ABB Solar Photovoltaic Power Plant Design & Solutions Overview

Budi Supomo
A global leader in power and automation technologies
Leading market positions in main businesses

- ~145,000 employees
- Present in +100 countries
- Formed in 1988
- Merger of Swiss (BBC, 1891) and Swedish (ASEA, 1883) engineering companies

$42 billion
In revenue (2013)
Power and productivity for a better world

ABB’s vision

As one of the world’s leading engineering companies, we help our customers to use electrical power efficiently, to increase industrial productivity and to lower environmental impact in a sustainable way.
How ABB is organized

Five global divisions

- Power Products
- Power Systems
- Discrete Automation and Motion
- Low Voltage Products
- Process Automation
ABB in the Solar Industry
ABB full offer for Solar on-Grid power plant

Low-voltage products
a - Contactors: GAF series, IVR bar contactors
b - DC string boxes
Switchboards: Gianni series,
Consumer units: Europa series
c - Fuse disconnectors: 690 V, Presses: 6-3P PV
d - Surge protective devices: OVM PV
e - Fuse disconnectors: LI 90
f - Switches: GTCO series,
Miniature circuit-breaker disconnectors: 6900 PV-M
g - Miniature circuit-breakers: S800 PV-S
    Miniature circuit-breakers: S800 MIO Z
h - Switch disconnectors: Tmax PV
i - Molded-case circuit breakers: Tmax
j - Surge protective devices: OVM F1 / F2
k - Contactors: A and AF series
l - Insulation monitoring devices: CM MN
m - Power supplies
n - Energy meters: LG meters
o - Residual current device breakers: GCL 600 B
    Residual current devices: F202 PV B and F204 B
    Miniature circuit breakers: S 200
p - OM-UO, MS2
q - ATV switchboards

Solar Inverters
r - Central inverters: PUB 600
    Remote monitoring port
String monitoring
s - PLC AC320
  1 - Current Measurement System (CMS)
Medium-voltage products
u - Secondary switchgear
v - Dry type transformers
w - Liquid-type oil-filled transformers
x - Compact secondary substations
Grid connected microgrid
Improved grid resiliency, higher power quality and increased self consumption

PCC: Point of Common Coupling
CHP: Combined Heat and Power
Highlights of the improved design – first time shown at Inter-solar 2014

- True three-phase bridge topology for DC/AC output converter
- Transformer-less topology
- Each inverter is set on specific grid codes which can be selected in the field
- Detachable wiring box to allow an easy installation
- Wide input range
- ‘Electrolyte-free’ power converter to further increase the life expectancy and long term reliability
- Integrated string combiner with different options of configuration which include DC and AC disconnect switch in compliance with international standards (-S2, -S2F and S2X versions)
- Natural convection cooling for maximum reliability
- Outdoor enclosure for unrestricted use under any environmental conditions
- Capability to connect external sensors for monitoring environmental conditions
- Availability of auxiliary DC output voltage (24V, 300mA)
- All-in-one ABB design and components
ABB central inverter, PVS800
Junction box with string monitoring

- Specifications for PVS-JB-8-M
  - String amount: 8 (80 A)
  - Vdc ratings: 1000 Vdc
  - Enclosure: plastic, UV protected, IP66
  - String connection with screw-clamp terminals
  - Includes:
    - Positive and negative protection with fuses in openable holders
    - Isolation switch
    - Overvoltage protection
    - Analog inputs and digital I/O

All-in-one ABB design and components
ABB central inverter, PVS800
Product highlights

- **High total performance** - high efficiency with low auxiliary power consumption and reliability

- **Advanced grid support functionality** - extensive grid code compatibility with adjustability

- **Proven technology platform** - high reliability and long operating life

- **Compact state of the art industrial design** - low space requirement and fast & easy installation with serviciability

- **All-in-one design with extensive DC and AC side protection** - ensuring maximum uptime of the plant

- **Lifecycle service and support** through ABB’s extensive global service network - rapid support anywhere in the world
ABB central inverter, PVS800
R8i Inverter Modules – most widely used platform

- Since 2003, ABB has delivered over 200,000 pieces R8i inverter modules which are used in ABB
  - Frequency converters (ACS800)
  - Wind turbine converters (ACS800)
  - Solar inverters (PVS800)

- R8i is the most widely used inverter module in the world and is backed up with ABB continuous development and life cycle service network

- ABB central inverter platform is based on this world leader power converting platform delivered so far over 100 GW globally
ABB Compact Solar Station
Packaged solution for multi-megawatt power plants

Features:
- Steel framed housing ready for overseas transportation
- 1 or 2 x 500/630/875/1000 kW PVS800 central inverters
- 1000/1250/1750/2400 kVA EcoDry type transformer
- MV switchgear gas insulates from 6,6/12/24/36 kV
- Auxiliary and Monitoring

Benefits:
- All ABB – proven and reliable components
- Compact and robust design – transportability
- High total efficiency - high return of investment
- Modular and serviceable system – reduced downtime
- Global life cycle services and support

ABB inverters based on R8i power conversion platform – large installed capacity globally
ABB remote monitoring portal
Remote monitoring portal - overview

Scope and application:
- Remote monitoring portal for ABB central and string inverters from medium sized systems up to multi-megawatt plants.
- Centralized solution with easiness, scalability and safety

Product highlights:
- Internet browser accessible solar portal
- All the database transactions are fully secured
- One way communication
- Easy reporting and trend analysis
- Centralized monitoring of sites
- Easy connectivity from almost any PC/mobile device with internet browser
- Alarms and reports to e-mail
- Secured and permanent data storage during whole plant life time
ABB remote monitoring portal
New features

- Support for PVS300
- String monitoring
- Performance ratio
- Environmental monitoring
- Plant performance
- Plant summary reports
ABB remote monitoring portal
Features – reports & Data flow

- Weekly, monthly, yearly and long-term performance reports with yields and fault summaries
- Database incoming data servers receive the emails and process the data to storage.
- Data accessible 24/7 by anyone with access rights
- Data trending and visualization on demand. Overload protection by separate servers for visualization
ABB remote monitoring portal
Features - plant performance

![Plant PowerTower Performance Graph]

Estimated and real energy (1/2/12 12:00 AM - 12/31/12 11:59 PM EET (UTC+0200))

<table>
<thead>
<tr>
<th>Year</th>
<th>Calendar</th>
<th>&lt;</th>
<th>&gt;</th>
<th>+</th>
<th>-</th>
<th>Apply to all</th>
<th>Reset</th>
<th>More...</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May-2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jul-2012</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Sep-2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Nov-2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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</tbody>
</table>

2 rows displayed

<table>
<thead>
<tr>
<th>Name</th>
<th>minimum</th>
<th>average</th>
<th>maximum</th>
<th>last value</th>
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<tbody>
<tr>
<td>Estimate</td>
<td>3508</td>
<td>10818</td>
<td>17753</td>
<td>3508</td>
</tr>
<tr>
<td>total</td>
<td>0</td>
<td>6799</td>
<td>20455</td>
<td>0</td>
</tr>
</tbody>
</table>
ABB remote monitoring portal
Features - forecast*

