Seven proven ways to improve LCoE in PV and Storage

New Gamesa Electric Proteus PV & BESS Inverters

PV Magazine & Gamesa Electric
Webinar May 3rd 2022 – 15:00 (CET +2)
With a worldwide installed capacity of over 118 GW, Siemens Gamesa Renewable Energy is a global technological leader in the wind industry with a presence in more than 90 countries.

Its end-to-end value chain expertise encompasses onshore and offshore wind turbine design, manufacturing, installation as well as cutting-edge service solutions.

- **Globally Installed (Sep 21)**: 120 GW
- **GW under Service (Sep 21)**: 79.2 GW
- **Order Book (Sep 21)**: € 32.5 B
- **Annual Revenue (Sep 21)**: € 10.2 B
- **Employees (Sep 21)**: 26,182
- **Worldwide presence**: >50 sales offices in 39 countries
Our facilities, our credentials

Spain

Bilbao
Headquarters

Reinosa
Wind Power
Hydroelectric

Valencia
Wind Power

Madrid
Wind Power
Photovoltaic
E. Storage
Power Quality
Drives & Converters

Brazil

Camaçari
Wind Power

India

Nellore
Wind Power
Photovoltaic

China

Tianjin
Wind Power

Dedicated Sales teams

USA
Photovoltaic
E. Storage

Australia
Photovoltaic
E. Storage

>4 GW Solar inverters
>29 GW Wind converters
8 Production centers
>900 Employees worldwide
268 M€ Turnover FY2020

**Product Overview**

**Gamesa Electric Proteus**

**Power Converters**
- Gamesa Electric Proteus PV
- Gamesa Electric Proteus PCS
- Gamesa Electric Proteus HYBRID
- Gamesa Electric Proteus DC-DC Converter

**Power Stations**
- Gamesa Electric Proteus PV Station
- Gamesa Electric Proteus HYBRID Station
- Gamesa Electric Proteus PCS Station

**Prebuilt Skids for batteries**
- Gamesa Electric STOR Skid

**Plant Controller**
- Gamesa Electric Orchestra
Gamesa Electric Proteus

The smart evolution of Utility-Scale Inverters

HIGHEST POWER DENSITY

HIGHEST EFFICIENCY

HIGHEST T RANGE

LONG LIFESPAN

9.4 MVA STATIONS
Lowering LCoE from the Inverter Perspective

**proven ways to improve LCoE in PV and Storage**

1. Higher Efficiency
2. Reduced Losses
3. Adjusted Costs

Success Story 50 MWp PV in Spain
Lowering LCoE from the Inverter Perspective

$$LCoE = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

- **Production Efficiency plus Availability**
- **Design Optimization** to adjust CAPEX
- **Opex Saving** Less Preventive & Corrective Maintenance tasks

**Gamesa Electric Proteus**
Introducing new ways to optimize production, reduce maintenance and optimize PV & BESS Plant Designs
Lowering LCoE: Why us…. And How?

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

- **Lowest THD**: THD 50th < 0.7%  
  THD 2500th < 1%  
  IEEE-519 and IEC-617272 certified

- **Highest Efficiency**: 99.45%  
  IEC-61683 certified

- **Highest MPPT Efficiency**:  
  \[ \eta_{\text{STATIC}} = 100\% \]  
  \[ \eta_{\text{DYNAMIC}} = 99.9\% \]  
  EN-50530 certified

- **Highest power density**:  
  PV \( \rightarrow \) Up to 4.7 MVA  
  PVS \( \rightarrow \) Up to 9.4 MVA

- **Lowest derating in Temperature**:  
  100\% - 40°C  
  89 \% - 55°C

- **100\% Performance**: Using clipping energy to feed auxiliaries

**Production**, **Design Optimization**, **Opex Saving**
Proven ways to improve LCOE in PV and Storage

1. **Focus decisions on obtaining max production**
   - Ultra-High Efficiency and MPPT Efficiency

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Success Story: 50 MWp PV in Spain
Proteus Peak efficiency is **99.45%**, and it’s almost ever above 99% even if weighted values are considered (IEC 61683 certified).

