RE Flagship Projects in the ECOWAS Region

Case Study: GRID INTEGRATION OF THE ELECTRIC WIND PROJECT

Cabo Verde

BACKGROUND

Cabo Verde is an archipelago country with nine inhabited islands and with a total population of around 540,000 people (2016). The promoters of this 0.5 MW wind power project are strategically targeting the islands with lower peak loads and began with the island of Santo Antão — with around 40,000 inhabitants.

The wind park of Santo Antão was co-financed by the government of the Netherlands, in the framework of the Program PSOM/PSI, whose main purpose was the promotion of the private sector in selected developing countries through economic partnerships between local and Dutch private entrepreneurs. A new company was created (*Electric Wind* SA), with a Cabo Verdean shareholder (*Electric,* Lda) and a Dutch shareholder (*Main Wind* BV). During project implementation, *Main Wind* BV went bankrupt, and it was replaced by another Dutch company, *Green Energy Services* BV. The wind park entered into operation in April 2011, with two wind turbine units of 250 kW, but the developers are expecting to install two other units of 250 kW which are expected to be commissioned by December 2018.

KEY FACTS

Site	Aguada de Janela, Paúl, Santo Antão island
Technology	Wind generators
Generation capacity	0.5 MW
Developer	Electric Wind SA
Operator	Electric Wind SA
Commissioning	April 2011
Investment cost	Approx. EUR 900,000
Financing	Equity, shareholder loans, grant

An Independent Power Producer (IPP) license was granted to *Electric Wind* by Cabo Verde's Directorate of Energy, and a Power Purchase Agreement (PPA) was signed with *Electra* SARL, the national electric utility, for a period of 20 years. A fixed price per kWh was agreed between both parties which has been lower than the avoided cost of fuel for thermal power generation by *Electra.* The tariff is not subsidized, but during the first five years of operation *Electric Wind* benefited from exemption of corporate income tax, in line with the legislation in force at the time.

THE **PROJECT**

When the wind farm started operations, the island of Santo Antão was served by two isolated electrical systems supplied by old diesel units. The wind farm was connected to the electrical system of Ribeira Grande that was powered by three small diesel generators (500 kVA, 1,000 kVA, and 1,000 kVA) which had an average power load diagram as shown in figure 2 (peak load of 1,500 kW and a base load of 800 kW) and served around 6,680 mostly domestic clients in 2011.

These conditions led to the selection of small wind turbine units of 250 kW (MICON M530-250/50) with the following technical characteristics: asynchronous generator, stall regulation, 28 meter high tower, 3 blades with a length of 13 meters. The wind turbines were manufactured in 1993, operated for 14 years in the Netherlands, were then stored for three years and finally reinstalled in Cabo Verde on December 2010.

The interconnection and modernization of the electric grid was performed in 2015/2016, the fifth and sixth year after the wind farm started operation. A great part of the overhead medium tension lines were replaced by underground lines, transformer posts and substation posts were renewed, protection relays were installed or replaced at the most sensitive points of the electric grid.

Along with the interconnection of the electric grids a new and centralized power plant with two new diesel groups of 1,875 kVA each was erected in Porto Novo, covering the entire island. This plant is temporarily burning diesel but is also designed for fuel 180. In addition, there are still the two existing diesel generators with a capacity of 1,000 kVA each.

The system is now serving around 12,000 clients, the peak load increased to 2,800 kW and the base load to around 1,500 kW.

PROJECT MILESTONES

2007

December: Signature of grant agreement with the Dutch government

2008

July: Formation and registration of the joint venture

November: Certification of foreign investor status, obtainment of power production license and signature of PPA with Electra

2010

March: Declaration of bankruptcy of Main Wind BV by the Court of Rotterdam

November: Replacement of Main Wind BV by Green Energy Services BV as SPV shareholder

2011

April: Commissioning of the wind farm

The developer chose second hand wind turbines which had been in operation for 14 years at the time of procurement, because of their cheap price at the time. Decreasing investment costs was crucial, because there was no subsidized price for wind power production in Cabo Verde and, moreover, the project had to offer a competitive price compared with the other electricity producers. To guarantee a good maintenance of the installed second hand units and timely availability of spare parts, the national promoter of the project chose a Dutch partner (*Green Energy Services* BV) that was operating the same type of wind turbines in the Netherlands.