*Up-coming feature / Piloting readiness
### ABB remote monitoring portal
#### Features – site info

<table>
<thead>
<tr>
<th>Site/project name:</th>
<th>ABB Eroof Pitäjänmäki</th>
</tr>
</thead>
<tbody>
<tr>
<td>location</td>
<td>Helsinki, Vaimo</td>
</tr>
<tr>
<td>coordinates</td>
<td>60 N, 23.14 E</td>
</tr>
<tr>
<td>altitude</td>
<td>50 m</td>
</tr>
<tr>
<td>plant timezone</td>
<td>Europe/Helsinki</td>
</tr>
</tbody>
</table>

**PV array power:** 181 kWp

- installation type: Fixed, roof mounted
- solar module: Naps NP215GK, poly crystalline
- array tilt: 30 degrees
- array orientation: +25 degrees from south

**Inverter power:**
- PVS800: 120 kW, 1 pcs
- PVS300: 3x8 kW + 3 x 6 kW

**General system info:**
- grid connection: LV grid
- string monitoring: For central inverter ABB junction boxes
- weather measurements: Solar irradiation, Tamb, Tmodule
- additional measurements: No

**Other information:**
- plant commissioned: 20.6.2010
- measured since: 9.7.2010
- CO2 coefficient: 0.0011 tons/kWh

- **Connectivity** – Accurate and easy system performance overview is reachable from any computer or mobile device with internet browser.

- **Faults and Alarms** – Users can get information about faults and warnings through web and by e-mail
ABB remote monitoring portal
Comparison figure
ABB remote monitoring portal

Scope

Applications

- Inverters
  - PVS300
  - PVS800

- Remote monitoring devices
  - NETA-01
  - SREA-50

Service opportunities

Inbound
- Email
- Http
- CSV

Outbound
- Web-access
- Public web-pages
- Email
- SMS

Users
- Public
- Investors and owners
- Site management
- Service
MV switchgear
e.g. ABB SafeRing,
SafePlus and UniSec.

Transformers
Dry-type and liquid-filled transformers
Solar PV Power Plant Design
Tools & Support from Concept to Commissioning

- Concept
- Feasibility Study
- Detailed Engineering
- Supply
- Installation & Commissioning
- Service & Optimisation

- Spreadsheet
- Energyflow
- Loadflow
- Stability
- Protection
- Tuning & Parameters
- Optimized

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April 16, 2015
### NASA Surface meteorology and Solar Energy: RETScreen Data

Latitude **-8.903** / Longitude **116.297** was chosen.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Climate data location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td><strong>-8.903</strong></td>
</tr>
<tr>
<td>Longitude</td>
<td><strong>116.297</strong></td>
</tr>
<tr>
<td>Elevation</td>
<td><strong>74</strong></td>
</tr>
<tr>
<td>Heating design temperature</td>
<td><strong>23.52</strong></td>
</tr>
<tr>
<td>Cooling design temperature</td>
<td><strong>28.35</strong></td>
</tr>
<tr>
<td>Earth temperature amplitude</td>
<td><strong>1.81</strong></td>
</tr>
<tr>
<td>Frost days at site</td>
<td><strong>0</strong></td>
</tr>
</tbody>
</table>
## Solar Project Design

### 20 Mwp Solar IPP Lombok (sample case)

<table>
<thead>
<tr>
<th>Month</th>
<th>Air temperature</th>
<th>Relative humidity</th>
<th>Daily solar radiation horizontal</th>
<th>Atmospheric pressure</th>
<th>Wind speed</th>
<th>Earth temperature</th>
<th>Heating degree-days</th>
<th>Cooling degree-days</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>26.6</td>
<td>83.2%</td>
<td>4.91</td>
<td>100.0</td>
<td>4.4</td>
<td>28.9</td>
<td>0</td>
<td>512</td>
</tr>
<tr>
<td>February</td>
<td>26.6</td>
<td>82.8%</td>
<td>4.92</td>
<td>100.0</td>
<td>4.6</td>
<td>28.6</td>
<td>0</td>
<td>468</td>
</tr>
<tr>
<td>March</td>
<td>26.6</td>
<td>83.3%</td>
<td>5.34</td>
<td>100.1</td>
<td>3.3</td>
<td>28.9</td>
<td>0</td>
<td>512</td>
</tr>
<tr>
<td>April</td>
<td>26.8</td>
<td>81.3%</td>
<td>5.52</td>
<td>100.1</td>
<td>3.7</td>
<td>29.0</td>
<td>0</td>
<td>503</td>
</tr>
<tr>
<td>May</td>
<td>26.8</td>
<td>77.4%</td>
<td>5.35</td>
<td>100.2</td>
<td>4.9</td>
<td>28.4</td>
<td>0</td>
<td>521</td>
</tr>
<tr>
<td>June</td>
<td>26.5</td>
<td>74.5%</td>
<td>4.92</td>
<td>100.2</td>
<td>5.6</td>
<td>27.8</td>
<td>0</td>
<td>494</td>
</tr>
<tr>
<td>July</td>
<td>25.9</td>
<td>72.5%</td>
<td>4.96</td>
<td>100.3</td>
<td>5.7</td>
<td>27.1</td>
<td>0</td>
<td>494</td>
</tr>
<tr>
<td>August</td>
<td>25.8</td>
<td>72.1%</td>
<td>5.47</td>
<td>100.3</td>
<td>5.3</td>
<td>26.9</td>
<td>0</td>
<td>488</td>
</tr>
<tr>
<td>September</td>
<td>26.0</td>
<td>74.9%</td>
<td>6.06</td>
<td>100.3</td>
<td>4.7</td>
<td>27.4</td>
<td>0</td>
<td>478</td>
</tr>
<tr>
<td>October</td>
<td>26.4</td>
<td>77.9%</td>
<td>6.27</td>
<td>100.2</td>
<td>3.7</td>
<td>28.5</td>
<td>0</td>
<td>506</td>
</tr>
<tr>
<td>November</td>
<td>26.5</td>
<td>82.3%</td>
<td>5.76</td>
<td>100.1</td>
<td>3.2</td>
<td>29.2</td>
<td>0</td>
<td>493</td>
</tr>
<tr>
<td>December</td>
<td>26.5</td>
<td>82.7%</td>
<td>5.33</td>
<td>100.1</td>
<td>3.2</td>
<td>29.1</td>
<td>0</td>
<td>510</td>
</tr>
</tbody>
</table>

| Annual   | 26.4            | 78.7%             | 5.40                             | 100.2                 | 4.4       | 28.3              | 0                   | 5979               |
| Measured at (m) | 10.0 | 0.0 |

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Solar Project Design
20 Mwp Solar IPP Lombok (sample case)
Solar Project Design
20 Mwp Solar IPP Lombok (sample case)
Solar Project Design
20 Mwp Solar IPP Lombok (sample case)

### System Sizing
- **Specify desired array size**
  - Desired array size: 20,000 kWdc
  - DC to AC ratio: 1.10

- **Specify modules and inverters**
  - Modules per string: 22
  - Strings in parallel: 4,000
  - Number of inverters: 20

### Configuration at Reference Conditions
**Modules**
- Nameplate capacity: 24,653,006 kWdc
- Number of modules: 88,000
- Modules per string: 22
- Strings in parallel: 4,000
- Total module area: 139,6560 m²
- String Voc: 851.4 V
- String Vmp: 699.6 V

**Inverters**
- Total capacity: 20,000,000 kWac
- Number of inverters: 20
- Maximum DC voltage: 1,000 Vdc
- Minimum MPPT voltage: 470 Vdc
- Maximum MPPT voltage: 900 Vdc

**Sizing messages** (see Help for details):
- Actual DC to AC ratio is 1.23.
- Voltage and capacity ratings are at module reference conditions shown on the Module page.