Thanks to:
- Cooling system
- Highly-refined hardware design
- Control algorithms

**Ultra-High Efficiency and MPPT Efficiency**

---

### PROTEUS PV4700

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>European efficiency</th>
<th>Californian efficiency</th>
<th>Maximum efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>99.17%</td>
<td>99.15%</td>
<td>99.34%</td>
</tr>
<tr>
<td>60</td>
<td>99.24%</td>
<td>99.24%</td>
<td>99.45%</td>
</tr>
</tbody>
</table>

---

**More Instant Production -> Reduced LCoE**

![Performance Graph](image-url)
1 - Focus decisions on obtaining maximum production
Ultra-High Efficiency and MPPT Efficiency

**MPPT Efficiency**

Proteus PV family has the highest MPPT efficiency in the market

- Static efficiency > 0.5%
- Dynamic efficiency > 0.75%
- Applies to Power Yields

Fast and accurate solar radiation tracking -> Reduced LCoE

<table>
<thead>
<tr>
<th>Ramp</th>
<th>η</th>
<th>Proteus PV</th>
<th>Inv 1</th>
<th>Inv 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% - 50%</td>
<td>Min</td>
<td>99.85%</td>
<td>98.02%</td>
<td>99.32%</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>99.97%</td>
<td>99.21%</td>
<td>99.60%</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>99.99%</td>
<td>99.67%</td>
<td>99.82%</td>
</tr>
<tr>
<td>30% - 100%</td>
<td>Min</td>
<td>99.98%</td>
<td>99.05%</td>
<td>99.35%</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>99.99%</td>
<td>99.43%</td>
<td>99.46%</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>100.00%</td>
<td>99.88%</td>
<td>99.61%</td>
</tr>
</tbody>
</table>
1. **Focus decisions on obtaining max production**
   Ultra-High Efficiency and MPPT Efficiency

2. **Maximize every opportunity to produce.**
   MPPT Extended Range

**Success Story:**
**50 MWp PV in Spain**
2 - Maximize every opportunity to produce MPPT Extended Range 2%

Evolution in Reactive Power affects to DC Voltage

Extended MPPT Range $\rightarrow$ Not limited to $V_{DC-Link} \geq \sqrt{2}V_{AC}$
- No DC-DC stage $\rightarrow$ Less components, more reliable, higher efficiency
- Harmonic distortion below international standards (IEEE519)

Increase power yields, more flexible design $\rightarrow$ reduce LCoE

<table>
<thead>
<tr>
<th>AC Voltage</th>
<th>Standard MPPT</th>
<th>Extended MPPT</th>
<th>Extra Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>690</td>
<td>976</td>
<td>955</td>
<td>2%</td>
</tr>
<tr>
<td>660</td>
<td>933</td>
<td>915</td>
<td>2%</td>
</tr>
<tr>
<td>630</td>
<td>891</td>
<td>875</td>
<td>2%</td>
</tr>
<tr>
<td>600</td>
<td>849</td>
<td>835</td>
<td>2%</td>
</tr>
</tbody>
</table>
proven ways to improve LCoE in PV and Storage

1. Focus decisions on obtaining max production
   Ultra-High Efficiency and MPPT Efficiency

2. Maximize every opportunity to produce.
   MPPT Extended Range

3. Power Quality… is also money.
   HF THDi

4. Success Story:
   50 MWp PV in Spain

5. Higher Efficiency

6. Reduced losses

7. Adjusted costs
3 – Power Quality… is also money
THDi Energy losses must be considered in all Frequency Range

Inverters Switching frequency
- Above 50th harmonic, not included in certificates
- Higher impact in harmonic losses
- It is partially mitigated by Phase-Shifting

PV plant behaves like Low Pass Filter
- Meters measured any current
- High frequency currents filtered by PV plant
- Transformers and cables heating

Embedded HF filter in Proteus PV & PCS

- Inverter THDi (50th)<3% ; THDi (2500th)<10%
- Gamesa Electric Proteus - THDi (50th)<0.8% ; THDi (2500th)<1%

- Measured at POI

E

EINV1 + EIN2

EIN

ESATION

EPOI-HV

Phase-shifting

LV/MV Transformer

MV cables

Substation Transformer

Proteus at POI
Similar THD
Higher Energy

Measured at POI

THDi

DC | AC
3 – Power Quality… is also money
Lower THDi means… lower LCoE

Proteus PV & PCS
THDi (50th order) 0.7%
THDi (2500th order) 1.0%

NO Energy Waste in 25 years

- Increased Grid stability
- More Revenues
- Reduces losses
- Avoid Transformer’s breakdowns.

