Solar Net-Metering in Pakistan – Opportunities and Challenges

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Outline

1. Concept
2. Technology Basics
3. Important technological and design consideration (Resource Estimation, Efficiency, Cost, Performance Metrics)
4. Case Study of LUMS PV System – Planning, execution and operation
5. Benefits and concerns with typical rooftop PV Systems
Why solar and why now?

• Higher emphasis on climate change mitigation and global shift towards green technologies
• Increasing conventional energy mix costs while the global energy demand is increasing
• Lowering PV panel and system costs

Ref: NREL (USA) PV system costs, 2017
1. Concept – How does this work?

- Consumer is Charged on the basis of **net units consumed**.
- The rate of **savings on electricity** generated for own use is equivalent to the DISCO’s **retail (off-peak) rate**.
- If a consumer is receiving a net export bill each month, then the DISCO will pay for the **net export energy** as per off peak rate in PKR **quarterly** (every 3 months).
- Solar (Grid-tied) is Supplementing (feeding) directly to the grid, i.e., **no grid - no solar** in conventional grid-tied systems.
1. Concept – Conventional Solar PV Grid-Tied System

Single Line Diagram of On Grid Roof Top PV System for Net Metering Interconnection
2. Technology Basics – Two Fundamental Components

A) Solar Panels

- Produces Varying DC
- Rated for Standard Testing
  Conditions (1000 W/m² irradiance, Cell Temperature 25°C and wind speed 1m/s)
- Most Viable options
  - Crystalline – Si (mono, poly)
    Theoretical maximum is 35% for a single junction cells but commercial panels are 15-20% efficient.
  - Thin film – CdTe, CIS and a-Si
    Typically 10-15 % efficient (Commercial).

B) Inverters

- Convert varying DC to 50 hz 230V AC
- Various types:
  - Central Inverters (typically for solar Farms)
  - String Inverters (domestic buildings)
  - Micro-Inverters (new technology – 1 inverter per panel)
3. Important technological and design consideration - Solar resource assessment and quantification

- All panels are rated for their operation at Standard Testing Conditions (1000 W/m² irradiance, Cell temperature 25°C and wind speed 1m/s). Therefore, the solar potential of a site is evaluated as ‘the amount of equivalent PSH’

http://www.aurorasolarenergy.com/average-daily-sun-hours/
3. Important technological and design consideration - Solar Panel Rating and Efficiency!

- **Panel Name Plate Capacity (Rating)**
  - A panel is rated on the basis of STC, so a 100Wp panel will produce 100 W for equivalent of Peak Sunlight Hours (PSH) in a day.
  - PSH for Lahore ~ 5.2 (average).
  - So (on average) a 100 Wp panel has a theoretical maximum production 100W for 5.2 hrs in Lahore.

- **Efficiency**
  - Efficiency of a panel is: output power/input power
  - The efficiency of a panel determines the area of a panel given the same rated output - an 8% efficient 100 watt panel will have twice the area of a 16% efficient 100 watt panel.
3. Important technological and design consideration – Price of panel/module

- **Price**
  
  It is specified as **Price per Watt Peak Wp**
  
  - Efficiency is not a concern for consumers once power rating is specified (of course deployment area is still a concern).
  
  - Prices are currently **as low as 0.3 $/Wp from ~ 4-5 $/Wp in 2008**.

- **Scalability**
  
  - Panel capacity ranges from 10 to 350 watt-peak (SCALABILITY)
3. Important technological and design consideration - Solar Panel Performance under high Temperature

- Solar Panels have negative temperature coefficient, i.e., their performance degrades with temperature rise. (internal cell/semiconductor physics)

- Crystalline-Si and Thin Film panels show different performance with Temperature
  - The temperature coefficient of c-Si is around \(-0.45\) to \(-0.5\)% per degree rise in temperature - This means that the power output of the cells will decrease by a minimum of \(0.45\)% of the rated with rise in \(1^\circ C\) above \(25^\circ C\).
  - On the other hand, the temperature coefficient for thin film solar cells is around \(-0.22\) to \(-0.25\)% per degree rise in temperature, roughly half of the c-Si based cells.

- This implies that the performance degradation of thin film panels would roughly be half to that of c-Si based panels!