### DC Subarrays
To model a system with one array, specify properties for Subarray 1. Disable Subarrays 2, 3, and 4. To model a system with up to four subarrays connected in parallel to a single bank of inverters, enable and specify a number of strings and other properties.

#### String Configuration
- Strings in array: 4,000
- Strings allocated to subarray: 4,000

#### Tracking & Orientation
- **Azimuth**: N=0
- **Tilt**: Vert.
Solar Project Design
20 Mwp Solar IPP Lombok (sample case)
Solar Project Design
20 Mwp Solar IPP Lombok (sample case)

- Shading and Snow Losses
  Use the shade calculator to draw a 3D representation of the photovoltaic system and nearby objects. The calculator generates a diagram table of shading losses and automatically populates the shading factors table for each subarray in the system. (For systems with more than one subarray, use the group name in the shade calculator to identify subarrays.) See help for details.

- System Design
<table>
<thead>
<tr>
<th>Subarray 1</th>
<th>Subarray 2</th>
<th>Subarray 3</th>
<th>Subarray 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules in subarray (from System Design page)</td>
<td>86,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GCR (from System Design page)</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Number of modules along side of row</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Number of modules along bottom of row</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

- External Shading
  Module area (from Module page) | 1,387.0 m²

- Self Shading
  Shading mode | None | None | None | None

- Snow Coverage
  Module orientation | Portrait | Portrait | Portrait | Portrait
  Estimate losses due to snow
  Enables to activate estimation of snow coverage losses for the designed system. This requires that the provided weather file contains hourly (or sub-hourly) snow depth data in units of cm. Depth values outside the range of 0 - 600 cm are considered erroneous.
Solar Project Design
20 Mwp Solar IPP Lombok (sample case)

### DC Losses

<table>
<thead>
<tr>
<th></th>
<th>Subarray 1</th>
<th>Subarray 2</th>
<th>Subarray 3</th>
<th>Subarray 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soiling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monthly soiling loss</td>
<td>Edit values...</td>
<td>Edit values...</td>
<td>Edit values...</td>
<td>Edit values...</td>
</tr>
<tr>
<td>Average annual soiling loss</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Loss Percentages</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mismatch</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Diodes and connections</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>DC wiring</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Tracking error</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nameplate</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DC power optimizer loss</td>
<td>All four subarrays are subject to the same DC power optimizer loss.</td>
<td>All four subarrays are subject to the same DC power optimizer loss.</td>
<td>All four subarrays are subject to the same DC power optimizer loss.</td>
<td>All four subarrays are subject to the same DC power optimizer loss.</td>
</tr>
<tr>
<td><strong>Total DC power loss</strong></td>
<td><strong>4,440</strong></td>
<td><strong>4,440</strong></td>
<td><strong>4,440</strong></td>
<td><strong>4,440</strong></td>
</tr>
</tbody>
</table>

*The total DC power loss is 100\% \times (1 - \text{the product of (1 - loss/100\%)}), not the sum of the percentages. See Help for details.*

### AC Losses

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC wiring</strong></td>
<td>1 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step-up transformer</strong></td>
<td>0 %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total AC power loss</strong></td>
<td><strong>1 %</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Total AC loss = 100\% \times (1 - \text{AC wiring/100\%}) \times (1 - \text{transformer/100\%}).*

### Curtailment and Availability

Curtailment and availability losses reduce the system output to represent system outages or other events.

Constant loss: 0.0 %

Hourly losses: None

Custom periods: None
### Solar Project Design

#### 20 Mwp Solar IPP Lombok (sample case)

**Direct Capital Costs**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>kWdc/unit</th>
<th>kWdc</th>
<th>$/Wdc</th>
<th>$/m²</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>88,000</td>
<td>0.3</td>
<td>24,653.9</td>
<td>0.50</td>
<td>0.49</td>
<td>$12,326,953.00</td>
</tr>
<tr>
<td>Inverter</td>
<td>20</td>
<td>1,000.0</td>
<td>20,000</td>
<td>0.15</td>
<td>0.10</td>
<td>$3,000,000.00</td>
</tr>
</tbody>
</table>

**Balance of system equipment**: 0.00  
**Installation labor**: 0.00  
**Installer margin and overhead**: 0.00  
**Subtotal**: $33,570,844.00

**Contingency**

<table>
<thead>
<tr>
<th>Contingency</th>
<th>% of subtotal</th>
<th>$</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3%</td>
<td></td>
<td>$1,007,125.25</td>
<td>$34,577,968.00</td>
</tr>
</tbody>
</table>

**Total direct cost**: $34,577,968.00

**Indirect Capital Costs**

<table>
<thead>
<tr>
<th>Item</th>
<th>% of direct cost</th>
<th>$/Wdc</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permitting and environmental studies</td>
<td>0</td>
<td>0.01</td>
<td>$246,539.03</td>
</tr>
<tr>
<td>Engineering</td>
<td>0</td>
<td>0.02</td>
<td>$493,078.06</td>
</tr>
<tr>
<td>Grid interconnection</td>
<td>0</td>
<td>0.03</td>
<td>$739,617.13</td>
</tr>
</tbody>
</table>

**Land Costs**

<table>
<thead>
<tr>
<th>Item</th>
<th>$/acre</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land area</td>
<td>$115.0</td>
<td>$0.00</td>
</tr>
<tr>
<td>Land purchase</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Land preparation</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

**Sales Tax**

<table>
<thead>
<tr>
<th>Sales tax basis</th>
<th>Sales tax rate</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>5.0 %</td>
<td>$1,728,828.38</td>
</tr>
</tbody>
</table>

**Total indirect cost**: $3,701,210.75

**Total Installed Cost**

- The total installed cost is the sum of the direct and indirect costs. Note that it does not include any financing costs from the Financial Parameters page.

