PHOTOVOLTAIC POWER PLANTS & INVERTERS

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Outline of the Presentation

- Components of the PV Power Plants
- MPPT
- Grid Interactive Inverters
- Basic Specifications of an Inverter
- International Standards of Grid Inverters
- Utility Disconnection Requirements
- Types of Grid Interactive Inverter
- The Evolution of the Inverters
- Conclusion
Renewable energy sources (RES) have become more important research area for the researchers due to increasing energy demand in the world.

The most common renewable resources are Solar and Wind.

Due to environment issues such as global warming and pollution, limited resources of fossil based fuels and energy crisis, renewable energy sources such as photovoltaic (PV) array, wind turbine, fuel cell, biomass system and the geothermal systems are becoming more and more popular in industrial and also residential applications.
Smart Grid Concept

110/220/380 kV

10/20 kV

400 V

Import/Export

Storage
Components of the PV Power Plants
PV modules

- All-in-module (US$/W) cost and plant capacity evolution (decreasing prices)
## Overview of major PV technologies

### PV modules

<table>
<thead>
<tr>
<th>Technology</th>
<th>1st Generation PV</th>
<th>2nd Generation PV</th>
<th>3rd Generation PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Units</td>
<td>Technology</td>
<td>Technology</td>
</tr>
<tr>
<td>Best research solar cell efficiency at AM1.5*</td>
<td>%</td>
<td>24.7</td>
<td>20.3</td>
</tr>
<tr>
<td>Confirmed solar cell efficiency at AM1.5</td>
<td>%</td>
<td>20-24</td>
<td>10-12</td>
</tr>
<tr>
<td>Commercial PV Module efficiency at AM1.5</td>
<td>%</td>
<td>15-19</td>
<td>7-11</td>
</tr>
<tr>
<td>Confirmed maximum PV Module efficiency</td>
<td>%</td>
<td>23</td>
<td>7.1/10.0</td>
</tr>
<tr>
<td>Current PV module cost</td>
<td>USD/W</td>
<td>&lt;1.4</td>
<td>~0.8</td>
</tr>
<tr>
<td>Market share in 2009</td>
<td>%</td>
<td>83</td>
<td>87</td>
</tr>
<tr>
<td>Market share in 2010</td>
<td>%</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Maximum PV module output power</td>
<td>W</td>
<td>320</td>
<td>300</td>
</tr>
<tr>
<td>PV module size</td>
<td>m²</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Area needed per kW</td>
<td>m²</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>State of commercialisation</td>
<td>Mature with large-scale production</td>
<td>Mature with large-scale production</td>
<td>Early deployment phase, medium-scale production</td>
</tr>
</tbody>
</table>

### Summary
- **Overview of major PV technologies**
### Top Ten by Power

<table>
<thead>
<tr>
<th>Power</th>
<th>Description and Location</th>
<th>Commissioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 MW</td>
<td>Agua Caliente Solar Project, Yuma County, Arizona</td>
<td>2012</td>
</tr>
<tr>
<td>214 MW</td>
<td>Charanka Park, Patan District PV Power Plant, Charanka, India</td>
<td>2012</td>
</tr>
<tr>
<td>200 MWP</td>
<td>Golmud PV Power Plant, Golmud, China</td>
<td>2011</td>
</tr>
<tr>
<td>150 MW</td>
<td>Mesquite Solar I, Sonora Desert, Arizona</td>
<td>2011</td>
</tr>
<tr>
<td>145 MWP</td>
<td>Solarpark Neuhardenberg, Neuhardenberg, Germany</td>
<td>2012</td>
</tr>
<tr>
<td>128 MW</td>
<td>Solarpark Templin, Germany</td>
<td>2012</td>
</tr>
<tr>
<td>115 MW</td>
<td>Centrale Solaire de Toul-Rosières, France.</td>
<td>2012</td>
</tr>
<tr>
<td>106 MW</td>
<td>Perovo I-V PV Power Plant, Ukraine</td>
<td>2011</td>
</tr>
<tr>
<td>97 MW</td>
<td>Sarnia PV Power Plant, Canada</td>
<td>2009</td>
</tr>
<tr>
<td>91 MW</td>
<td>Solarpark Briest, Germany</td>
<td>2011</td>
</tr>
</tbody>
</table>

- Top large scale PV power plants
An alternative approach is based on each PV module having its own small inverter (i.e., micro-inverter) mounted directly onto the backside of the panel. These ac modules allow simple expansion of the system, one module at a time, as the needs or budget dictate.
Today’s inverters are already smart as they
- monitor the PV array, track the maximum power and operate at that point,
- sense the presence of the grid, synchronize to and inject a current in phase with the voltage,
- monitor the grid and disconnect in case of trouble (e.g., swings in voltage or frequency).
Components of PV Power Plants - Today’s Grid - Tied PV Inverters
Components of PV Power Plants - Today’s Grid-Tied PV Inverters
Components of PV Power Plants-Interfacing with the utility