Wind data was collected on site by the project developer during a 12-month period (May 2008 to April 2009), and the corresponding statistical analysis results are as follows (see also figures 1, 2 and 3):

i. Average wind speed of 9.42 m/s at 10 meters height;
ii. Wind blowing from N-NNE-NE directions during 90% of the time;
iii. Daily pattern showing higher wind speeds during the period 10 am to 5 pm;
iv. Annual wind pattern with higher wind speeds from January to July and lower wind speeds from August to December.

Could this project achieve an acceptable amount of wind power production and thus financial sustainability? Could it maintain a steady operation of the second hand wind turbines over the years, along with a good technical performance, allowing a stable operation of the whole electrical system by the system operator?

Figure 1: Wind speed frequency distribution

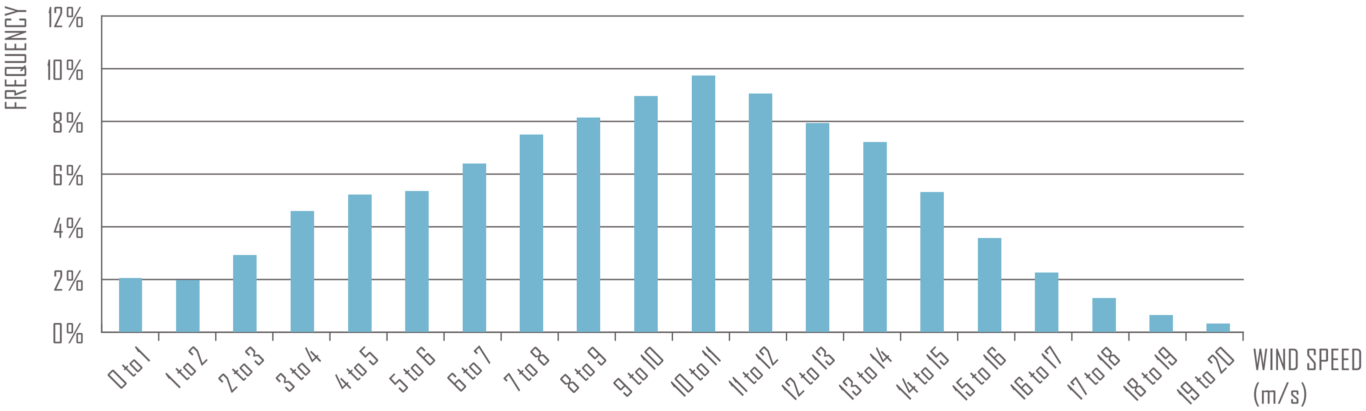


Figure 2: Daily wind speed pattern versus average power demand

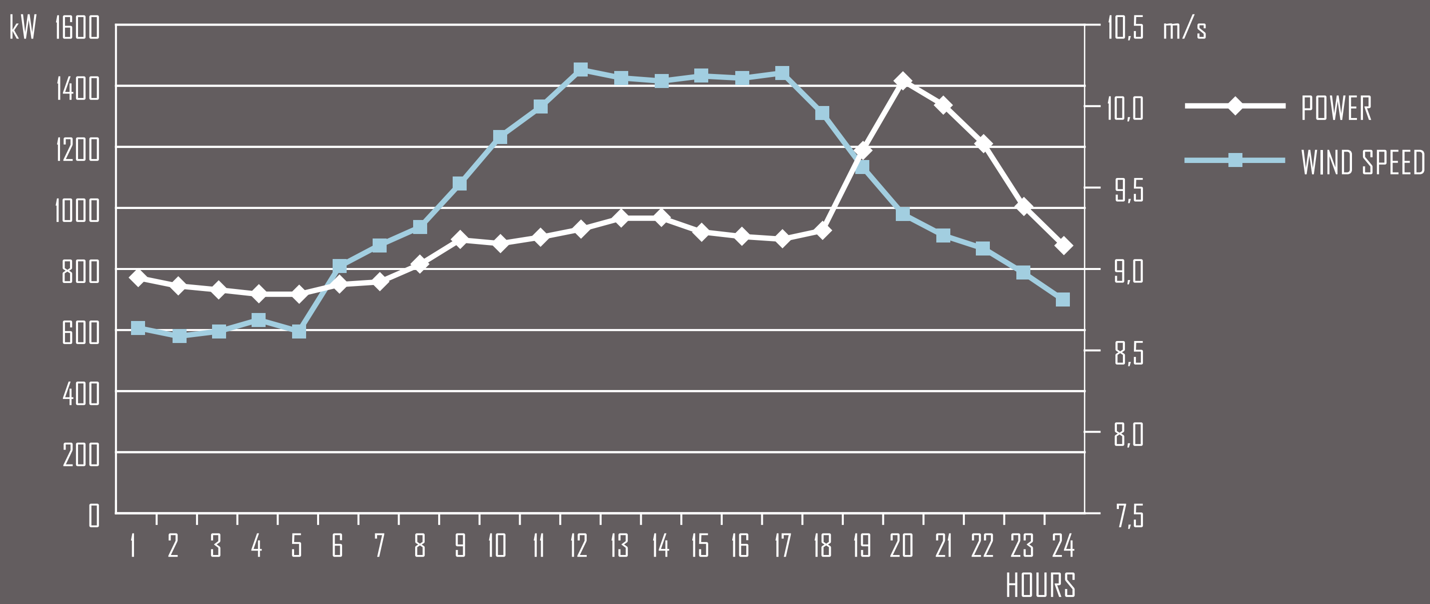
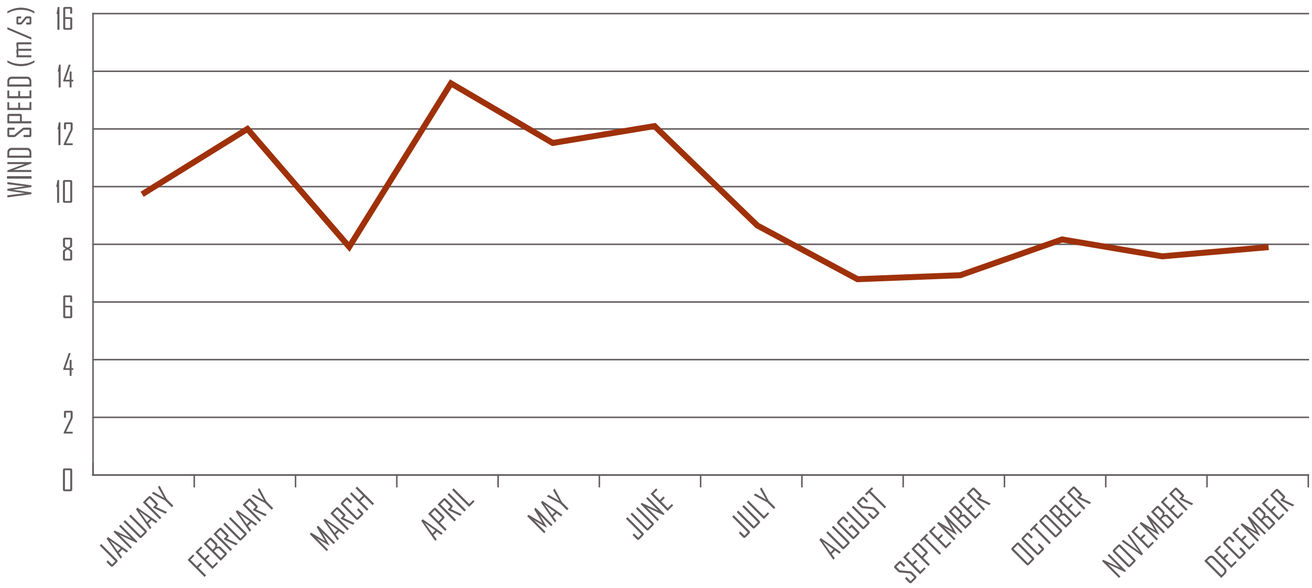