-> Reduced LCoE

Case A: Central + HF
THDi (50th order) 2.3%
THDi (2500th order) 3.2%

Case String
THDi (50th order) 2.3%
THDi (2500th order) 10.3%

Year 0: -200 k€ // Year 25: -2.9 M€

Year 0: -338 k€ // Year 25: -4.9 M€

*235 MVA plant, energy price of 35 €/MWh and discount rate of 5% per year. The economic calculations only contemplate the pure ohmic losses, skin effect neither the impact on transformers nor capacitors are considered.
proven ways to improve LCoE in PV and Storage

1. Focus decisions on obtaining max production
   Ultra-High Efficiency and MPPT Efficiency

2. Maximize every opportunity to produce.
   MPPT Extended Range

3. Power Quality… is also money.
   HF THDi

4. Smarter if adaptable to instant conditions.
   100% Performance

Success Story:
50 MWp PV in Spain
4 - Smarter if adaptable to instant conditions

100% Performance

Proteus PV inverters are designed to compensate inverter losses for clipping without affecting to nominal inverter power

Proteus PV could harvest its own losses from the clipped energy

100% Performance: The equivalent performance ratio is increased to 100%

Extra energy production -> Reduced LCoE
proven ways to improve LCoE in PV and Storage

Focus decisions on obtaining max production
Ultra-High Efficiency and MPPT Efficiency

Maximize every opportunity to produce.
MPPT Extended Range

Power Quality… is also money.
HF THDi

Smarter if adaptable to instant conditions.
100% Performance

Bigger… is better.
Power Density to save costs and CO2 emissions

Success Story:
50 MWp PV in Spain
5 – Bigger… is better
Advantages of Power Density for saving costs and CO2

PV Panels Evolution

2018

2022

91% higher power in 50% larger surface

EPC Comparison: 55 MW_{ac} Plant

Using 11 x 5 MVA LV/MV Stations

Gamesa Electric Proteus PV Stations: 6 x 9 MVA

- Less land
- Less roads
- Less Inverter foundations
- Less and shorter HV cabling
- Less substation feeders
- Less connections

-> Reduced LCoE
## 5 – Bigger… is better
**Positive Impacts for LCOE and Environment**

<table>
<thead>
<tr>
<th>Proteus PV Stations</th>
<th>Market</th>
<th>Proteus PV Stations</th>
<th>Market</th>
<th>Proteus PV Stations</th>
<th>Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.34 W/Kg</td>
<td>0.24 W/Kg</td>
<td>316 W/m²</td>
<td>235 W/m²</td>
<td>1x 40ft</td>
<td>1.5 x 40ft</td>
</tr>
</tbody>
</table>

**Simple, less units per project and less CO2 emissions --> Reduced LCoE**

Evaluation done in Q1 2022 comparing Gamesa Electric Proteus PV Station 9400 with 10 largest Utility Inverter Stations from 7 top-ten central inverter brands.
proven ways to improve LCoE in PV and Storage

1. **Focus decisions on obtaining max production**
   Ultra-High Efficiency and MPPT Efficiency

2. **Maximize every opportunity to produce.**
   MPPT Extended Range

3. **Power Quality… is also money.**
   HF THDi

4. **Smarter if adaptable to instant conditions.**
   100% Performance

5. **Bigger… is better.**
   Power Density to save costs and CO2 emissions

6. **Thermal Regulation is the key.**
   Coolbrid Cooling System

---

Success Story:
50 MWp PV in Spain
CoolBrid: hybrid system with forced-aid + liquid:
Liquid cooling in inverter bridge and grid filter
Forced-air in small switches, electronics, fuses…

Perfect inner temperature regulation

Best performance in extreme conditions:
- Up to 4.7 MVA per unit (UEP)

Low maintenance
Compact solution; space and weight saving

Extended lifetime and high MTBF:
- Components work far from its maximum capabilities

Reliability:
- More than 18 years of experience manufacturing liquid-cooled converters for wind turbines

Less Maintenance, more production -> Reduced LCoE
proven ways to improve LCoE in PV and Storage

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>Focus decisions on obtaining max production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>Maximize every opportunity to produce.</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Power Quality… is also money.</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Smarter if adaptable to instant conditions.</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Bigger… is better.</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Thermal Regulation is the key.</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Limits are there… but to be overcome.</td>
</tr>
</tbody>
</table>

Focus decisions on obtaining max production
Ultra-High Efficiency and MPPT Efficiency

Maximize every opportunity to produce.
MPPT Extended Range

Power Quality… is also money.
HF THDi

Smarter if adaptable to instant conditions.
100% Performance

Bigger… is better.
Power Density to save costs and CO2 emissions

Thermal Regulation is the key.
Coolbrid Cooling System

Limits are there… but to be overcome.
More than 30 years lifetime with just preventive maintenance