<table>
<thead>
<tr>
<th>Total installed cost per capacity</th>
<th>$1.55/Wdc</th>
</tr>
</thead>
<tbody>
<tr>
<td>$38,279,180.00</td>
<td></td>
</tr>
</tbody>
</table>
Solar Project Design
20 Mwp Solar IPP Lombok

- Nominal POA (kWh)
  - 300,401,856

- Nominal DC energy (kWh)
  - 50,379,324

- Net DC energy (kWh)
  - 43,377,320

- Gross AC energy (kWh)
  - 42,294,832

- Annual energy (kWh)
  - 41,871,884
Solar Project Design
20 Mwp Solar IPP Lombok (sample case)
Solar Project Design
20 Mwp Solar IPP Lombok (sample case)
## Single Owner Inputs

<table>
<thead>
<tr>
<th>SYSTEM DESIGN</th>
<th></th>
<th>KEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nameplate capacity (kW)</td>
<td>24,653.90</td>
<td>Calculated</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SYSTEM COSTS</th>
<th></th>
<th>Input from SAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total installed cost ($)</td>
<td>39,074,344</td>
<td>SAM result</td>
</tr>
</tbody>
</table>

### SYSTEM COSTS

<table>
<thead>
<tr>
<th>METRICS</th>
<th></th>
<th>Value depends on option in SAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total installed cost ($)</td>
<td>39,074,344</td>
<td></td>
</tr>
</tbody>
</table>

### OPERATION AND MAINTENANCE COSTS

<table>
<thead>
<tr>
<th>METRICS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed annual cost ($/yr)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Escalation (% above inflation)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Fixed cost by capacity ($/yr)</td>
<td>15.00</td>
<td></td>
</tr>
<tr>
<td>Escalation (% above inflation)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Variable cost by generation ($/MWh)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Escalation (% above inflation)</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

### FUEL COSTS (CSP, GENERIC, AND BIPOWER SYSTEMS ONLY)

<table>
<thead>
<tr>
<th>METRICS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (CSP and generic system only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual usage (kWh)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Heat rate (MMBtu/MWh)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Cost ($/MMBtu)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Escalation (%/year above inflation)</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>METRICS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass feedstock (biopower system only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual usage (dry ton)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Cost ($/dry ton)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Escalation (%/year above inflation)</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>METRICS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal feedstock (biopower system only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual usage (dry ton)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Cost ($/dry ton)</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Escalation (% above inflation)</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

"n/a" indicates O&M costs entered as annual values. See "ANNUAL VALUES" below.


---

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| Slide 36 |
## Solar Project Design
### 20 Mwp Solar IPP Lombok (sample case)

### FINANCIAL PARAMETERS

<table>
<thead>
<tr>
<th>Solution Mode</th>
<th></th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRR Target</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPA price ($/kWh)</td>
<td></td>
<td>0.18</td>
</tr>
<tr>
<td>PPA price escalation (%/year)</td>
<td></td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analysis Parameters</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis period (years, 40 max)</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Inflation rate (%/year)</td>
<td></td>
<td>2.50</td>
</tr>
<tr>
<td>Real discount rate (%/year)</td>
<td></td>
<td>5.50</td>
</tr>
<tr>
<td>Nominal discount rate (%/year)</td>
<td></td>
<td>8.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tax and Insurance Rates</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal income tax rate (%/year)</td>
<td></td>
<td>35.00</td>
</tr>
<tr>
<td>State income tax rate (%/year)</td>
<td></td>
<td>7.00</td>
</tr>
<tr>
<td>Sales tax (% of total direct cost)</td>
<td></td>
<td>5.00</td>
</tr>
<tr>
<td>Insurance rate (annual, % of installed cost)</td>
<td></td>
<td>0.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property Tax</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessed percentage (% of total installed cost)</td>
<td></td>
<td>100.00</td>
</tr>
<tr>
<td>Assessed value ($)</td>
<td></td>
<td>39,074,344.00</td>
</tr>
<tr>
<td>Annual decline (%/year)</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>Property tax rate (%/year)</td>
<td></td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Salvage Value</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Net salvage value (% of total installed cost)</td>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>End of analysis period value ($)</td>
<td></td>
<td>0.00</td>
</tr>
</tbody>
</table>

### PROJECT TERM DEBT

<table>
<thead>
<tr>
<th>Debt sizing mode</th>
<th></th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debt percent (mortgage style with constant payments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of debt for mortgage style</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Debt service coverage ratio (sculpted payments with constant DSCR)</td>
<td></td>
<td>1.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Debt Parameters</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenor (years)</td>
<td></td>
<td>18.00</td>
</tr>
<tr>
<td>Annual all-in interest rate (%)</td>
<td></td>
<td>7.00</td>
</tr>
<tr>
<td>Debt closing costs ($)</td>
<td></td>
<td>450,000</td>
</tr>
<tr>
<td>Up-front fee (% of total debt)</td>
<td></td>
<td>2.75</td>
</tr>
<tr>
<td>Up-front fee amount ($, from SAM results)</td>
<td></td>
<td>1,254,230</td>
</tr>
</tbody>
</table>

### COST OF ACQUIRING FINANCING

| Financing cost ($) |                          | 0.00       |

### CONSTRUCTION FINANCING

| Total construction financing cost ($) |                          | 781,487.00 |

---

Mortgage-style size of debt is the product of the debt fraction and total capital cost. The total capital cost includes debt service reserve funding and debt up-front costs, which are both calculated from the size of debt value. To calculate the value, SAM uses a two-step iteration that is not possible to replicate in this workbook using static formulas.
### Solar Project Design
**20 Mwp Solar IPP Lombok (sample case)**

#### Annual Values

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual energy (AC kWh)</td>
<td>0</td>
<td>41,871,884</td>
<td>41,663,524</td>
<td>41,454,212</td>
<td>41,246,940</td>
<td>41,040,704</td>
<td>40,835,500</td>
<td>40,631,324</td>
</tr>
<tr>
<td>PPA price</td>
<td>0.000</td>
<td>18,000</td>
<td>18,000</td>
<td>18,000</td>
<td>18,000</td>
<td>18,000</td>
<td>18,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Annual PPA revenue ($)</td>
<td>0</td>
<td>7,536,940</td>
<td>7,499,250</td>
<td>7,461,760</td>
<td>7,424,450</td>
<td>7,387,227</td>
<td>7,350,300</td>
<td>7,313,640</td>
</tr>
</tbody>
</table>

**Operation and maintenance costs specified as annual values**

- **Fixed**
- **Fixed Cost ($/DC kWh)**
- **Variable Cost ($/AC kWh)**

**TOTAL Energy 25 years (AC kWh)** 985,332,044

**TOTAL PPA revenue 25 years (US$)** 177,539,769
SLD – Draft for Central and String inverter
(** Not Price offering / Quotation..!!)
Global CoC Microgrids

Smart System/Microgrid Solutions
Technology and Capabilities
Microgrid Definition

Integrated energy system consisting of distributed energy resources and multiple electrical loads operating as a single, autonomous grid either in “grid-connected” or “off-grid” mode with respect to the existing utility power grid.