- The cell temperature is usually significantly higher than ambient temperature.
3. Important technological and design consideration –

**Solar Panel Performance under high Temperature**

- Cell temperature is typically much higher than ambient temperature due to enclosed nature of the module!
  - For instance if ambient temperature is 40°C, then the cell temperature will typically be higher than 75°C.
  - So how would the a standard Si or Thin film panel behave?

**C-Si:**

\[-0.48 \times (75-25) = 24\% \text{ decrease in the power output i.e., a 100 Wp panel would only be producing 76 W even at standard Irradiance (1000 W/m}^2)\]

**Thin Film:**

On the other hand thin film panel will reduce by 12.5% i.e., \[-0.025 \times (75-25) = 12.5\% \text{ i.e., a 100 Wp thin film panel would be producing 87.5 W even at 1000 W/m}^2\]

If area is not a concern then Thin-film installation in hot climatic regions!
Shading concern!

- Thin film also produce better under shading condition

Relative Performance Output

Ref: Hotspots and performance evaluation of crystalline-silicon and thin-film photovoltaic modules  S Ahsan, KAK Niazi, HA Khan, Y Yang, Microelectronics Reliability, 2018
3. Important technological and design consideration - Inverters

- Various type of commercial inverters,
  
  - Central (Multiple strings attached to a central inverter)
  
  - String (Multiple strings feeding to the grid with Maximum Power Point Tracking (MPPT) at individual strings)
  
  - Microinverters (Module level DC to AC inversion)
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3. Important technological and design consideration – PV System Costs

- Mentioned in terms of price per watt or price per watt peak or USD/Wp or PKR/Wp

Includes:
- PV Panel costs
- Inverter Costs
- Balance of System BOS costs
- Installation costs
- Maintenance Costs
- Financing costs + insurance and other costs

Overall Price of a system may typically range from 1 - 3 USD per Wp
3. Important technological and design consideration - How can we ascertain the performance of a PV system?

➢ Single most Important Performance Metric for a PV system is its PERFORMANCE RATIO (PR)
  • **Performance Ratio**

The performance ratio (PR) describes the relationship between the actual and theoretical energy outputs of the PV plant.

$$PR = \frac{\text{Actual Energy Output annually (AC)}}{\text{Theoretical maximum (nominal) Energy Output annually (DC)}}$$

➢ **Capacity Factor**

The capacity factor is the average power generated, divided by the rated peak power.

   o A 5MW wind turbine produces power at an average of two megawatts, then its capacity factor is 40% (2÷5 = 0.40, i.e. 40%).
   o A 5MW Coal plant produces power at an average of four megawatts, then its capacity factor is 80% (4÷5 = 0.80, i.e. 80%).
3. Important technological and design consideration - How can we ascertain the performance of a PV system?

- **Payback Period**
  - Time in which the initial FINANCIAL investment is recovered

- **Energy Payback Period**
  - Time required to produce enough energy that was consumed to make a generation resource/panel or a plant

- **Levelized Cost of Electricity**
  - Measures lifetime costs divided by energy production $/kWh (or ¢/kWh or $/MWh).

\[
LCOE = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}
\]

- Calculates present value of the total cost of building and operating a power plant over an assumed lifetime.
- Allows the comparison of different technologies (e.g., wind, solar, natural gas, coal) of unequal life spans.
3. Important technological and design consideration – Net Present Value (NPV) of an Investment!

- It includes **Time value of money**—that is, the fact that 1000Rs 0 years from now is not as good as having 1000Rs in your pocket today.

- \[ ROI = \frac{\text{Total returns in NPV}}{\text{Total investments in NPV}} \]

For solar investments, ROI is 2-4 depending on incentives and other aspects


Fig: ROI and Payback period for a typical 48 kWp system with: Micro String and Central Systems with no shading
4. Case Study of LUMS PV system – Planning, execution and operation

• Grid-tied solar is feeding directly to the grid, i.e., no grid no solar.

• So backup(captive) generation is required for such implementations.

• This was done in Three Phases:
  o **Phase 1**: 42kWp Grid Tied System on ONE (Library) Building in **2013**
  o **Phase 2**: 310kWp system installed in **2015**
  o **Phase 3**: 400kWp system due to be installed in Sep. **2018**
Conventional Solar PV Grid-Tied System

Phase 1: 42kWp Grid Tied System Library

Key Parameters

1. **Readily available grid power & captive generation**
   - Grid tied systems (No battery bank)

2. **Limited space – Rooftop installation**
   - Selection of panels
   - Shadowing effects

3. **Safety concerns**
   - Cater for high winds
   - 4-inch deep bolts sealed with Epoxy

4. **Maintenance requirements**
   - Cleaning requirements

5. **Monitoring station**
   - Wind speed, solar irradiation, ambient temperature
   - Daily energy output
Phase 1: 42kWp Grid Tied System Library
Rooftop Snapshot Before Installation
Phase 1: 42kWp Grid Tied System Library Panel orientation on the Rooftop!