Figure 3: Annual wind pattern

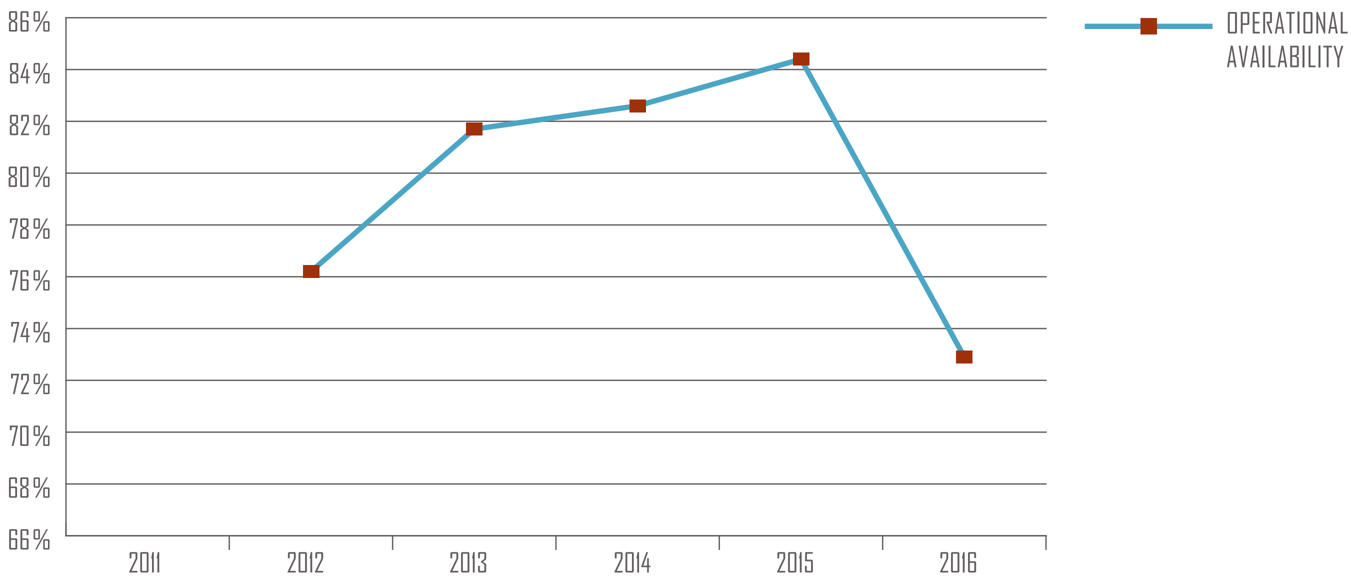


OPERATIONAL **PERFORMANCE**

Operational availability

The operational availability of the wind park increased continuously in the period 2011 to 2015 (see figure 4). In 2016, a major damage of wind turbine unit no. 2 occurred, which lasted for three months, and as a result there was a significant decrease of the average operational availability during that year. Considering that the wind turbines are second hand units with 20 years of operation, the overall operational availability has been very good. After repair of wind turbine no. 2 it is expected that the operational availability will increase again to the reference level of 80%.

Figure 4: Operational availability



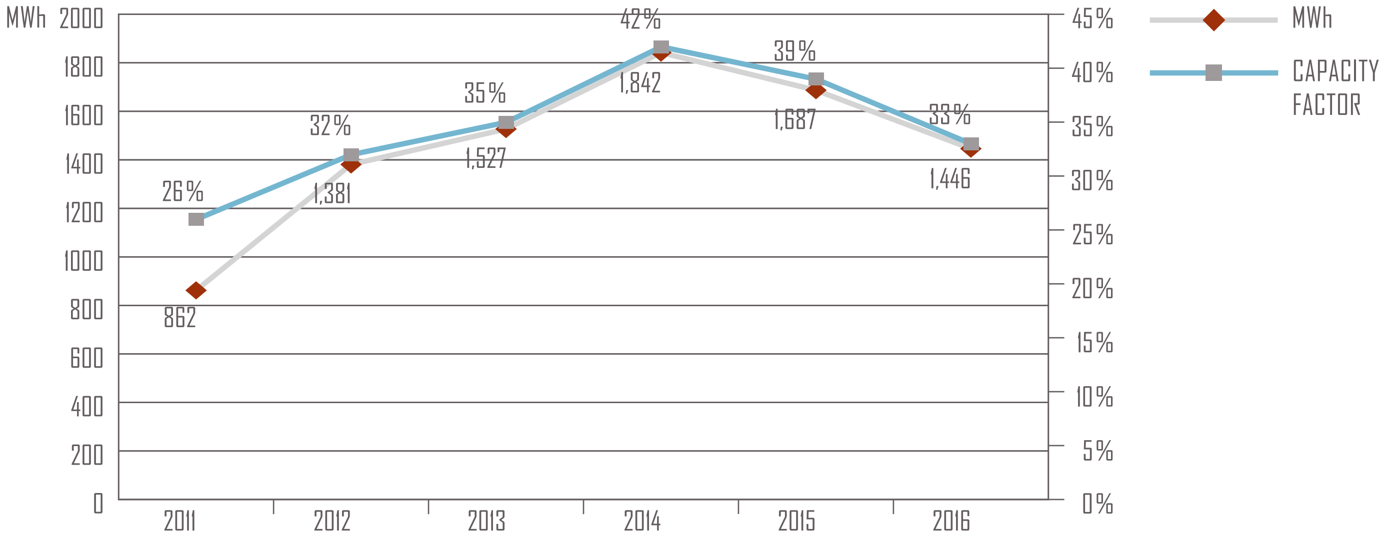
Production and capacity factor

The electricity production is the combined result of the operational availability and the wind conditions. Thus, it is not surprising to find an oscillatory profile for the electricity production.

