits

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**Diagram Description**

**OID**
- Active Power [kW] vs. PV output–load ratio
- Curtailed power levels
- 77.5kW threshold

**Volt/VAr**
- Reactive Power Qc
- Power Curtailment Pc
- PV hosting capacity
- Injected Power

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