

*/ Danvest / THEnergy study*

# Low-load Gensets for Solar– Diesel Hybrid Plants in the Mining Industry

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# 1 Introduction

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Often, remote mines are not connected to the power grid and so generate their electricity through conventional diesel power plants. The price of diesel at these remote mines is also rather elevated owing to additional transportation costs, taxes, and theft. In general, the costs of power generation in remote and isolated areas are relatively high. In many sectors, off-grid hybrid power systems with diesel gensets in combination with solar or wind energy are gaining importance as prices of photovoltaics (PV) and wind turbines have fallen lately and technologies have matured. In recent years, the combination of PV and diesel has often become the first choice for powering remote locations. Nevertheless, in comparison to the global potential of diesel gensets, this trend is still in the early stages. Bloomberg New Energy Finance estimated the installed base of diesel gensets in 2011 at 150 GW in developing countries alone.<sup>1</sup>

This trend has reached the mining industry with the first projects in South Africa, Tanzania, and Australia.<sup>2</sup> Furthermore, many mining companies have expressed their ambitions to use renewable energy in the near future.

In most PV–diesel hybrid systems, diesel gensets and intermittent PV systems are not very compatible with generating a high share of PV power in the overall system. Diesel gensets typically cannot provide the optimal load ranges as low-loads damage the diesel gensets. If the diesel gensets are run at the lowest possible load point, they are not very economical. Given that the PV component in PV–diesel hybrid systems is not very stable and clouds can affect the output rather quickly, the diesel gensets need to be flexible and have to balance this situation by providing spinning reserve accordingly. In traditional solar–diesel hybrid systems, the solution is low PV penetration rates<sup>3</sup> and the use of storage systems for providing the so-called spinning reserve<sup>4</sup>. All these approaches are crude. A more straightforward approach would be to make diesel gensets themselves more optimized for this specific application: flexible low-load generators with an overall low fuel consumption for the entire power plant.

Danvest Energy A/S successfully developed and applied such a low-load diesel solution several years ago for wind–diesel hybrid systems. For the mining industry, Danvest is commercializing its new genset concept together with Siemens in Australia for wind–diesel.

In recent years, the PV–diesel hybrid market has shown much more dynamism than the wind–diesel hybrid energy markets. Danvest sees huge potential for its solutions and has recently entered the PV–diesel hybrid market. The concept mainly consists of the modification of traditional synchronous gensets. The solution has been proven with traditional generators from CAT and Cummins.

The main objective of the study is to evaluate the commercial potential of low-load generators in PV–diesel hybrid applications in the mining industry.

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<sup>1</sup> Bloomberg New Energy Finance, Power to the People? PV and batteries for the 150 GW diesel market, Dec 2011.

<sup>2</sup> TheEnergy plant database for “Renewables in Mining”: <http://www.th-energy.net/english/platform-renewable-energy-and-mining/database-solar-wind-power-plants/>

<sup>3</sup> The PV penetration rate in this study is defined as ratio (in per cent) of the total maximum PV nominal plant power to the total maximum power of the gensets operated in parallel (compare SMA for further details).

<sup>4</sup> Spinning reserve in this study is defined as generation capacity that can respond within 10 seconds to compensate for losses of the PV system or load increases.

## 2 Methodology and design of the study

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On the technical side, a considerable amount of testing has been conducted for low-load diesel genset solutions. External reports exist for both solar–diesel and wind–diesel applications. This study has a different research objective than these technical evaluations of the low-load genset solution. Nevertheless, technical aspects are important pillars for the assessment of the low-load gensets for solar–diesel applications in the mining industry.

As such, this study integrates the results of application tests that have been previously conducted, and of simulations and expert interviews. Twenty-one experts with different backgrounds were interviewed regarding market-related questions: mainly from the mining industry and the solar sector.

The interviews were mainly conducted by telephone. The interviewed experts are from three different continents with a focus on Africa. The experts from the mining industry are energy managers and engineers. On the energy side, the majority of the interviewees are responsible for engineering and business development.

