Bonaire's Wind-Diesel Hybrid Power Plant

One-Time-Only or Trend-Setting Project?

Michael Raila
Strategic Business Unit Power Plants
MAN Diesel & Turbo SE, MDT
Augsburg, Germany
michael.raila@man.eu

Timothy Meyers
Sales Manager Carribean Islands
MAN Diesel & Turbo SE, MDT
Augsburg, Germany
timothy.meyers@man.eu

***Abstract*—MAN Diesel & Turbo (MDT) has already proven its expertise in integrating renewable energy sources (RES) and fossil fuel power plants with the realization of world's largest wind-diesel-hybrid power plant on the island Bonaire in 2011. This wind diesel project was managed in a consortium between MDT and Enercon, it includes 14 MW of IC engines and 11 MW of wind turbines and enables an environmental friendly, reliable and economic operation.**

I. History & Background information

The island of Bonaire is a small island with approx. 14,000 inhabitants in the Caribbean and a surface area of 280 km². The island is part of the Netherlands Antilles, belonging to the Dutch kingdom. Electricity consumption is approx. 75,000 MWh per year with a daily peak demand of 11 MW. (5,4 MWh per inhabitant per year). The average electricity cost of Bonaire are about 40 $ct/kWh.

Bonaire as part of the ABC-islands bears ideal conditions for renewables, especially for wind resources. It is located south of the hurricane belt and shows no wind intermittency, but very strong and constant wind speeds.

Bonaire does not have a lot of industry, the main demand is driven by tourism. Hence there is also no significant heat-demand, so that renewable wind energy is widely utilized with penetration rates up to 70 %, whereas the average usage of wind is 35 % over the year.

Going back to Bonaire's history:

A. *Diesel-Based-Generation*

Like many Caribbean islands, Bonaire originally relied on diesel fuel to generate electricity for residents, with a peak demand of 11 MW. This fuel had to be shipped in from other nations, resulting in high electricity prices for Bonaire residents, along with uncertainty about when and how much prices might increase with changing fuel costs. In 2004, everything changed when a fire destroyed the existing diesel power plant.

To serve the load demand and bridge the gap, rental units for power generation have been installed transitionally.

B. *Wind-Diesel-Hybrid-Generation*

In 2006/07 the development of the wind-diesel-hybrid project has been initiated and in 2011 the plant has been commissioned. Since then the plant is in operation providing electricity for major part of the island's inhabitants.

II. Why Hybrid-Solutions?

Bonaire, the Caribbean diver's paradise, has high environmental goals. Bonaire wanted to be the first island which in the long term produces its entire electricity 100 % CO2-free.

Bonaire has perfect wind conditions without annual hurricane seasons. The average wind speed is higher than 9 m/s at the hub height of the turbines. The target for the wind farm was to produce 45 % of all power demand on the island.

According to measurements of wind speed, taken in 2007/08 the wind speed on the islands was as good as on offshore wind farms. There are very few on-shore spots with such constant und high wind-speed throughout the whole year. This was the reason why the idea to build world's largest wind-diesel-hybrid project initially came up.

A. *Project & Cost Structure*

The Project has been developed in an SPV called "EcoPower". This wind diesel project was managed in a consortium between MDT and Enercon as EPC, it includes 14 MW of medium speed engines, 11 MW of wind turbines, high-speed engines and batteries for backup. This solution enables an environmental friendly, reliable and economic operation. Income of the operational unit is generated from power sales to the grid operator (WEB) and sales of carbon credits.

The extremely high local costs as well as the high project development costs lead to total investment cost in the wind diesel hybrid project of approx. 62 million US$ (2400 US$/kW). Taking into consideration the annual fuel savings and the costs for fuel transport and handling, the project is profitable. The economic basis for the investment was a 15 year power purchase agreement.

