Lab Validation of PV Solar Inverter Control as STATCOM (PV-STATCOM)

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Novel Concept

Utilization of PV Solar Farm in Night and Day as STATCOM!

Termed as PV-STATCOM patent pending
Concept of Control:
PV Solar Farm Inverter as STATCOM

Nighttime: Entire Inverter Capacity Utilized for STATCOM
Daytime: Remaining Inverter Capacity Utilized for STATCOM

\[ Q = \sqrt{S^2 - P^2} \]
PV-STATCOM Technology

• Applications - Motivation
  • Enhancement of Power Transfer Capacity
  • Improvement of Neighbouring Wind Farm Connectivity

• Lab Validation
  • Inverter for PV Solar system
  • Inverter as STATCOM
  • Inverter as PV-STATCOM
Applications of PV-STATCOM Technology
Enhancement of Power Transfer Capacity

Large generating complex supplying power over a 200 km line at 400 kV. A 100 MW PV solar farm is connected at line midpoint.
Increasing transmission capacity

- A 100 MW solar farm as PV-STATCOM can increase transmission limit by
  - 168 MW in the night, and
  - 142 MW during the day time even at high solar power generation (~ 94MW)

- Cost of PV-STATCOM Controller: ~ $200k
- Cost of equivalent SVC/STATCOM: ~ $50 Million
Improvement of Neighbouring Wind Farm Connectivity

- 4.5 MW PV solar farm
- 15 MW wind farm
A 4.5 MW solar farm as PV-STATCOM helps to connect an additional 7 MW of wind power in the night bringing ~ $2.1 Million new revenues annually for wind farm.

Similar benefits also achievable to substantial degree during daytime.

Cost of new Solar Farm Controller several orders of magnitude lower than a conventional STATCOM.
Lab Validation
prior to
Field Implementation in an Ontario Utility Network

- voltage regulation
- power factor correction
Test System

10 kW Inverter
Stages of Testing

- Hardware-In-Loop (HIL)
- RTDS studies
- PSCAD/EMTDC studies
- Laboratory validation studies
Conceptual/Actual Development of PV-STATCOM

PV-STATCOM

PV-STATCOM Controller

PV Inverter

6-pulse IGBT Bridge

Conventional PV Controller
Inverter Control for PV Solar System
PV Simulator Characteristic
Real Power Control – Steady State Operation

4kW Active Power

2.7kW Active Power

PCC Voltage

Inverter Current
Real Power Control - Transient Response

Step Change in Real Power from 4 kW to 6 kW Reactive Power ~ 0 VAr
Implemented by Step change in DC Voltage ~ 423 Vdc (4kW) to 400 Vdc (6kW)
Inverter Control for STATCOM
STATCOM Test ➔ Voltage Regulation

**Inductive Mode**
- AC Voltage
- DC Voltage
- PV Power (kW)
- Inverter Current

**Capacitive Mode**
- AC Voltage
- DC Voltage
- PV Power (kW)
- Inverter Current

**PCC Voltage**

**Inverter Current**
**Transient Response**  
Condition: Real Power ~ 0 kW  
Reactive Power ~ -6 to +6 kVAr  
Step change of Reference Voltage ~ 0.92 PU (110V rms) to 1.07 (128V rms)
Inverter Control
for
PV-STATCOM
PV-STATCOM Test → Voltage Regulation

### Inductive Mode
- **Reference Voltage**
  - Vref rms: 110, 115, 120, 125, 128
  - PCC Voltages (rms):
    - Va: 109.6
    - Vb: 111.0
    - Vc: 110.4

- **DC Voltage**
  - DC Reference: 400
  - DC Voltage: 399.1

- **PV STATCOM Mode**
  - Active

- **PV Power (kW)**
  - 5.54

- **Remaining Reactive (kVAR)**
  - 8.33

- **Inverter Reactive Power (kVAr)**
  - -6.11

### Capacitive Mode
- **Reference Voltage**
  - Vref rms: 110, 115, 120, 125, 128
  - PCC Voltages (rms):
    - Va: 123.8
    - Vb: 131.2
    - Vc: 124.0

- **DC Voltage**
  - DC Reference: 400
  - DC Voltage: 399.4

- **PV STATCOM Mode**
  - Active

- **PV Power (kW)**
  - 5.89

- **Remaining Reactive (kVAR)**
  - 8.08

- **Inverter Reactive Power (kVAr)**
  - +4.45

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### PCC Voltage

- C1: Inverter Current-Phase A
- C2: Inverter Current-Phase B
- C3: Inverter Current-Phase C

### Inverter Current

- A1: Inverter Current-Phase A
- A2: Inverter Current-Phase B
- A3: Inverter Current-Phase C
**Transient Response**

Real Power ~ 6 kW

Change in Reactive Power: -6 to +6 kVAr

Step change of Reference Voltage ~ 0.92 PU (110Vrms) to 1.07 (128Vrms)

- **PCC Voltage**
- **Inverter Current**
**PV-STATCOM Test → Power Factor Correction**

**Transient Response**

PV Real Power ~ 3 kW

Load Power ~ Active: 6 kW, Reactive: +9 kVAr (Inductive)

Step change in Power Factor ~ From 0.32 lag to Unity

Response time < 1 cycle

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Grid Voltage

Active power (phase A)

Reactive power (phase A)

Grid Power Factor

PCC Voltage

Current (rms)

Inverter (phase A)

Load

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Grid Current

Inverter Current

Load Current

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Inverter

Load

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Grid
**PV-STATCOM Test → Power Factor Correction**

**Transient Response**

- PV Real Power ~ 3 kW
- Load Power ~ Active: 6 kW, Reactive: -3 kVAR (Capacitive)
- Step change of Power Factor ~ From 0.707 leading to Unity

Response time < 1 cycle
Control Coordination of Two PV-STATCOMs

Grid

Transformer

PV Solar Simulator#1

Coupling Transformer

Three Phase VSC

RLC Filter

Photovoltaic System#1

Transformer

PV Solar Simulator#2

Coupling Transformer

Three Phase VSC

RLC Filter

Photovoltaic System#2

RLC Load
Conclusions

- Novel Control of PV solar farm as STATCOM (PV-STATCOM)

- Controls validated in Lab for voltage regulation and power factor correction on single 10 kW inverter

- Potential to bring:
  - New revenues to solar farms during nights and day
  - Better network performance for utilities
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Thank You Questions?