## 3 Traditional Diesel Gensets in Solar–Diesel Hybrid Systems

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In recent years, the price of solar power has decreased considerably. However, solar power still has the reputation of being expensive. In countries such as Germany, which has extensive experience in solar, the price of solar energy in tenders has fallen to well below 10 US\$/kWh. In many remote locations in Africa, Australia, Latin America, and Asia the solar irradiation is much higher and the yield of the installations is almost twice as high as in Germany. In sunny regions, PV is already competitive.

Remote villages and industrial consumers, such as mines, are often not connected to the power grid. Typically, power is generated by diesel gensets. In these regions, diesel prices are far above the world market price for diesel owing to transportation costs, taxes, and theft. Even with decreased oil prices, we see electricity costs of well above 0.30 US\$/kWh.

In these cases, solar is an attractive alternative to diesel power. The exact benefit of solar depends on various parameters (e.g. energy demand, interest rates, fuel prices, fuel price inflation, solar irradiation, plant location) of each energy source and has to be examined for every project individually. No general price advantage can be derived. It is, however, certain that the price of fossil fuels will rise. Solar energy can be used to hedge that price risk as the main cost driver of the technology is capital expenditure for construction, whereas the overall costs decrease with a longer project lifetime as there are no fuel costs and very low maintenance costs. The opposite applies for diesel gensets. The investment costs are significantly lower but the fuel cost and the estimated fuel price inflation lead to much higher costs per kWh throughout the lifetime of the genset.

Typical cost savings from adding a PV power plant are in the range of 25–30%. In very remote locations with elevated diesel prices, the savings can amount to more than 70%.

Many diesel gensets have been upgraded with solar installations in order to reduce diesel consumption and improve the cost of electricity generation. There are numerous examples of newly built PV–diesel hybrid power plants.

## 4 Low-load Diesel Gensets

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### 4.1 Background

Danvest, with a heritage in the Danish diesel industry, has a long background with the concept of combining renewable energy sources with diesel gensets, first applied to wind–diesel hybrid solutions. Several installations have been built in America, Asia, and Europe. Amongst others, Siemens has tested the Danvest solution for wind–diesel applications. The two companies have formed a partnership for wind–diesel for the Australian mining market.

The wind turbines applied with the Danvest solution so far range from 75 kW to 3.6 MW per turbine. Danvest builds low-load diesel-based genset modules of up to 2 MW per genset, which are easily installed and can be scaled up for multiple units.

Lately, the solar–diesel hybrid market has developed new dynamics and we see many more PV–diesel hybrid systems than wind–diesel hybrid systems. This is driven by a combination of different factors:

1. Drastically falling prices of PV components
2. Easier logistics for remote locations
3. Industry is losing key markets in Europe owing to changing incentive schemes
4. An increasing number of control solution providers
5. Only require a short feasibility study and short construction time

Expectations about the market size vary largely. Bloomberg New Energy Finance estimated a 150-GW installed base of diesel gensets in developing countries. A large portion of that could be upgraded with solar. The new dynamic can be seen for applications in various industries. Media has drawn attention to large projects in the mining, tourism, real estate, agriculture, retail business, and chemical, food and textile industry. Other project examples can be found in refugee camps and rural electrification, especially for remote villages.

The renewable energy penetration rate is a crucial factor. In many projects, it is important to increase the share of renewable energy in the total system as much as possible. Storage technology is frequently applied to achieve this objective. Some of the biggest solar–diesel hybrid projects that have been finished lately or are under construction use storage solutions, for example:

- 5.2 MWp PV with 2.2 MW storage in Cobija, Region Pando, Bolivia for rural electrification with an additional genset capacity of 15.2 MVA
- 10.6 MWp PV with 6 MW storage in Australia for the Sandfire Degruusa mining project with an additional genset capacity of 20 MVA

However, all these projects use traditional gensets that are slow to start up, cannot be run in low-load mode, and are not very flexible for balancing the unstable solar component.