Success Story:
50 MWp PV in Spain
7 – Limits are there… but to be overcome
More than 30 years lifetime with just preventive maintenance…

Reduction of costs in replacement

- Critical components achieve 30 years of lifetime
- Main components account for 70% of PV inverter cost.
- Components operating far below their thermal limits.
- No inverter replacement during project lifecycle:
  - Reduced costs
  - Reduced risks
- -> Reduced LCoE

<table>
<thead>
<tr>
<th>Proteus PV Critical Component</th>
<th>Load</th>
<th>Lifetime years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Busbars</td>
<td>80%</td>
<td>-</td>
</tr>
<tr>
<td>DC Disconnector</td>
<td>77%</td>
<td>&gt;40</td>
</tr>
<tr>
<td>DC Bus Capacitors</td>
<td>65%</td>
<td>&gt;40</td>
</tr>
<tr>
<td>IGBT</td>
<td>96%</td>
<td>&gt;50</td>
</tr>
<tr>
<td>AC Inductance</td>
<td>99%</td>
<td>&gt;50</td>
</tr>
<tr>
<td>AC Breaker</td>
<td>98%</td>
<td>&gt;50</td>
</tr>
<tr>
<td>AC Filter Capacitors</td>
<td>75%</td>
<td>&gt;30</td>
</tr>
<tr>
<td>CCU</td>
<td>-</td>
<td>&gt;40</td>
</tr>
</tbody>
</table>

Working conditions

Full Power @ 55°C 12 hours / day
Reactive power 12 hours / night
Lifetime calculation limited by supplier curves.

“Inverter Replacement currently represents 25% of O&M Costs”
North America Solar PV Capital and OPEX Cost 2022 – IHS Markit
proven ways to improve LCoE in PV and Storage

<table>
<thead>
<tr>
<th></th>
<th>Focus decisions on obtaining max production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ultra-High Efficiency and MPPT Efficiency</td>
</tr>
<tr>
<td></td>
<td><strong>HIGHER EFFICIENCY</strong></td>
</tr>
<tr>
<td></td>
<td>Maximize every opportunity to produce.</td>
</tr>
<tr>
<td>2</td>
<td>MPPT Extended Range</td>
</tr>
<tr>
<td></td>
<td><strong>REDUCED LOSSES</strong></td>
</tr>
<tr>
<td></td>
<td>Power Quality… is also money.</td>
</tr>
<tr>
<td>3</td>
<td>HF THDi</td>
</tr>
<tr>
<td></td>
<td><strong>ADJUSTED COSTS</strong></td>
</tr>
<tr>
<td></td>
<td>Smarter if adaptable to instant conditions.</td>
</tr>
<tr>
<td>4</td>
<td>100% Performance</td>
</tr>
<tr>
<td></td>
<td>Bigger… is better.</td>
</tr>
<tr>
<td>5</td>
<td>Power Density to save costs and CO2 emissions</td>
</tr>
<tr>
<td></td>
<td>Thermal Regulation is the key.</td>
</tr>
<tr>
<td>6</td>
<td>Coolbrid Cooling System</td>
</tr>
<tr>
<td></td>
<td>Success Story: 50 MWp PV in Spain</td>
</tr>
<tr>
<td>7</td>
<td>Limits are there… but to be overcome.</td>
</tr>
<tr>
<td></td>
<td>More than 30 years lifetime with just preventive maintenance</td>
</tr>
</tbody>
</table>
Success Story: 50 MWp in Spain

Improvement of PR above 2.6%

- Location: Andalucia (Spain)
- Temperatures: -10°C / 45°C
- Nominal power: 50MWp
- Equipment: 13 x Gamesa Electric PV Inverters in 7 Stations
- Ratio DC/AC: 1.06
- Commissioning date: 2020
- Comparison of the PR calculated by PVSyst in the initial phase of the project with the PR measured in 2021

- Average annual improvement: 2.67%
- Availability in Year 2021 > 99.5 %
We have shown some ways to reduce LCoE taking maximum advantages of our Power Inverters.

We reinforce this approach with results from an Utility-Scale Plant in Spain with our Inverter Stations.

Excellence is not a skill. It is a commitment to give you better solutions.
Contact for more info
Antonio Montoto
Sales Manager Hybrid & BESS
amontoto@gamesacorp.com