B. *Technology*

The solution is a wind diesel hybrid system which combines 14 MW from diesel engines (5x 9L27/38, 2,85 MW each) running initially on oil-based fuel (and later on own production algae oil) and 11 MW from wind turbines (12x Enercon E-44, 900 kW each). For emergency purposes a 3 MW/1.3 MWh battery system (3x1 MW Saft Battery Containers) and emergency diesel generating sets (3x 1 MW Cummins high-speed-engines) have been installed as back-up.

Communication between the diesel engine-based generating sets and the wind farm has been realized via an enhanced power management system. Grid stability, which is of fundamental importance to the island, will be secured by the lead of the diesel engine power plant, which is taking over the service of frequency control and frequency regulation.

III. Experience / Lessons Learned

A. Medium-Speed Engines

Medium Speed engines show various advantages especially as base-load application, just to name a few:

- Engine speeds <1000 rpm
- Overall Lifetime – 20 y +
- Plant Availability – 95 % +
- Efficiency – 45 % +, Highest rates of efficiency in the prime mover field, especially in part-load
- Start time – 1 to 3 minutes
- Maintenance - major overhaul 18,000 h
- Fuel flexibility thanks to gaseous, oil-based fuels or dual-fuel applications

B. High-Speed Engines

High Speed Engines show significant advantages in terms of dynamical behavior, the engines are used for managing load fluctuations and provide additional power in low-wind-seasons.

Advantages / Disadvantages of high-speed engines:

- Engines speeds 1500 rpm+
- Overall Lifetime – 5 to 10 years
- Availability – depends on operation
- Efficiency – 37 %
- Start time – >30 sec
- Maintenance – refurbishment after 30,000 h

C. Battery System

The Battery System is not used frequently, because the high speed engines are providing most of the services (e.g. smoothening load-fluctuations, spinning reserve, additional power). Due to recent degression in costs, the battery design will be completely different today.

D. What would we do differently?

1) Battery Storage

Larger Battery Storage providing services like spinning-reserve, load-shifting, load-leveling or peak-shaving might be installed. With the use of larger batteries the amount of high-speed engines could be reduced or even completely replaced. As the high-speed-engines are used for smoothing fluctuations in wind generation and load, the medium speed engines could run on a more efficient operating point providing baseload power, whereas the fluctuations of wind can be buffered by batteries.

Hence a combination of Medium-Speed-Engines together with batteries might be more efficient and more economic.

2) Engines

Medium-Speed-Engines will be used for base-load-operation. Multiple engines are needed to provide flexibility and to serve the demand for the residual spinning reserve or high load fluctuations between low-wind and high-wind-seasons.

In combination with batteries the medium-speed engines might be sufficient to manage high volatility of the wind generation and to fill the gap between high-wind and low-wind season.

Due to the relatively high operation costs, the amount of high-speed engines might be reduced and a larger battery will take over the services.

IV. Technological limits

A. Renewables (e.g. Wind, PV)

The power output of a RES plant is dependent on the wind speed/solar irradiation. Slow changes during the day are subject to the course of the sun during the day. As fluctuations are very slow they can usually be met by load increase of engines.

More critical are sudden irradiation changes due to cloud coverage or changes in wind speed due to gusts or flurries.

A study of irradiation changes for Spain has analyzed irradiation fluctuations for different time steps. Within a timeframe of one second the irradiation can drop by as much as 60 %/s. In 20 seconds the irradiation can drop by more than 90 % of the total load. The same order of magnitude or even less can be observed for wind. Wind fluctuations show figures up to 65 % within 60 seconds for one wind plant and 45 % within 60 s for three wind plants. [1, 2]

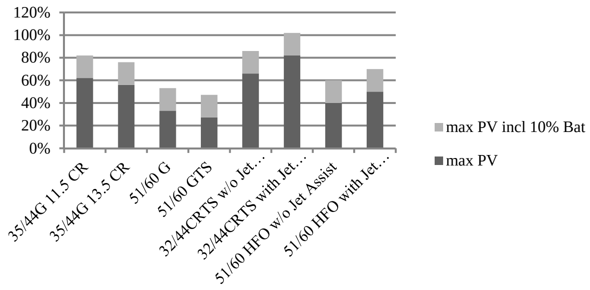
Especially the size of the power plant has delicate influence on the maximum load fluctuations. This is mainly due to the dimension a hybrid plant has.