Top View

Design Design
Phase 1: 42kWp Grid Tied System
Rooftop Snapshot After Installation
Phase 1: 42kWp Grid Tied System Library
Inverter Mounting on the Wall
Phase 1: 42kWp Grid Tied System Library System Orientation

- 176 panels (240 Wp each)
- Stationary (no physical solar tracing)
- 3 SMA grid tied Inverters rated at 15kW, 15kW and 10.5kW
- Series connection of 22 panels
  - 3 strings of 22 panels (16 kWp) (Inverter 1)
  - 3 strings of 22 panels (16 kWp) (Inverter 2)
  - 2 strings of 22 panels (10.5 kWp) (Inverter 3)
Phase 1: 42kWp Grid Tied System Library
Configuration of Inverters
4. Case Study of LUMS PV system – Key parameters governing the overall energy output

• Shading losses
• Cleaning issues
• Teething problems (GenSet synchronization problems)
• Maintenance issues and inverter replacements
• Limitations due to high volatility of resources
Shading losses - Energy Output from all 3 Inverters

<table>
<thead>
<tr>
<th>Inverter</th>
<th>Capacity (kW)</th>
<th>Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter 1</td>
<td>15</td>
<td>41.74</td>
</tr>
<tr>
<td>Inverter 2</td>
<td>15</td>
<td>63.53</td>
</tr>
<tr>
<td>Inverter 3</td>
<td>10</td>
<td>45.41</td>
</tr>
<tr>
<td>Total Energy</td>
<td></td>
<td>150.68</td>
</tr>
</tbody>
</table>
Phase 1: 42kWp Grid Tied System Library
Configuration of Inverters

Inverter # 1
- MPPT 1
- String 1
- String 2
- MPPT 2

Inverter # 2
- MPPT 1
- String 1
- String 2
- MPPT 2
- String 1

Inverter # 3
- MPPT 1
- String 1
- String 2
- MPPT 2
- String 1
Phase 1: 42kWp Grid Tied System Library Configuration of Inverters

Actual view of the installation (on left) and aerial view of installation (on right) showing structures causing shading
Shading losses - Energy Output from 3 Inverters on a Cloudy Day

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</thead>
<tbody>
<tr>
<td>Inverter 1</td>
<td>15kW</td>
<td>22.26</td>
</tr>
<tr>
<td>Inverter 2</td>
<td>15kW</td>
<td>26.03</td>
</tr>
<tr>
<td>Inverter 3</td>
<td>10kW</td>
<td>17.56</td>
</tr>
<tr>
<td><strong>Total Energy</strong></td>
<td></td>
<td><strong>65.85</strong></td>
</tr>
</tbody>
</table>
Key Parameters governing the overall energy output

• Shading Losses
• Cleaning issues
• Teething problems (GenSet synchronization problems)
• Maintenance Issues and Inverter replacements
• Limitations due to high volatility of resources
LUMS Power System Operation

Utility grid
Step down transformer
Smart Panel
Step down transformer
Gas turbine
Diesel generators
Loads connected to main bus
Limitations due to high volatility of resources
DIP Management System at LUMS to minimize Switch over problems
5. Summary - Benefits and Concerns for Rooftop PV

• For Consumers:
  • Reduces grid dependency and cheaper alternative to grid power
  • Lowers Diesel costs
  • Safe choice against projected increase in energy costs
  • For domestic consumers, it must be seen from an investment alternative and not as a complete backup for optimum gains!
  • Mandatory requirement of Grid Power or major upgrades in captive generation infrastructure.

• From Distribution Company’s Perspective:
  • Reduces peak demand in summer day times
  • Onus on users to produce their own electricity
  • Loss of ‘high value/Safe’ consumers
  • Impact on the LV distribution grid (voltage levels, Stresses at grid stations, uneven loadings, etc.) from high penetration of a large number of distributed solar generators
Thank you

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