- Whenever the PV system delivers more power than the local demand, the electric meter runs backwards, building up a credit.
- When demand exceeds that supplied by the PV, the grid provides supplementary power. This arrangement is called *net metering* (the customer’s monthly electric bill is only for that net amount of energy that the PV system is unable to supply).
Components of PV Power Plants - Communications

- Existing SCADA Standards
- Smart Inverter DNP3 Standard
- RS232, RS485, Ethernet

Diagram showing the components of a PV power plant, including Utility Distribution, Substation SCADA Head-End, DER Plant, and various devices such as Smart Inverters, Energy Storage, and CPV Trackers.
Components of PV Power Plants - Reactive power requirement.
Low Voltage Ride Through Time of Different National Codes
Components of PV Power Plants - Energy Storage

PHOTOVOLTAIC POWER PLANTS & INVERTERS
PV maximum power curves.

a) Daily irradiation level and temperature

b) Daily MPPT curve*

* Red line (MP traction line) shows clearly sky condition. It changes cloudy sky, temperature, PV pullation etc.
PV maximum power curves.
MPPT control methods can be grouped in two categories as off-line and on-line methods. This classification whether it is based on actual MPPT or not.

- On-line methods obtain real MPPT independent from environmental and PV system conditions. Although response speeds of these on-line methods are variable depending on their structures and control methods, they are slower than the off-line methods.

- Off-line methods, the output power of PV system is not read and calculated. MPPT process is obtained by using PV values (Isc, Voc, temperature and irradiation). Although off-line methods are simple, low cost and useful, switching off loads to determine the MPP is a problem.
The grid interactive inverter consists of a PV power supply, a power conditioning unit, distribution panels and a inverter stage.
Basic Specifications of an Inverter

Typical specifications required for a grid of interactive inverter is determined as follows;

- The current injected to the grid must be in sinusoidal waveform and its harmonics have to be within the limits specified in the regulations.
- The power factor of the grid interactive inverter must be unity.
Basic Specifications of an Inverter

Typical specifications required for a grid of interactive inverter is determined as follows (continue);

- The radio interference due to the high-frequency switching of power components in the inverter must be under control.
- The grid interactive inverter has to be separated from the grid when the grid fails.
- In order to keep the highest RES efficiency, the withdrawal of maximum power must always be provided.
There are some rules and constraints about the rectifying AC voltage generated by RES, inverting DC voltage, exporting energy to the grid.

A typical grid interactive inverter injects a sinusoidal current to the line, and must meet the international standards like IEC61727, IEEE1547 and EN61000-3-2, and radio frequency interference due to high frequency switching should be under control.
## PHOTOVOLTAIC POWER PLANTS & INVERTERS

### Summary of the most interesting standards dealing with grid interactive systems

<table>
<thead>
<tr>
<th>Subject</th>
<th>IEC61727</th>
<th>IEEE1547</th>
<th>EN61000-3-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>10 kW</td>
<td>30 kW</td>
<td>16A X 230V = 3,7 kW</td>
</tr>
<tr>
<td>Indivudial Harmonic Limits</td>
<td>(3-9) %4,0</td>
<td>(2-10) %4,0</td>
<td>(3) 2,30 A</td>
</tr>
<tr>
<td></td>
<td>(11-15) %2,0</td>
<td>(11-16) %2,0</td>
<td>(5) 1,14 A</td>
</tr>
<tr>
<td></td>
<td>(17-21) %1,5</td>
<td>(17-22) %1,5</td>
<td>(7) 0,77 A</td>
</tr>
<tr>
<td></td>
<td>(23-33) %0,6</td>
<td>(23-34) %0,6</td>
<td>(9) 0,40 A</td>
</tr>
<tr>
<td></td>
<td>(&gt;35) %0,3</td>
<td></td>
<td>(11) 0,33 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(13) 0,21 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(15-39) 2,25/h</td>
</tr>
<tr>
<td>Even harmonics should be %25 less then Odd harmonics in this range</td>
<td></td>
<td>Approximately Equal or less then %30 of Odd harmonics</td>
<td></td>
</tr>
<tr>
<td>Maximum Total Harmonic Distortion</td>
<td>5.00%</td>
<td>5.00%</td>
<td>-</td>
</tr>
<tr>
<td>Power Factor at %50 Rated Power</td>
<td>0,9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DA Current Injection</td>
<td>Less then %1 of rated current</td>
<td>Less then % 0.5 of rated current</td>
<td>&lt;0.22A - 50W Suitable for half wave rectifier</td>
</tr>
<tr>
<td>Nominal Working Voltage Range</td>
<td>%85 - %110</td>
<td>%88 - %110</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(196V - 253V)</td>
<td>(97V - 121V)</td>
<td>-</td>
</tr>
<tr>
<td>Nominal Working Frequency Range</td>
<td>50±1 Hz</td>
<td>59.3 Hz – 60.5 Hz</td>
<td>-</td>
</tr>
</tbody>
</table>
## IEEE 929 Utility disconnect requirements

