Solutions for Integrating Photovoltaic on Diesel Grids
Ingeteam

- 3,000+ People
- 13 Countries
- 6 Divisions

- ENERGY Division
- INDUSTRY Division
- NAVAL Division
- TRACTION Division
- TECHNOLOGY Division
- SERVICES Division
Energy Division

- Photovoltaic:
  - **INGECON SUN** inverters from 2.5 to 1000 kW.
  - More than **3.5 GW** supplied throughout the world

- Wind Power:
  - **INGECON WIND** inverters from 2.5 to 10 MW.
  - More than **24 GW** supplied throughout the world

- Plant control
- Solar thermal
- Hydropower
- Biomass
- Biofuels
- Smart-grid
1. Diesel generation

Advantages:
- Simple off-grid networks
- Moderate initial investment
- Match generation and consumption
- They endure power steps up to 30-35%

Disadvantages:
- Great dependence on diesel
- CO₂ emissions
- Diesel cost increase → High cost of energy

Diesel CapEx = 0,3 €/W; O&M = 3% annual; Interest = 6,4% a 12 years
Diesel cost: Price actual + 3%/annual
1. Diesel generation

The addition of PV energy can reduce the price of energy
2. Diesel-Photovoltaic hybrid systems

Diesel-Photovoltaic hybrid systems:

**Battery-based**
- Genset is used as a back-up

**Genset-based**
- Genset is always used for grid generation
2. Diesel-Photovoltaic hybrid systems

Genset-based hybrid systems

- Diesel generators establish the grid voltage & frequency (voltage source)
- Photovoltaic energy works as a load reduction

- Advantages:
  - Reduction of diesel consumption
  - Lower cost of energy
  - Unlimited resource & Resource availability (Peak Sun Hours - PSH)
2. Diesel-Photovoltaic hybrid systems

Photovoltaic Solar Electricity Potential in European Countries

Global irradiation* [kWh/m²]

<600 <450
800 600
1000 750
1200 900
1400 1050
1600 1200
1800 1350
2000 1500
>2200 >1650

Solar electricity** [kWh/kWp]

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PVGIS http://re.jrc.ec.europa.eu/pvgis/

* Yearly sum of global irradiation incident on optimally-inclined south-oriented photovoltaic modules
**Yearly sum of solar electricity generated by optimally-inclined 1kWp system with a performance ratio of 0.75

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EC - Joint Research Centre
In collaboration with ENSAF, www.cmasaf.eu

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2. Diesel-Photovoltaic hybrid systems

**LCOE on PV based systems**

- $2.00 \text{ €/Wp}$
- $1.50 \text{ €/Wp}$

**LCOE on genset systems**

- $PV_{\text{CapEx}} = 2 - 1.5 \text{ €/Wp}$
- $PV_{\text{OpEx}} = 1.5\%$ annual
- $\text{Degradation: } 0.4\%$ annual; $\text{PR}= 0.85$, 20 years
- $\text{Diesel}_{\text{CapEx}} = 0.3 \text{ €/W}$
- $\text{Diesel}_{\text{OpEx}} = 3\%$ annual
- $\text{Diesel cost: actual price } + 3\%/\text{annual}$
- Interest loan $= 6.4\%$, 12 years
- Time: 20 years
2. Diesel-Photovoltaic hybrid systems

Example of a Diesel – Photovoltaic system:

\[ P_{\text{GEN}} = 400\text{kW} \]

\[ P_{\text{LOAD}} = 310\text{ kW} \]

\[ E_{\text{LOAD}} = 6639\text{ kWh} \]

\[ P_{\text{FV}} = 225\text{ kW} \]

\[ E_{\text{FV}} = 1793\text{ kWh} \]
2. Diesel-Photovoltaic hybrid systems

✓ **Challenges** of Diesel-PV integration:
  - Guarantee the **generator’s minimum load** (longer engine life)
  - Protection against **reverse power** (total load disconnection)
  - Stability against **irradiance variations** (cloud shading)

✓ **High PV penetration on diesel systems:**
  - A controller is needed
  - Change in the inverter’s working mode: MPPT → Power setpoint
Types of diesel **systems & solutions**:

### Continuous operation genset
- Single genset
- Multiple gensets Drop-control or other

Gensets are not switched off

### On-Demand genset
- Multiple gensets Master-Slave Control

Genset are switched off with low load

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2. Diesel-Photovoltaic hybrid systems
2. Diesel-Photovoltaic hybrid systems

Types of diesel systems & solutions:

- Continuous operation genset
- On-Demand genset
3. Systems with INGECON EMS Manager

✓ Valid for new and existent continuous operation systems
System functionalities:

- Guaranty of genset minimum load
- Protection against reverse power
- Monitoring (INGECON EMS Tools)
- Load control

Stability against irradiance variations is guaranteed by the spinning reserve due to the installation sizing

Example

Events:
1. Disconnection of a 150kW load
2. Irradiance drop
3. Systems with INGECON EMS Manager

**Elements of the system**

- INGECON EMS Manager
  - Management element
  - Communication with:
    - power meter
    - inverters
  - Load control

- Power meter

- Certified grid-connected Ingecon Sun inverters:
  - INGECON SUN 1play
  - INGECON SUN 3Play
  - INGECON SUN Power
  - INGECON SUN Power Max
System sizing:

\[ P_{PV} = P_{LOAD} - P_{GEN,min} \]