## 4.2 Characteristics

Danvest has developed low-load diesel genset solutions for application in hybrid solutions with intermittent renewable energy components. The traditional gensets are modified in a way that they can run in low-load and operate in reverse mode whilst hardly consuming any diesel, but with the full ability to react quickly to output changes from the PV array or to changes in demand.

In addition, a dump load system regulates in parallel, but separately from the Danvest genset. The dynamic dump load control system ensures a governing of the total system, where the heavy masses from the diesel generator in combination with the PV component comprise a dynamic frequency system that is optimized regarding:

- Inertia gust
- Wearing at bearings, couplings and gear wheels
- Transients in the electric system
- Fluctuations from solar and consumers

The dump load assists the engine and when the frequency increases to more than 0.3 Hz (set point) the dump load system controller will take over the frequency control keeping the power balance. The Danvest dump load control is fast and dynamic through the activation and de-activation of small resistors with a reaction time below 1 ms.

When the Danvest fitted hybrid genset is reduced to a load below 30% of prime power, the genset goes into low-load operation mode, where pre-pressuring, pre-heating, and coolant temperature level are activated. The engine can continue into reverse power operation mode, i.e. operation below 0% load where the engine is drawn by the solar power at very low emission levels and fuel consumption. The genset can continue all the way down into Danvest-defined “full reverse power” at minus 10/11% on the genset where emission and fuel consumption falls to zero.

Furthermore, for reducing engine wear, the Danvest solution has an engine stop function. The genset is fitted with a clutch system that provides the ability to stop the diesel engine by declutching it from the alternator when surplus renewable energy hits a set point. Fuel consumption is zero under these circumstances. The alternator still provides reactive power as it remains connected to the busbar and, in combination with the dump load, continues to control:

- Reactive power
- Voltage
- Frequency
- Diesel engine conditions

If the power from the PV plant decreases in the hybrid system, the genset has to fill that gap very quickly. The Danvest modification gives the engine the ability to restart very quickly with the clutched-out diesel engine only having to startup itself and clutch-in. The Danvest technology allows for “parking” the engine when solar energy is sufficient for powering the consumers on its own. In traditional solar–diesel hybrid systems, often the diesel genset cannot

be switched off, even if the PV generation is very stable, because it is the grid-forming unit in the system.