<table>
<thead>
<tr>
<th>State</th>
<th>Voltage</th>
<th>Frequency</th>
<th>Max. Off Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.5 ≤ Vnom</td>
<td>fnom</td>
<td>6 cycle</td>
</tr>
<tr>
<td>B</td>
<td>0.5 Vnom &lt; V &lt; 0.88 Vnom</td>
<td>fnom</td>
<td>2 second</td>
</tr>
<tr>
<td>C</td>
<td>0.88 Vnom ≤ V ≤ 1.10 Vnom</td>
<td>fnom</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>1.10 Vnom &lt; V &lt; 1.37 Vnom</td>
<td>fnom</td>
<td>2 second</td>
</tr>
<tr>
<td>E</td>
<td>1.37 Vnom ≤ V</td>
<td>fnom</td>
<td>2 second</td>
</tr>
<tr>
<td>F</td>
<td>Vnom</td>
<td>f &lt; fnom - 0.7 Hz</td>
<td>6 cycle</td>
</tr>
<tr>
<td>G</td>
<td>Vnom</td>
<td>f &gt; fnom + 0.5 Hz</td>
<td>6 cycle</td>
</tr>
</tbody>
</table>
Types of Grid Interactive Inverter

- There can be one or two or more power processing stages in the grid interactive inverters. Single-stage inverter carries out all tasks such as MPPT, grid current control and, if necessary, like voltage step up.
Types of Grid Interactive Inverter

- Transformer-included inverter examples.

a) Line frequency transformer is connected between the line and the inverter.

b) High-frequency transformer is embedded in an HF-link inverter.

c) High-frequency transformer is embedded in DC-DC converter.
Types of Grid Interactive Inverter

- Current and voltage fed grid interactive inverters.

a) Current fed grid commutated inverter switching at twice the grid frequency.

b) Voltage fed, self commutated inverter at high frequency.
Types of Grid Interactive Inverter

- Multilevel grid interactive inverter.

Three Level NPC Grid interactive inverter.
Types of Grid Interactive Inverter

- These topologies synthesize voltage waveform with a number of semiconductor devices connected in a special arrangement, rated at a fraction of the dc bus voltage.

Description of Multilevel Inverter
Advances of the semiconductor power switching devices and the developed new high frequency low loss core materials give idea to the designers investigate of new topologies.

High performance dedicated processors help to the designers for the realization of the digital control.

Increasing demand of the grid interactive inverter also tends the manufacturers and researchers to find lower cost and higher efficiency products.
Historical overview of PV inverters (a) Past centralized (b) Present string (c) Present and future AC-module and AC cell technologies.
The Evolution of the Inverters

Different AC module topologies.
The Evolution of the Inverters

Different AC module topologies.
The Evolution of the Inverters

Different AC module topologies.
The Evolution of the Inverters

Different AC module topologies.
The Evolution of the Inverters

Different AC module topologies.
The Evolution of the Inverters

- Team concept is the notion of another PV system.
- Combining the string technology with the master-slave technology increases the system efficiency compared to the separately operated inverters in the PV systems which has multi inverters.
The multi-string concept shown in figure is designed to combine the low cost feature of the central inverters with the high efficiency feature of the string inverters. In less-powerful DC-DC converters are connected to the PV strings individually. Each PV string has own MPPT which optimizes the power output by operating independently from the other strings.
Conclusion

- In this study, an extensive research on the grid interactive inverters used in PV applications has been presented.
- The operation modes of the grid interactive inverter and the basic features of the inverter required to be possess has been explained.
- Also the international standards on issues like the power quality, the detection of island mode and the grid impedance changes are noted.
- In addition, the historical development of the grid interactive inverters used in PV applications summarized and the future expectations are given.
- As a result, the research activities continue in order to develop the inverters which are low-cost, easy to install, long life and operable with high efficiency even though the input voltage and the power change in a wide range due to the natural conditions.
THANK YOU

QUESTIONS