The yearly production estimated during the planning stage was about 1,600,000 kWh. Figure 5 shows that the wind farm behaved as expected. The year 2011 was an exception because of the learning curve and, additionally, the wind park operated for only nine months (April to December).

The capacity factor of the wind park varies with the production variation, and values higher than 40% are considered good. The average capacity factor for the period 2011 to 2016 was 35% which is a good value for second hand equipment. However, this indicator could be improved in the future.

Figure 5: Wind farm production (MWh) and capacity factor (%)

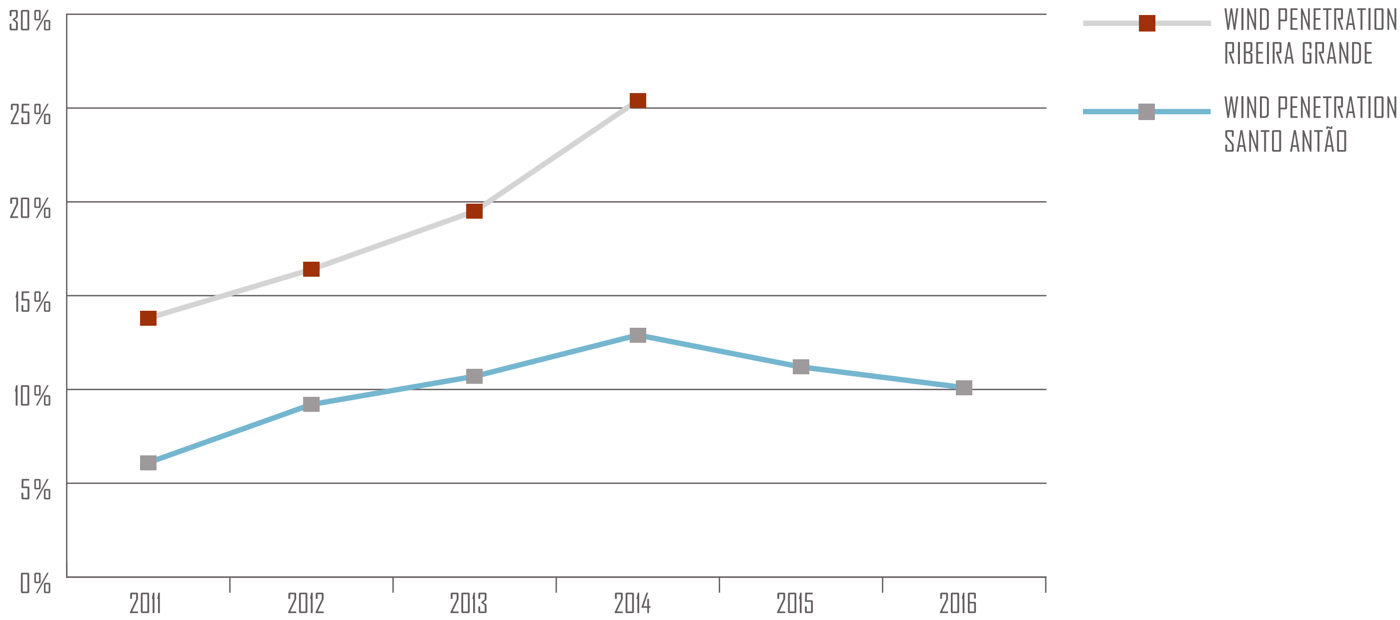


Wind power penetration

Until 2014 the island of Santo Antão was served by two separated electrical systems. In the period 2012 to 2014 the yearly average wind power penetration in the electric system to which the wind park was connected (Ribeira Grande) varied between 16% and 25% as shown in figure 6.

In 2016 the interconnection of the two electrical systems was concluded. If the wind penetration is calculated in relation to the whole island the wind power contribution varies between 9% and 13%. The interconnection of the two electrical systems opened the possibility for the implementation of the second phase of the project which foresees the erection of two additional wind turbines of 250 kW each. As a result the wind penetration is expected to increase again to around 25%.