A power system where any single load or generator can effect every load or generator.
Off Grid Microgrid
The goal is not 100% renewable energy

- Sweet Spot
- Need for Integration Technology

- Source: HOMER ENERGY Newsletter 06-2013
Off Grid Microgrids
Managing renewable power output fluctuations

- Inherent volatility of renewable energy can compromise grid stability
- The renewable energy integration solution must address requirements traditionally fulfilled by diesel generation (base load)
  - Frequency and voltage control
  - Sufficient spinning reserve
  - Sufficient active and reactive power supply
  - Peak shaving and load levelling
  - Load sharing between generators
  - Fault current provision
- Renewable energy generation capacity should be sized to maximize ROI and fuel savings

ROI: Return on investment
# Microgrid Technologies
## Energy Contribution versus Power Penetration

<table>
<thead>
<tr>
<th>Microgrid Integration Technologies</th>
<th>Average Renewable Energy Contribution</th>
<th>Maximum Renewable Power Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>No integration technology</td>
<td>7 - 10%</td>
<td>20 – 30%</td>
</tr>
<tr>
<td>Power control &amp; Optimization (GEN+RE)</td>
<td>10 - 15%</td>
<td>20 – 50%</td>
</tr>
<tr>
<td>Microgrid stabilising (high power; low energy)</td>
<td>25 - 40%</td>
<td>100%</td>
</tr>
<tr>
<td>Power control &amp; Optimization (Gen+RE+Load)</td>
<td>60 - 80%</td>
<td>100%</td>
</tr>
<tr>
<td>Energy storage (low power; high energy)</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

- **Note:** Percentages vary between wind/diesel and solar/diesel
- **Energy contribution is the measure for fuel savings**
Microgrid Solutions
Peace of mind from ABB

ABB technology enables medium and high penetration of up to 100% into diesel microgrids

- **Proven Technology:**
  - 15+ years Microgrid Plus System
  - 10+ years PowerStore synthetic inertia stabilisation system

- **Expertise in engineering and consulting**
  - 25+ years of system design, modelling and optimization
  - Highest number of projects integrating renewables into microgrids worldwide.
  - Global centre of competence based in Australia
  - Continous incremental development to modern technology
  - Experience with both Wind and Solar projects in challenging remote areas (WA, Antarctica)

- **Supported by Global ABB R&D**
  - Productisation and testing in ABB Test Facilities prior to deployment
  - Global research support with selecting new technologies e.g. battery technology
  - Strength of ABB R&D to support any unknown scenarios
  - Product Lifecycle support.
### Microgrid Plus system

- Distributed control system designed to efficiently and reliably manage power generated from multiple energy resources
- Maximizes fuel savings
- Optimizes use of renewable energy
- Guarantees optimum loading and spinning reserve in fossil fuel generators
- Distributed logic enhances reliability and scalability for future system expansions

### PowerStore

- Containerized system that includes an energy stabilization or storage system and a power electronics interface
- Can be used in isolated grids or in grid support mode
- Maximizes fuel savings through highest possible renewable penetration
- Ensures high power quality by stabilizing renewable energy generation
Microgrid Plus Automation & Optimisation System Design criteria

- **Main application Design Criteria:**
  - Minimise fuel consumption
  - Maximise average renewable penetration
  - Account for availability and maintenance features of all possible Generation and Energy Storage devices
  - Delivering stable, safe and reliable “utility quality” power supply

- **Main system Design Criteria:**
  - Simple, non-proprietary I/Os to fit all common conventional and renewable power generation control systems
  - Non-invasive functional overlay to existing control systems
  - Ability to introduce system functionality progressively into an existing Microgrid (first monitor, then dispatch, then control)
  - Distributed, fault-tolerant, scalable control application, easy design and extension of distributed system by configuring the application
Networked Power Control & Optimization System
Microgrid Plus System

- Retrofit to any existing diesel/gas plant
- Integrate generators and loads
- Uses simple non proprietary Interface
- Configuration by Power System Engineers
Technology: Microgrid Plus
Networked System Architecture

Microgrid Plus System

Local Area Network (Microgrid Plus Protocol)
Technology: Microgrid Plus
Hardware and Software, Control & System Operation

- Simple, unified Hardware MGC600
- Each controller gets “impressed” with specific software implementing a set of functionalities specific to the type of the attached generator or load
- Coordination via broadcast of status information between controller only
Technology: Microgrid Plus
Distributed functionalities

- Ideal Loading Power Set point
- Intermittency Support
- Power Station Black Start
- Step Load Requirements
  - Proactive Load
  - kW / kVAr sharing
  - Reclose
- Spinning Reserve Requirements
  - kW / kVAr sharing
  - Mgmt.
- Overload Support
- Many more . . .
MGC600 Controller
The Generator Controller MGC600-G

Monitoring
- Power measurement of key values
- High resolution data recording
- Interface to M+ Operations
- Publishing of values into M+ System

Automation
- Automatic start/stop control
- Automatic Blackstart capable
- Interface to C/B Protection Relay

Control
- Power Management
- kW, kVar load sharing
- Frequency Drift Time Correction
- Plant dispatch control
Microgrid Stabilising using Flywheel or Battery

PowerStore Grid Stabilising System

fast

absorb inject
Microgrid technology solutions
PowerStore – Grid Stabilising System - Battery

Features:
- Grid Stabilising
- Scalable & Modular
- Frequency Control
- Introducing SYNTHETIC INERTIA
- Voltage Control
- Fault ride through
- Grid forming
- 1.5MW in 40ft container

Inverters 100– 1,500 kVA

1 MWhr Li Ion Battery

© ABB Group CONFIDENTIAL April 16, 2015
PowerStore-Flywheel Construction

- Two main parts: flywheel and skid assembly
- Flywheel consists of 2.9T spinning mass and integrated drive motor
- Skid assembly consists of cabinets that build up the inverter drive chain and control equipment
- Inverter drive housed in converter racks
PowerStore-Flywheel

Performance Data:
- Net energy content: 15.2-18 MWs
- Max. input/output power: 1650 kW
- Speed range: 1800 to 3600 rpm
- Total weight: 6000 kg
- Rotor weight: 2900 kg
- Idling losses: 12 kW
- Greasing frequency: 5 years
- Bearing service life: 8 years

Features:
- Helium filled
- Magnetic support
- Redundant bearings
Technology: PowerStore-Flywheel
1000kVA PowerStore-Flywheel System Schematic
PowerStore-Battery
Construction

- Two main parts: batteries and skid assembly
- Skid assembly consists of cabinets that build up the inverter drive chain and control equipment
- Inverter drive housed in converter racks
Technology: PowerStore-Battery
PowerStore Grid Stabilisation

Power Converters

- Power Converters are used for both the PowerStore-Flywheel and the PowerStore-Battery
- Based on the ABB PCS100
- Converter pairs (flywheel and grid) are housed in racks
- Depending on the size of PowerStore different size racks are used
- Racks are suitable for indoor installation only
# Grid Stabilisation versus Energy Storage

<table>
<thead>
<tr>
<th>Application</th>
<th>Time Frame</th>
<th>Energy</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Standalone (diesel off)</td>
<td>millisec</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>2 Stabilize (f,V support)</td>
<td>seconds</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>3 Statcom (Power Quality)</td>
<td>seconds</td>
<td>zero</td>
<td>high</td>
</tr>
<tr>
<td>4 Spinning Reserve</td>
<td>seconds/minutes</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>5 Smoothing (Renewable Energy)</td>
<td>minutes</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>6 Shaping (Peak Lopping)</td>
<td>minutes/hours</td>
<td>medium</td>
<td>Low</td>
</tr>
<tr>
<td>7 Shifting (Load levelling)</td>
<td>hours</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>
Powerstore Energy Storage Technology

ABB is the integration provider but does not create the energy storage technology.