B. Engines

It can generally be deduced, that liquid engines can integrate more RES, due to their better load applications. Furthermore smaller engines are generally faster and therefore prone for RES integration to a certain level. In case of large RES plants fast load-fluctuations cannot be managed by thermal technology anymore, due to dynamical limitations based on mechanical inertia.

C. Batteries

The following figure shows, how much a battery can improve the maximum RES integration. The maximum RES size is generally limited by the maximum load engines can apply in a short timeframe, which is required when RES output drops unexpectedly. The example shows an ESS with a maximum power output which is equal to 10 % of the engines rated power output. The most critical point is just before the engine can apply the second load step. Since the RES output has decreased by 50 % by that time, the integration of 10 % extra battery power for ramping can increase the maximum RES integration by 20 %.



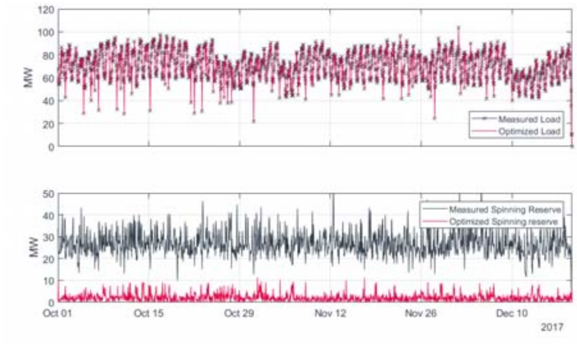
Next to ramping, batteries are especially suitable for providing spinning reserve. If the battery power and capacity is high enough single engines can be replaced. The required battery power depends on the peak-load and the total number of the engines.

Two different configurations are examined. In this case the battery shall provide the same or even more spinning reserve than the engine did. In high load operation the engines share the required power with the minimum number of engines required to serve the load. Since this will usually not be 100 %, a certain amount of reserve is provided by the engines. The rest of the required spinning reserve required to ensure no power shortfall in case of an engine failure will be provided by the battery. The required battery power output can be derived by following formula:

$$P_{Bat} = \frac{P_L}{n} - \left[(n-1)(P_E - \frac{P_L}{n}\right]$$

With:
P_{Bat} = Battery Power
P_L= Peak Load
n= roundup $(\frac{P_L}{P_E})$= number of engines required for peak load
P_E= Engine max output

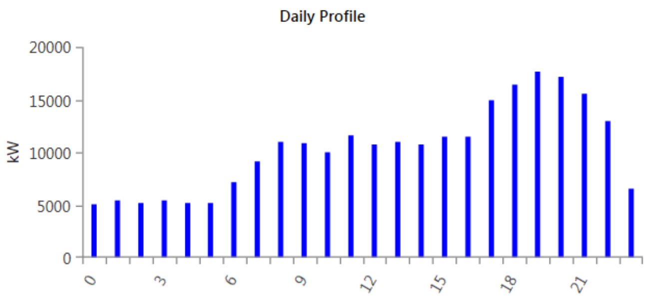
The following figure illustrates the reduction of spinning reserve provided by engines and operational reserve provided by the battery.



V. Conclusion

A. Off-Grid Applications

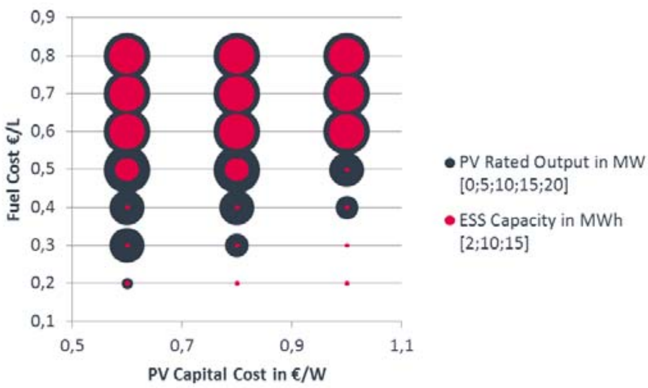
As a typical island size a 40 MW peak load power plant is simulated for this island-application. A load profile meeting typical island characterizes is used for simulation. Typically touristic islands tend to have a strong summer-winter load variation due to increasing number of inhabitants in summer and increasing power demand for cooling. The used load profile for island grids is shown in the following figure for a winter day. During summer the daily peak increases to 40 MW.