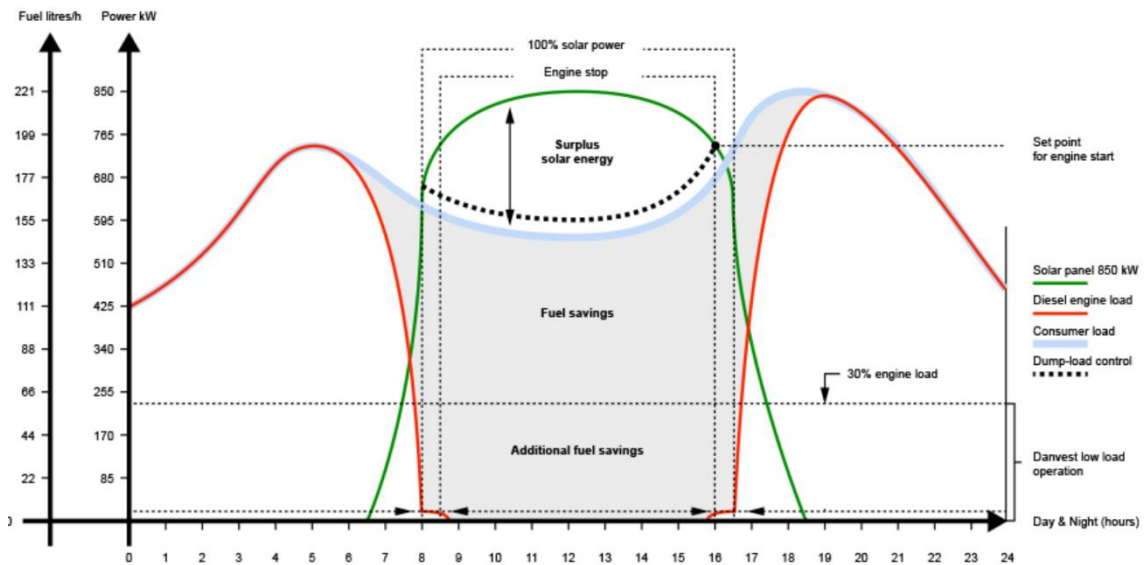


Image 1: The logic of the Danvest solution in a PV–diesel hybrid system

Tests that were carried out together with the CAT dealer Pon Power showed that the Danvest low-load gensets can respond to any drop in solar generation.

A typical worst-case criterion for a sudden extreme shading of solar arrays is a solar power drop of 80% of the rated solar power within 10 seconds. For a 700 kWp PV plant this equals  $700 \text{ kWe} \times 0.8 / 10 \text{ s} = 56 \text{ kWe/s}$ .

In the test, the Danvest-fitted 648 kWe genset passed this worst-case load step test keeping a high frequency quality (even at load steps of 65 kWe/s the frequency stayed within  $\pm 0.5 \text{ Hz}$ ). The Danvest-fitted genset could also handle large load step tests in which a large load of 400 kWe (more than 60% of the genset capacity) was added in 1 sec. The test showed that the response capability is equal whether the genset in the Danvest hybrid solution is in reverse power, low load, or normal load.<sup>5</sup>

According to Danvest, leading engine manufacturers have accepted Danvest hybrid technology and issue their standard worldwide guarantee for their products in Danvest solutions.

Danvest has partnered with Pon Power, the owner of a Northern European Caterpillar dealership. Pon Power has the capabilities to assemble Danvest Power Boxes in factories in Denmark, Sweden, and the Netherlands. In combination with the original engine manufacturer, commissioning and service for the Danvest solution will be offered on a global level through local subsidiaries and dealerships.

<sup>5</sup> Source of the presented test results is a CAT Pon Power Performance Test for Model: Danvest HSD-648, August 2015.

### 4.3 Economics

The main advantages of the Danvest solution are that the share of renewable energy can be considerably increased in the hybrid system and that the diesel engine consumes almost no fuel in the low-load modes.

A PV system, which has a penetration rate of less than 20%, can be connected with a genset relatively easily. In principle, no additional hybrid control units are needed

At “none” low-load solar–diesel applications with a PV penetration in the range of 20–60%, hybrid controllers can often balance the system. The problem is that the traditional gensets need to provide the spinning reserve, cannot be stopped, and they run inefficiently at lower load points. Therefore, sometimes solar power cannot be used and needs to be cut off.

For even higher penetration rates, the traditional solution is to use battery storage.

The Danvest Power Box is an alternative for penetration rates of more than 20% and gains particular economic interest at large-scale installations with penetration rates of more than 60% (high penetration systems). At a penetration rate of 100%, the Danvest-fitted genset is in reverse power operation or stopped at little or no fuel consumption.

The Danvest Power Box with its low-load capabilities and dump load set-up requires some additional investment costs, which typically are compensated by more efficient diesel operations and high direct fuel savings achieved without using energy storage systems.

A typical payback time of a Danvest solution, including the PV plant and hybrid controllers with a technical/economical lifetime of 15–20 years, is in the range of 4–7 years. In 24-hour operations with a flat load profile like at a mine, the PV energy share can be increased to more than 30%. In cases where the load is considerably lower at night; this rate can normally go up to 40–50%. These penetration rates would only have been possible by using large storage solutions.

### 4.4 Exemplary Project Simulation Results

Various simulations show that the PV penetration rate can be increased considerably by low-load diesel gensets. Table 1 gives an overview of the results of three typical simulations:

	Mining	Mining	Island electrification
Average load/peak	9.6/11.7 MW	320/375 kW	1.10/1.45 MW
PV capacity	12 MW	400 kW	2 MW
% PV consumption	30%	29%	39%
Payback time	5 years	7 years	4 years

Table 1: Exemplary simulations of Danvest solutions for different applications

Two cases concern mining and one is an island electrification project. The table gives an overview of the main characteristics of the projects. The payback time of the additional investment for the hybrid installation (extra costs of low-load gensets, PV + controllers) is calculated compared to the installation costs of traditional gensets without solar.