Figure 6: Yearly average wind penetration in the electrical system



The monthly average wind power penetration varies greatly in the course of the year as illustrated by figure 7, with maximum values between 28% and 38% and minimum values between 5% and 10%. It should be noted that there is a single electrical system for the whole island since July 2015 and thus, from then on, the values of monthly average wind power penetration were significantly lower than before. Peaks of instantaneous wind power penetration have been around 50%.

Averaging the monthly values of wind penetration over the whole period 2011 to 2016 leads to a clear picture of seasonal variation with a profile that is very similar to the yearly wind speed pattern shown in figure 3.

Figure 7: Evolution of monthly average wind penetration in the electrical system

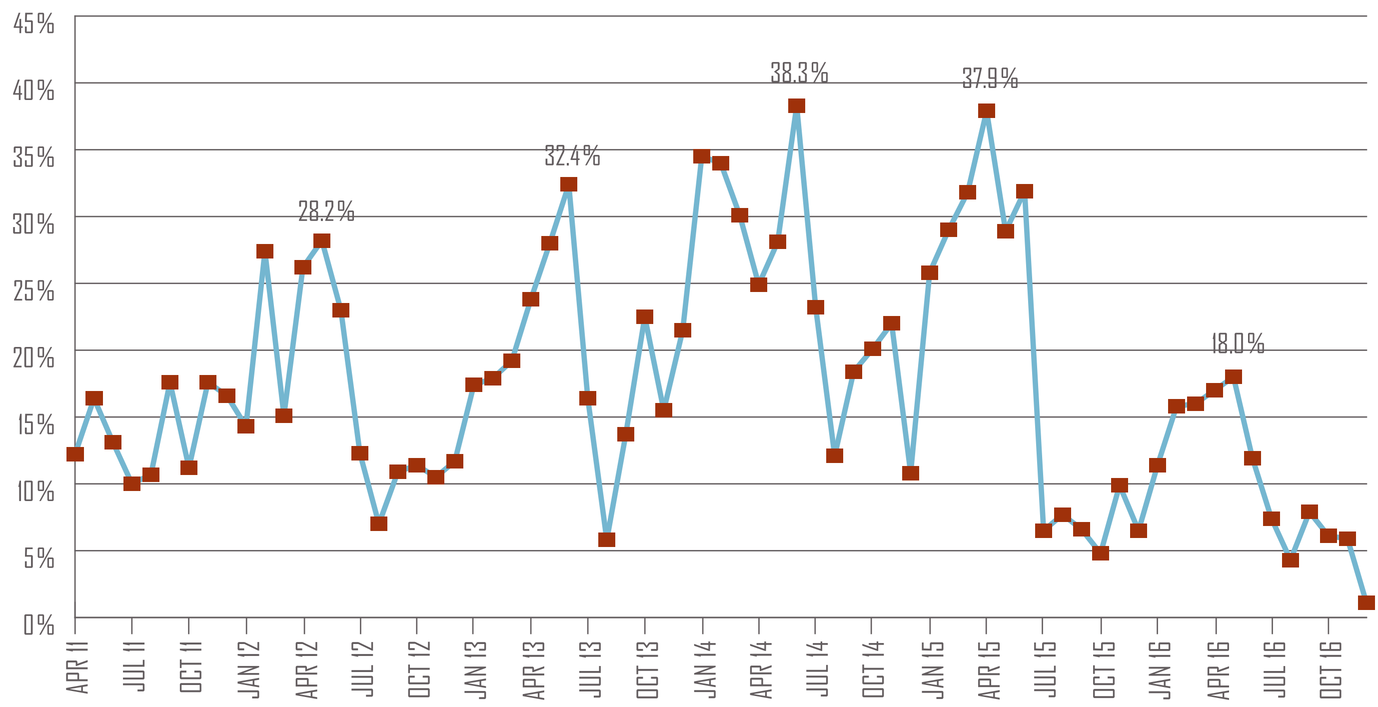
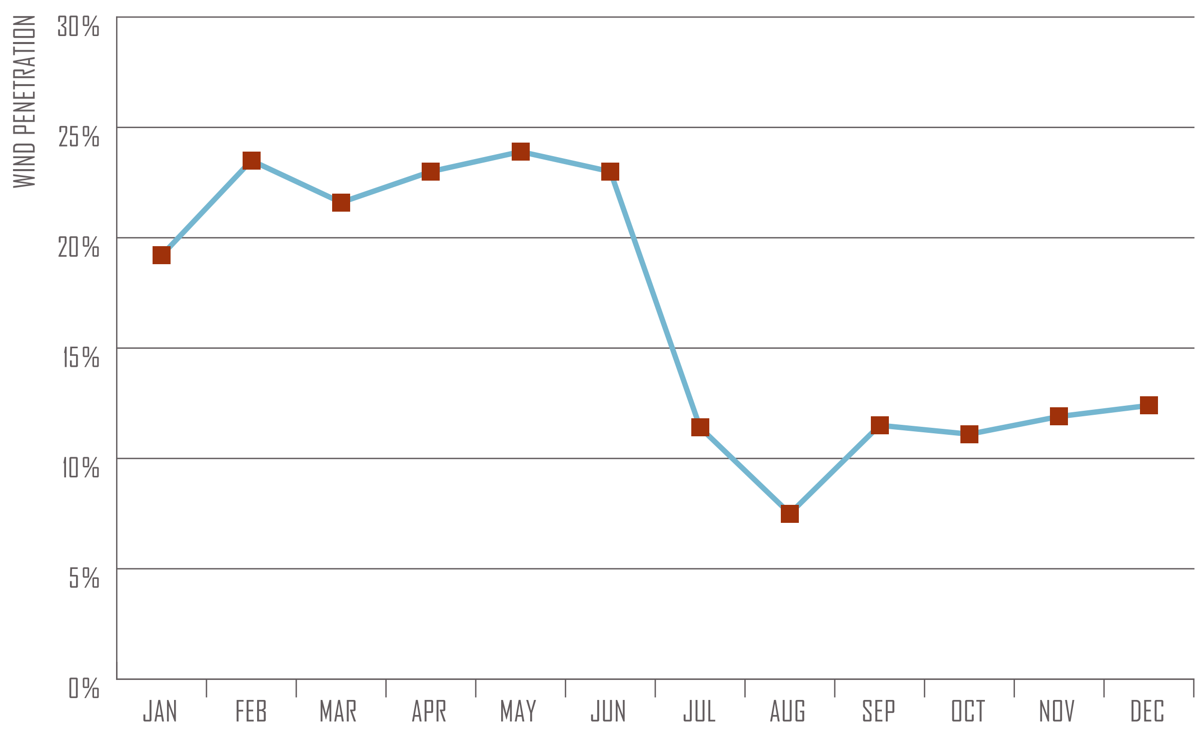