ABB Powerstore has same capabilities with both battery and flywheel components. Differences are in energy storage capacity, system size and associated capex.

Powerstore Flywheel sub-supplied by Piller Power Systems.

Powerstore Battery provided in consortium agreement Samsung SDI.

New energy storage systems able to be investigated and integrated by ABB.
PowerStore Control Modes

Virtual Generator (Grid Forming)

PowerStore operates like a diesel/gas synchronous generator with
- Isochronous/droop Frequency & Voltage Control
- Proportional kW loadsharing
- Proportional kvar loadsharing
- Proportional energy sharing
- Fault ride through & fault current
- Standalone or parallel operation with other generators

Grid Support (Grid Following)

PowerStore responds to frequency and voltage changes in the network
- Frequency & Voltage support
- Fault ride through
- External Power/Reactive power setpoint
- Parallel operation with other generators
PowerStore Grid Support

Before
- No PowerStore

After
- With PowerStore
Microgrid technology solutions
PowerStore – Grid Support
PowerStore Virtual Generator
Field Testing: 850 kW load steps

- 850kW ON
- 850kW OFF
Technology: Microgrid Plus
Networked System Architecture – SCADA and HMI
M+ Operations
Typical communication system

Point to point connections
Managed by gateway
Connection to external SCADA through TCP/IP connection
M+ Operations
Functionality

- Data acquisition of all monitored points from the connected MGC600s
- Maintenance-free, high resolution trending
- Modbus Master and Slave interface functions
- Web based visualisation packages
- Remote firmware update and parameter configuration for MGC600 devices
- Local and remote access to all power station data
- Operator plant control through HMI
Microgrid Plus System
Hardware components

- **Industrial PC (IPC)** is designed to gather information from the Microgrid Plus System. There is one per system, collecting and storing information periodically.

- **Ethernet Router Gateway** provides remote communications to the System’s network over a variety of interfaces. The router also has a time server function which obtains a reference time from GPS satellites and then broadcasts this as the authoritative time on the network. All of the devices on the network are then able to synchronise to this time source.

- **M+ Operations HMI** is a web browser interface which allows:
  - Monitoring of data points;
  - Parameter setting;
  - Issue operator control commands (like remote start, stop, etc.);
  - Display real-time and historical trending of analogue and digital signals;
  - Alarm and / or event reporting;
  - Generator priority scheduling
Microgrids Project Development
Tools & Support from Concept to Commissioning

- ABB has many years of experience integrating renewable energy sources in technically-challenging Microgrids, and this experience combined with strict adherence to industry-accepted modelling and design tools, and power systems standards, is the foundation of ABB’s consulting offering.

- Making the right economic and technical decisions can be difficult, but using sophisticated simulation tools, ABB can tailor a solution to fit specific wind and solar conditions, commercial considerations and technical requirements.

- To start, ABB consultants evaluate design options for both off-grid and grid-connected distributed generation applications. Optimisation and sensitivity analysis algorithms evaluate the economic feasibility of many technology options, and account for cost variations and energy resource availability. In addition to thorough economic analysis, ABB provides a strong technical consulting capability, including flexible, dynamic simulation tools that produce extremely accurate grid models.

- ABB’s Microgrid Solutions’ experience with remote power generation is constantly helping to improve the tools and design process in these studies, while an experienced engineering team guarantees the end result is a high-quality, technically-detailed project simulation. ABB verifies its models with data taken from similar completed, commissioned projects; this helps to identify problems in the simulation process, and increases the accuracy of future models.

- In this way, ABB consultants can rely on real-world experience and working systems to ensure the most valid simulation models are delivered.
Microgrids Project Development
Tools & Support from Concept to Commissioning

1. Initial Consultation
   - Microgrid suitability using FOYER analysis tool
     - Basic case study analysis
   - Basic renewable resource investigation
   - Initial report creation

2. Microgrid Analysis
   - Microgrid analysis using HOMER Microgrid tool;
     - Energy Flow Analysis
     - Microgrid configuration modeling;
       - Renewable Resource configuration
       - On Grid/Off Grid comparison
       - Backup Diesel generation configuration
       - Powerstore Energy Storage configuration
     - Case study simulations involving different Microgrid configurations
   - Renewable Resource investigation and monitoring system proposals
   - Financial and Economic Modeling
   - Analysis of Microgrid integration into existing power systems
   - Creation of Reports and Results of Simulations and Studies with conclusions and suggested Microgrid configurations.

3. Microgrid Detailed Design
   - Encompassed in contracted works to construct the selected solution
   - Microgrid Power System Analysis
     - Steady-state Study
     - Dynamic Study
   - Microgrid power system protection studies
   - Detailed Report creation

NB: Scope of consulting limited to investigation of selected scenarios. Analysis of vast integrated power networks for suitable energy storage integration not currently provided as a consulting service.
Microgrids Project Development
Tools & Support from Concept to Commissioning
Microgrids Project Development
Prefeasibility Study: Select Option and proof viability

> 100,000 Users worldwide

Integration Plugin
Microgrids Project Development
Tools & Support from Concept to Commissioning

- Feasibility studies to find optimal system type

- Load Flow, Dynamic stability & Protection studies
  - Real and Reactive Power Flow Calculations
    - Loading of cables, transformers, turbines and other equipment
    - Sizing of components
  - Dynamic stability investigation
    - Power system transient behavior
  - Short Circuit Calculations
    - Selection of protection relays
    - Identification of protection parameters
    - Design of system protection philosophy with a focus on distributed RE
Three key Integration Technologies
Feasibility Study: Definition and Planning

Interfaces
- What interfaces are available?
- How can I interface to the plant?

Grid Stability
- When do I need it?
- How much is required?