The share of solar energy, as a percentage of the total energy consumed, depends largely on the load profile. The Danvest solution maximizes the renewable energy consumption during the day with close to 100% direct fuel savings during solar hours.

## 5 Solar/Diesel Hybrid in the Mining Industry

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### 5.1 Recent Developments

The mining industry is often regarded as the best target industry for solar–diesel hybrid applications. The main reasons are:

- High electricity consumption
- Scale and duration of operation
- Remote locations with high diesel prices also owing to transportation
- Mining groups are considered as a reliable partner

The first PV–diesel installation on the MW-scale was built in 2012 by Cronimet Mining Power Solutions at a chromium mine in South Africa. Since then, many experts have been expecting a boom in this specific market segment, but progress has been slow.

The global mining industry has been in crisis lately as commodity prices have fallen considerably. Many projects that were underway have been postponed. Electricity was often not the main priority in this situation.

It took three years until First Solar commissioned the second MW-scale PV–diesel hybrid project. After the insolvency of the original EPC, First Solar recently finished a 1.7 MW installation at Rio Tinto’s Weipa mine in Australia. Several other projects have been announced and commenced in the meantime. For example, JuWi has announced a groundbreaking 10.6 MW installation with 6 MW storage at Sandfire’s Degussa mine in Australia.

Many other companies report a substantial project pipeline for solar–diesel hybrid projects in the mining industry. In the meantime, renewables play an important role in the mining press and several conferences with a focus on renewables and mining have been established.

In addition, PV prices have fallen considerably in the last years and mining companies see renewable energy an alternative for them to reduce energy costs. Furthermore, innovative business models are evolving and several external investors are offering to finance off-grid PV installations. They either rent or lease back the PV plant to the mine, or sell the electricity via a long-term power purchase agreement (PPA) to the mine.

However, in this market diffusion process, falling oil and diesel prices slowed down the development at a certain stage. Most often, the business cases for PV–diesel hybrid applications are still positive. Therefore, it is no surprise that the low oil prices slowed down the development, but did not stop it, and that many companies report a serious pipeline for solar–diesel hybrid projects.

## 5.2 Cost Saving Potential for Low-load Gensets

The mining industry has a long and thorough experience with diesel gensets. Mines often have dedicated energy managers who were sometimes skeptical regarding the operation of traditional diesel gensets in mining without additional energy storage.

Energy professionals now understand that low-load diesel gensets have various advantages, which go far beyond increasing the renewable energy penetration at mines. They also see additional benefits regarding control, power quality, and cost savings.

Low-load gensets require some additional investment costs, which are not fully proportional to the size of the genset. There are considerable economies of scale for larger low-load diesel gensets. As mining is energy intensive, larger diesel gensets are typically found.

The return on investment (ROI) is particularly high for large mining applications. External investors that intend to finance PV solutions normally require a certain size due to transaction costs in the financing process. Typically, the equity part is expected to be in the range of at least 2–5 million US\$. That means that on the one hand they need industries with large loads and energy requirements, such as the mining industry, and on the other hand they have an interest to build PV plants as large as possible without affecting the internal rate of return (IRR) in a negative way.

From the financial community, a special interest in low-load gensets was identified as they allow achieving a renewable energy penetration of up to 100% with relatively low additional investment requirements for the low-load modifications of the gensets.

The high PV penetration rate of low-load diesel gensets helps to create higher interest in PV–diesel hybrid solutions from mining companies. More relatively inexpensive but well-used solar power means additional energy cost savings and a bigger relevance for the solar solution. A common criticism amongst mining companies used to be that PV–diesel hybrid systems displace too little diesel to be considered as a relevant option. Some mining companies were reporting that they would be waiting for cheaper storage solutions that would allow them to shut off the diesel engines during the daytime when the sun is shining for longer periods.