For the island of Martinique a HFO price of 21 US$/GJ which is equal to about 0,78 €/l was set. A price increase towards 0,84 €/l is expected by 2028.[3]. The maximum PV size was limited to 20 MW given the space requirements of a PV plant, which allows for a maximum RES penetration of 50%. The maximum possible LCOE reduction is then about 18 % compared to an engine only system.

B. Simulation Results

The simulations show a strong tendency towards high penetration rates. Depending on fuel price and cost of the RES-plant different optimal systems were derived as can be seen in following figure for the 32/44CRTS engine.



It can be observed that the RES size is in most cases limited to the maximum RES penetration. Without limitation the system with the lowest LCOE would be a system with up 80 MW RES plant. In cases with lower fuel prices as low as 0,6 €/l, the RES size is smaller than the maximum of 20MWp. The large RES sizes are next to the comparably high fuel costs a direct outcome of the irradiation. Since irradiation on islands is extremely high, the LCOE of RES plants are rather low. In combination with high fuel prices and therefore higher marginal generation cost, RES systems are in most cases an attractive option.

By increasing the storage capacity of the batteries, excess PV electricity which cannot be used when available, can be stored and reused at times with lower irradiation. This becomes attractive with increasing fuel cost and larger RES plants. The energy storage system in those cases can therefore provide three advantages: improve ramp rates, provide spinning reserve and store excess RES production.

Based on the desired system configurations the resulting LCOE reductions stated in the following chart can be achieved. For a fuel price of 0,3 €/l and RES capex 1 €/W no RES system is included. This reduction is solely based on the replacement of the spinning reserve engine. Generally the savings increase exponentially when the fuel price increases. With increasing RES capex the LCOE reduction decreases linearly.

Compared to Engine +ESS

	0,3 €/l	0,75 €/l	0,8 €/l	0,85 €/l
0,6€/W	-3,05%	-13,90%	-14,96%	-15,57%
0,8€/W	-1,53%	-12,11%	-13,25%	-13,93%
1€/W	0,00%	-9,87%	-11,11%	-12,30%

Compared to Engine Only

	0,3 €/l	0,75 €/l	0,8 €/l	0,85 €/l
0,6€/W	-8,63%	-17,24%	-18,11%	-18,58%
0,8€/W	-7,19%	-15,52%	-16,46%	-17,00%
1€/W	-5,76%	-13,36%	-14,40%	-15,42%

C. Future Challenges

Looking at the electricity generation costs, a hybrid solution is a very attractive solution. But this solution needs to sustain comparison with conventional generating units.

Due to the above mentioned technical limitations and commercial boundary conditions, the crucial part in every hybrid project is the financial feasibility of the whole project financing, including a profitable PPA.

This results in high competition on CAPEX for the thermal generation units, as well as for battery units and all EPC-project overheads coming with the realization of a hybrid power plant.

[1] Dr.-Ing. Siegfried Heier, „Windkraftanlagen im Netzbetrieb“, Springer Fachmedien Wiesbaden GmbH, vol. 2, pp. 271-272., 1996

[2] J. Marcos, L. Marroyo, E. Lorenzo, D. Alvira and E. Izco, “Power output fluctuations in large scale PV plants”, Prog. Photovolt: Res. Appl. 2011; 19:218-227, Wiley Online Library, 2010

[3] Nexant Final Report submitted to World Bank, “Caribbean Regional Electricity Generation, Interconnection and Fuel Supply Strategy”, 2010