Automation & Control Software
- How do I best control the system?
- How to determine performance?
Feasibility Study: Grid Stabilising Technology
Taking diesel generators offline

System Studies to determine/confirm
- Power versus Energy ratings
- Choice of storage technology
- Protection Settings
- Control Settings
- Grid connection requirements

Key parameters for studies
- Use of verified plant models
- Understanding critical assumptions
- System acceptance criteria
Feasibility Study: Automation & Control Software

Optimise Hybrid System Performance

Integration System Platform
- Modular and expandable
- Use of type tested software with customized interfaces
- Use of verified Integration System Models to reduce risk

Operation and Control
- Use of Parameters to optimize plant operation remotely
- Compare site data versus modelled data to optimize performance
Project References
Solar Rooftop Project – 10 Kwp System
Finished Installation (66 Kw System)
Finished Installation (Grid Tie Inverter)
Finished Installation (50 Kw System)
ABB solar inverter example cases

Bulgaria, Popeda: 50,6 MWp PV plant

- **System description**
  - PV plant: 50,6 MWp
  - Application: ground-mounted power plant
  - Grid connection: 110/20 kV grid
  - Solar modules: cSi

- **Solution**
  - PVS800: 86 pcs 500 kW
  - Locally manufactured 2 MW housings with 2 x 1000 kVA transformers, 20 kV switchgear and 4 inverters
  - 20/110kV step-up substation and rehabilitation of surrounding 110kV grid
  - Service contract for maintenance
  - Commissioning June 2012

**Customer:**
Investor looking for reliable supplier with local presence
ABB solar inverter example cases
Bulgaria, Cherganovo: 29,3 MWp PV plant

- **System description**
  - PV plant: 29,3 MWp
  - Application: ground mounted power plant
  - Grid connection: 110 kV/20kV
  - Solar modules: poly-csi

- **Solution**
  - 52 pcs of PVS800-0500kW-A
  - Locally manufactured 2 MW housings with 2 x 1000 kVA transformers, 20 kV switchgear and 4 inverters
  - 20/110kV step-up substation and rehabilitation of surrounding 110kV grid
  - Service contract for maintenance
  - Commissioning June 2012
ABB solar inverter example cases

India, Mithapur: 17 MW PV plant

- **System description**
  - PV plant: 17 MWp
  - Application: ground mounted power plant
  - Grid connection: MV grid
  - Solar modules: poly-csi

- **Solution**
  - 34 pcs of PVS800-0500kW-A
  - ABB’s string monitoring junction boxes with SCADA system
  - Commissioning: January 2012

**Customer:**
An EPC and power company that was looking for reliable supplier with local presence
ABB solar inverter example cases

India, Gujarat: 15 MW PV plant

- **System description**
  - PV plant: 15 MW
  - Application: ground mounted power plant
  - Grid connection: MV grid
  - Solar modules: thin-film, Cd-Te

- **Solution**
  - 29 pcs of PVS800-0500kW-A
  - ABB’s string monitoring junction boxes with SCADA system
  - Commissioning: February 2012

**Customer:** An EPC and that was looking for reliable supplier with local presence
ABB solar inverter example cases

Germany: 13,1 MWp PV plant

- System description
  - PV plant: 13,1 MWp section of 91 MWp plant
  - Application: ground mounted power plant
  - Grid connection: 20 kV
  - Solar modules: poly-csi

- Solution
  - 9 pcs of PVS800-MWS-1250kW-20
  - Skytron monitoring system
  - Commissioning: December 2011

Customer:
a large plant developer and system integrators looking for reliable supplier with rapid response and local presence
**ABB solar inverter example cases**

**Thailand, BSP Ubonrachathani : 5 MWp PV plant**

- **System description**
  - PV plant: 5 MWp
  - Application: ground mounted
  - Grid connection: MV grid, 22 kV
  - Solar modules: a-Si single junction

- **Solution**
  - PVS800: 9 x 500 kW
  - Solar inverter complete care, 5 years
  - LV products, SCADA system, MV switchgear
  - Commissioning: March 2012

**Customer:**
Investor looking for reliable SI with proven components
### ABB solar inverter example cases

**Italy, Borgo Montello: 3 MWp PV plant**

<table>
<thead>
<tr>
<th>System description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV plant: 3 MWp kWp</td>
</tr>
<tr>
<td>Application: ground mounted power plant</td>
</tr>
<tr>
<td>Grid connection: MV grid</td>
</tr>
<tr>
<td>Solar modules: poly-csi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVS800: 12 x 250 kW</td>
</tr>
<tr>
<td>ABB transformer and switchgear</td>
</tr>
<tr>
<td>ABB Inverter and MV housing</td>
</tr>
<tr>
<td>ABB monitoring system</td>
</tr>
<tr>
<td>Commissioning: May 2011</td>
</tr>
</tbody>
</table>

**Customer:**
Investor looking for secured return of investment and one-stop shopping

© ABB Group
November 30, 2016 | Slide 92
**System description**
- PV plant: 1.4 MWp
- Application: ground mounted
- Grid connection: MV grid, 22 kV
- Solar modules: a-Si single junction

**Solution**
- PVS800: 2 x 500 kW + 250 kW (negative grounding, 1000 Vdc)
- Solar inverter complete care, 10 years
- String monitoring junction boxes, LV products, SCADA system
- Commissioning: November 2011
ABB solar inverter example cases
Thailand, ENERQ Phase 3: 1,4 MWp PV plant

- System description
  - PV plant: 1,4 MWp
  - Application: ground mounted
  - Grid connection: MV grid, 22 kV
  - Solar modules: poly crystalline

- Solution
  - PVS800: 2 x 630 kW
  - Solar inverter complete care, 10 years
  - String monitoring junction boxes, LV products, SCADA system
  - Commissioning: May 2012
### ABB solar inverter example cases
**Slovakia, Sirkovce: 1 MWp PV plant**

<table>
<thead>
<tr>
<th>System description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV plant: 1 MWp</td>
</tr>
<tr>
<td>Application: ground mounted power plant</td>
</tr>
<tr>
<td>Grid connection: MV grid, 22 kV</td>
</tr>
<tr>
<td>Solar modules: poly-cSi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVS800: 4 x 250 kW</td>
</tr>
<tr>
<td>Transformer: ABB, oil</td>
</tr>
<tr>
<td>Switchgear: ABB</td>
</tr>
<tr>
<td>Commissioning: August 2010</td>
</tr>
</tbody>
</table>

**Customer:** Investor wanting reliable supplier with full offering to guarantee return of investment
ABB solar inverter example cases
India, Osmanabad: 1 MW PV plant

- System description
  - PV plant: 1 MWp
  - Application: ground mounted power plant
  - Grid connection: MV grid
  - Solar modules: poly-csi

- Solution
  - 2 pcs of PVS800-0500kW-A
  - ABB’s string monitoring junction boxes with SCADA system
  - Commissioning: July 2011

Customer:
An investor looking for reliable supplier with local presence
ABB solar inverter example cases

India, Mailadudhurai: 1 MW PV plant

- System description
  - PV plant: 1 MWp
  - Application: ground mounted power plant
  - Grid connection: MV grid
  - Solar modules: poly-csi

- Solution
  - 2 pcs of PVS800-0500kW-A
  - ABB’s string monitoring junction boxes with SCADA system
  - Commissioning: August 2011

Customer:
An investor looking for a reliable supplier with local presence
System description

- PV plant: 750 kWp
- Application: machinery workshop flat roof
- Grid connection: MV grid
- Solar modules: poly-csi

Solution

- PVS800: 2 x 250 kW + 100 kW
- Commissioning: June 2010
Taiwan: 475 kWp PV plant

System description
- PV plant: 475,2 kWp
- Application: factory roof
- Grid connection: MV grid, 22 kV
- Solar modules: poly-cSi

Solution
- PVS800: 2 x 250 kW
- Commissioning: May 2011

Customer:
Investor looking for reliable SI with proven components
ABB solar inverter example cases