Figure 8: Seasonal variation of wind power penetration during the period 2011/2016



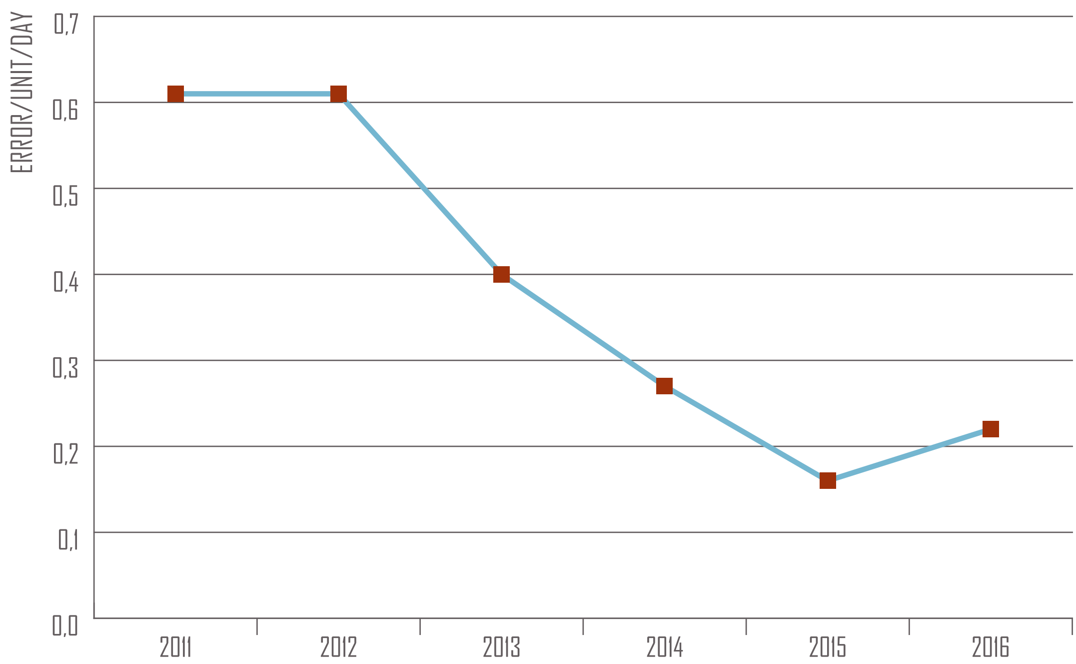
Grid integration challenges

In the case of a weak and isolated electric system, the grid integration of a wind farm requires a thorough evaluation of several technical variables. A single wind farm may lead to a high percentage of the total electricity production in a small system like Santo Antão's. Therefore, proper planning needs to take into account total installed wind power capacity versus total installed capacity, in order to avoid negative effects on the functioning of the grid (e. g. effects on grid frequency).