Example:

- \( P_{GEN} = 400 \text{kW} \)
- \( P_{GEN,min} = 0.25 \cdot 400 \text{kW} \)
- \( P_{LOAD} = 300 \text{kW} \)
- \( E_{LOAD} = 6639 \text{kWh} \)
- \( P_{FV} = 225 \text{kW} \)
- \( E_{FV} = 1793 \text{kWh} \)
4. Systems with INGECON EMS Plant Controller

✓ Valid for **new and existent On-Demand** systems
4. Systems with INGECON EMS Plant Controller

**System functionalities:**

- Guaranty of genset minimum load
- Protection against reverse power flux
- Monitoring
- **Spinning reserve guarantee**
- **Reactive power control**

- Control guarantees stability against irradiance variations

- Maximum PV is determined by the instantaneous spinning reserve
4. Systems with INGECON EMS Plant Controller

System elements

✓ INGECON EMS Plant Controller
  ▪ PLC
  ▪ Communication (Ethernet cable or optic fiber):
    ▪ General power meter
    ▪ Inverters
    ▪ Gensets (Power meters or Modbus TCP)

✓ Power meter

✓ Certified grid-connected INGECON SUN inverters:
System sizing:

- Maximum photovoltaic penetration is determined by the load value used by the M/S control to switch off generators.

**Spinning Reserve:**

\[ N_{on} \cdot P_{GEN} \geq P_{LOAD} - P_{PV}, \text{guaranteed} \]

**Genset controller:**

\[ N_{on} \cdot P_{GEN} \cdot \%_{off} \leq P_{LOAD} - P_{PV} \]

**Sizing example**

- \( P_{GEN} = 1600 \text{ kW} \)
- \( N_{GEN} = 12 \)
- \( P_{LOAD} = 12500 \text{ kW} \)

<table>
<thead>
<tr>
<th>Switching off load</th>
<th>40%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{FV} \text{ (kW)} )</td>
<td>8000</td>
<td>3000</td>
</tr>
<tr>
<td>( N_{on} )</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

- It is recommended to decrease the diesel generators’ switching-off load.
5. Systems with Ingecon EMS Plant Manager and batteries

- Use of batteries allows:
  - Increase the photovoltaic penetration. **There is no need of guaranteeing the spinning reserve**
  - Stop generators
- Batteries of small capacity (associated to the gensets' starting up time)

- $P_{FV} + P_{BAT}$:
5. Systems with INGECON EMS Plant Controller and batteries

**System functionalities:**

- Guaranty of genset minimum load
- Protection against reverse power flux
- Monitoring
- **Ramp rate control** (grid stability)
- Reactive power control

- There is no need of monitoring the individual gensets’ production

- Certified battery inverter:

  **INGECON EMS Plants**

- Valid for **new and existent On-Demand** systems
5. Systems with INGECON EMS Plant Controller and batteries

System sizing:

✓ Maximum PV penetration is determined by the minimum number of the diesel generators that must remain switched on.

✓ It is advisable that diesel gensets always work at least at a 30% level for guaranteeing system stability:
  - Load current harmonics
  - Load steps
  - Reverse sequence loads (unbalance loads)

✓ Recommended photovoltaic power

\[
P_{FV} \geq P_{LOAD} - N_{on} \cdot P_{GEN} \cdot \%_{GEN}
\]

\[
P_{BAT} \approx 0.8 \cdot P_{FV} \text{ (depending on gensets’ switching off ratio)}
\]

Sizing example:

\[
\begin{align*}
P_{GEN} &= 1600 \text{ kW} & P_{LOAD} &= 12500 \text{ kW} & P_{FV} &= 8500 \text{ kW} \\
N_{GEN} &= 12 & N_{on} &= 3 & P_{BAT} &= 6800 \text{ kW}
\end{align*}
\]

\[
T_{GEN, \text{ start}} = 60 \text{ s}
\]
5. Systems with INGECOM EMS Plant Controller and batteries

Behavior in a irradiance variation from 100% to 20%

\[ \text{Pelec} \quad \text{Pdiesel} \quad \text{Pdiesel+Pelec} \quad \text{Ppv} \]

\[ P_{\text{GEN}} = 1600 \text{ kW} \]
\[ N_{\text{GEN}} = 12 \]
\[ T_{\text{GEN, start}} = 60 \text{ s} \]
\[ P_{\text{LOAD}} = 12500 \text{ kW} \]
\[ P_{\text{FV}} = 8500 \text{ kW} \]
\[ P_{\text{BAT}} = 6800 \text{ kW} \]
5. Systems with INGECON EMS Plant Controller and batteries

- Photovoltaic generation ≠ Consumption → Increase storage capacity
Photovoltaic energy integration in diesel systems allows:
- To reduce the diesel consumption
- To reduce the energy cost

**Ingeteam solutions:**

- **Continuous operation**
  - INGECON EMS Manager

- **On-Demand**
  - INGECON EMS Plant Controller
  - INGECON EMS Plant Controller + Batteries

**Characteristics:**
- Valid for new and existent installations
- Guarantee of generators’ minimum load
- Protection against reverse power flux
- Guarantee of network stability against irradiance variations
Thank you for your attention