Low-load diesel gensets address exactly this issue. In sunny regions, the PV–low-load diesel hybrid system runs during the daytime with only marginal diesel consumption as the diesel engine is in low-load or standby-mode.

## 6 Conclusions

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The study identifies the huge impact that the innovative Danvest low-load solution will have on the solar diesel hybrid markets. The system is optimized from a technical perspective. The technical achievements automatically lead to improved economics of the whole hybrid solution. The payback time of the solar–diesel hybrid system, with a technical/economical lifetime of 15–20 years, typically falls to 4–7 years by using the Danvest solution.

The study shows this by starting with an introduction to solar–diesel hybrid plants and the limitations of traditional diesel gensets in these systems as they are slow to start-up, have limited flexibility and no low-load capability. The limitations stem from the fact that traditional gensets are optimized for peak power.

If gensets are combined with renewable energy sources, their main functions are to establish the grid and balance fluctuations of the instable renewable energy source. They have to provide the additional power if the PV array is shaded or the wind pauses.

Low-load gensets were first applied in hybrid systems in combination with wind energy. As solar–diesel hybrid systems have recently shown increased dynamics, it is no surprise that the diesel genset industry has also brought this field of application into focus. Danvest has developed a low-load diesel concept using either CAT or Cummins diesel engines that allow for operations in low-load and in reverse mode with only marginal diesel consumption. In addition, the low-load genset solution can form the grid at any given time.

Energy consumers have direct advantages as low-load genset solutions can increase the share of renewable energy in the hybrid system considerably and replace more expensive diesel electricity with relatively inexpensive solar energy. At the same time, the low-load diesel genset operates more efficiently at low-loads. The approach is laboratory- and field-tested, and reputable genset manufacturers sustain their warranties on the engines after the modifications.

PV–diesel hybrid applications have developed new dynamics with the operational experience of Cronimet’s Thabazimbi mine in South Africa, as well as the commissioning of Rio Tinto’s Weipa mine and start of construction of Sandfire’s Degussa mine, both located in Australia.

Low-load gensets fit particularly well to applications in the mining industry as they show advantages for large-scale applications. Mines typically have high power requirements in remote locations with elevated electricity prices owing to long transportation distances for the diesel fuel. Low-load gensets allow for powering mines during sunny days with a PV penetration rate of 100%, i.e. diesel consumption is decreased towards zero when the PV plant operates at peak power. This can typically increase the share of PV power in the total hybrid system to approximately 30% at mines with a 24/7 flat load profile and up to approximately 40% if the load profile is more optimal with a lower night consumption. These subsequent fuel saving values via low-load gensets are otherwise only possible with large storage systems and bigger PV solutions.

## About Dr. Thomas Hillig Energy Consulting (THEnergy)

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THEnergy assists companies in dealing with energy-related challenges. Renewable energy companies are offered strategy, marketing and sales consulting services. For industrial companies THEnergy develops energy concepts and shows how they can become more sustainable. THEnergy combines experience from conventional and renewable energy with industry knowledge in consulting. In addition to business consulting, THEnergy is active in marketing intelligence and as an information provider in select fields such as renewables and mining through the platform [th-energy.net/mining](http://th-energy.net/mining) or renewables on islands through the new platform [th-energy.net/islands](http://th-energy.net/islands). **For more information visit [www.th-energy.net](http://www.th-energy.net).**

## About Danvest Energy A/S

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### **About Danvest Energy A/S**

Danvest is an innovative diesel technology company from Denmark and a world leader in hybrid wind–diesel power. Its hybrid technology optimizes wind–diesel as well as solar–diesel operations. Increased wind and solar penetrations results in annual reductions of fuel consumption and carbon dioxide emissions of up to 70 per cent when compared to conventional diesel generator plants. **For more information visit [www.danvest.com](http://www.danvest.com).**

## Legal Disclaimer

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