Taiwan: 238 kWp PV plant

- **System description**
  - PV plant: 238 kWp
  - Application: factory roof
  - Grid connection: MV grid, 22 kV
  - Solar modules: poly-cSi

- **Solution**
  - PVS800: 1 x 250 kW
  - Commissioning: April 2011

**Customer:** Investor looking for reliable SI with proven components
ABB solar inverter example cases

Australia, Harvey bay: 266 kWp PV plant

- **System description**
  - PV plant: 266 kWp
  - Application: Hospital roof-top system
  - Grid connection: LV grid, 230/400 V
  - Solar modules: mono-cSi

- **Solution**
  - PVS300: 26 x 8 kW and 12 x 4,6 kW
  - ABB metering and low voltage products
  - Commissioning: July 2012

Customer: Queensland Health wanting to reduce the bought energy of the hospital in Harvey Bay
ABB solar inverter example cases
Finland, Pitäjänmäki: 181 kWp PV plant

- **System description**
  - PV plant: 181 kWp
  - Application: factory flat roof
  - Grid connection: LV grid, 400 V
  - Solar modules: poly-cSi

- **Solution**
  - PVS800: 1 x 120 kW
  - PVS300: 7 pcs
  - Commissioning: June 2010
ABB solar inverter example cases
Japan: 116 kWp PV plant

- System description
  - PV plant: 116 kWp
  - Application: flat roof system on industrial building
  - Grid connection: MV grid, 6,6 kV
  - Solar modules: poly Si

- Solution
  - 1 pcs of PVS800-0100kW-A
  - Inverter mounted in an outdoor enclosure
  - ABB Junction boxes with monitoring, PVS-JB-8-M
  - ABB remote monitoring portal
  - Commissioning: August 2012

Customer:
Property management of ABB Robotics factory in Shizuoka Japan.
### ABB solar inverter example cases

**Italy: 96 kWp PV plant**

<table>
<thead>
<tr>
<th>System description</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV plant: 96 kWp</td>
<td>PVS300: 12 x 8 kW, with power balancing (3 inverters)</td>
</tr>
<tr>
<td>Application: roof-top system on tilted factory roof</td>
<td>Commissioning: January 2012</td>
</tr>
<tr>
<td>Grid connection: LV grid, 230/400 V</td>
<td></td>
</tr>
<tr>
<td>Solar modules: poly-cSi</td>
<td></td>
</tr>
</tbody>
</table>

**Customer:** Office furniture factory owner wanting to improve their image and taking advantage of the FIT
ABB solar inverter example cases
France: 90 kWp PV plant

System description
- PV plant: 90 kWp
- Application: roof-top system on light aircraft hangar
- Grid connection: LV grid, 230/400 V
- Solar modules: poly-cSi

Solution
- PVS300: 9 x 8 kW + 3 x 4.6 kW, with power balancing (3 inverters)
- Commissioning: May 2011
ABB solar inverter example cases
Taiwan: 9,68 kWp PV plant

- System description
  - PV plant: 9,68 kWp
  - Application: sloping roof system on office building
  - Grid connection: LV grid, 230/400 V
  - Solar modules: cSi

- Solution
  - PVS300: 3 x 3,3 kW, with power balancing (3 inverters)
  - Commissioning: November 2011

Customer:
Company investing on solar for green image
Belgium: 4,59 kWp PV plant

- System description
  - PV plant: 4,59 kWp
  - Application: roof-top system on single family house
  - Grid connection: LV grid, 230 V
  - Solar modules: cSi, 18 x 255 Wp

- Solution
  - PVS300: 1 pcs 4,6 kW
  - Commissioning: November 2011

Customer: Private single family house owner
## ABB solar inverter example cases

### Switzerland, Mont Soleil: 555 kWp PV plant

<table>
<thead>
<tr>
<th>System description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV plant: 554.6 kWp</td>
</tr>
<tr>
<td>Application: ground mounted</td>
</tr>
<tr>
<td>Grid connection: MV grid</td>
</tr>
<tr>
<td>Solar modules: mono-cSi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pcs 500 kW (prototype)</td>
</tr>
<tr>
<td>Commissioning: January 1992</td>
</tr>
<tr>
<td>Extensively Monitored over 20 years</td>
</tr>
<tr>
<td>Still operating</td>
</tr>
</tbody>
</table>
References – Hybrid power plant
Marble Bar, PV/Diesel

Project name
Marble Bar

Country
Western Australia, Australia

Customer
Horizon Power
Government of WA

Completion date
2010

ABB solution
- PV/diesel Microgrid with PowerStore grid-stabilizing technology and Microgrid Plus System
- The resulting system consists of:
  - Diesel (4 x 320kW)
  - PV (1 x 300kW)
  - PowerStore-flywheel (1 x 500kW)
  - Microgrid Plus System

Customer benefits*
- Minimize diesel consumption, 405,000 liters of fuel saved annually
- Minimum environmental impact, 1,100 tonnes CO2 avoided annually
- Reliable and stable power supply
- 60% of the day time electricity demand is generated by the PV plant

About the project
Marble bar and Nullagine are the world`s first high penetration, solar photovoltaic diesel power stations

*For both Marble Bar and Nullagine projects
DeGrussa Mine - PV/Diesel

Project name
DeGrussa Copper-Gold Mine
Country
Australia
Customer
juwi Renewable Energy
Completion date
To be completed in 2016

ABB solution
- Integration of a new 10.6 megawatt (MW) solar PV field and a battery storage system with existing diesel generation to provide reliable base-load power.
- The resulting system consists of: PowerStore™ grid stabilization solutions (2 x 2 MW), solar inverter stations (5 x 2 MW), solar MV stations, a transformer (5 MVA) and the Microgrid Plus System

Customer benefits
- Expected diesel fuel saving is 5 million liters per year, cutting diesel consumption by 20%

About the project
- The new hybrid solar facility will be the largest integrated off-grid solar and battery storage plant in Australia.
- Once fully integrated, the plant will reduce CO2 emissions by 12,000 tons.
References – Hybrid power plant

Longmeadow, PV/Diesel/Battery

Project name
Longmeadow

Location
South Africa

Customer
Longmeadow Business Estate

Completion date
2016

About the project
The microgrid solution is for the 96,000 sqm facility houses hosting ABB South Africa’s headquarters as well as manufacturing facilities with around 1,000 employees. The innovative solution will help to maximize the use of solar energy and ensure uninterrupted power supply.

ABB solution

- PV/diesel microgrid with battery-based system to maximize solar contribution and ensure security of power supply at ABB’s premises in Johannesburg
- The resulting system consists of:
  - 750 kWdc rooftop PV plant, including ABB PV inverter
  - 1 MVA/380 kWh battery-based PowerStore
  - Microgrid Plus System

Customer benefits*

- Reliable and stable power supply
- Optimized renewable energy contribution to the facility
- Ability to island from the grid in case of an outage
- CO2 reduction: over 1,000 tons/year
- Up to 100% renewable energy penetration
Power and productivity for a better world™