It should also be ensured that the operation of the wind farm will not increase occurrence of anomalies at the conventional power plants such as black outs or lead to diesel generators functioning below the minimum efficiency recommended by the manufacturer. Based on accurate forecasts for wind conditions and load demand, dispatching rules should be agreed between the national utility and wind farm operator in order to adjust the amount of wind power production to the demand and to the required conditions for the adequate operation of the thermal power units. Finally, for used wind turbines, it is important to monitor the percentage of errors due to aging as compared with other type of errors.

When an anomaly occurs, the monitoring and control system of the wind turbine stops the unit and registers an error signal. The total number of errors has been significantly decreasing from 0.61/unit/day in 2012 to 0.22/unit/day in 2016, the equivalent of one error per wind turbine unit each 4.5 days. This is a very significant achievement, showing a great improvement in the technical performance of the wind farm.

Figure 9: Functioning errors at the wind farm



What is the most common type of error?

Since the wind farm is working with aged wind turbines with no capability to control the active power production delivered to the electric grid, the variation of wind conditions necessarily implies variation of wind power production. On the other hand, before the interconnection of Santo Antão's two electric grids, the wind farm was working together with a small diesel power plant whose control and regulation systems of frequency and voltage was not efficient enough. Under those technical limitations, the main problem was to avoid that the instantaneous wind power penetration exceeds 50%. Above this penetration rate, the control systems at the diesel power plant were unable to guarantee a stable functioning, and the frequency started to oscillate.

Besides the above-mentioned problem, others have occurred. The anomalies can be classified in four different groups as shown in figures 10 and 11: (i) errors related to grid stability; (ii) errors related to problems in the public electric grid; (iii) errors directly related to the wind turbines; and (iv) other types of errors.

Problems related to grid stability are mostly errors of frequency fault which occur when the frequency is outside the 49.0 Hz–51.0 Hz range (original setting). Usually, this error is associated with strong wind conditions and occurs when instantaneous wind power penetration is higher than 50%. During the first six months of operation of the wind park there was a conference call with *Electra* twice a day to monitor the wind power production, the power diagram at the diesel power station and the performance of the diesel generators. Wind power production forecasts for 12 hours were done in an empirical way based on wind speed information from the website www.windfinder.com combined with the daily wind profile at the site of the wind farm. According to the situation on the respective day one of the following decisions was made for the next 12 hours: (i) the two wind turbine units should continue running together; (ii) one unit should be stopped during daytime (manual stop); (iii) one unit should be stopped during night time (manual stop).

Based on the experience of the first six months of operation the following actions were taken to reduce the quantity of manual stops of the wind turbines and allowing the control system to act automatically: (i) the allowed frequency range was extended to 48.0 Hz–52.0 Hz; (ii) the trigging time for the frequency fault protection was set at different values at each turbine, avoiding both of the units being stopped at the same time; (iii) the stall regulation of the wind turbines was changed in order to reduce the production capacity under high wind intensity from 300 kW to 260 kW. As a result, the number of frequency faults became lower and lower, and compared with an initial share of 64% in the total number of errors in the year 2011, they represented only 8% of all errors in 2016 (see figures 10 and 11). Due to this positive evolution, the daily conference call was replaced with occasional conference calls since 2014. After the interconnection of the two grids at the beginning of 2016, there has been no need for power curtailment and, therefore, requests from the national utility to disconnect the wind farm are now only related with regular maintenance and problem solving at the electric grid.

Anomalies at the wind turbine units are now the main reason for the wind farm to be out of operation. This is not surprising, because component failures become more and more common after 20 years of operation. However, a more strict maintenance plan is under implementation in order to guarantee a normal operation of the wind farm during its entire life time.

Regarding the problems on the electric grid side, these are expected to reduce during the next years, due to the considerable investments made by the public utility to modernize the grid and construct a new and modern thermal power plant.

Figure 10: Absolute number of errors per type

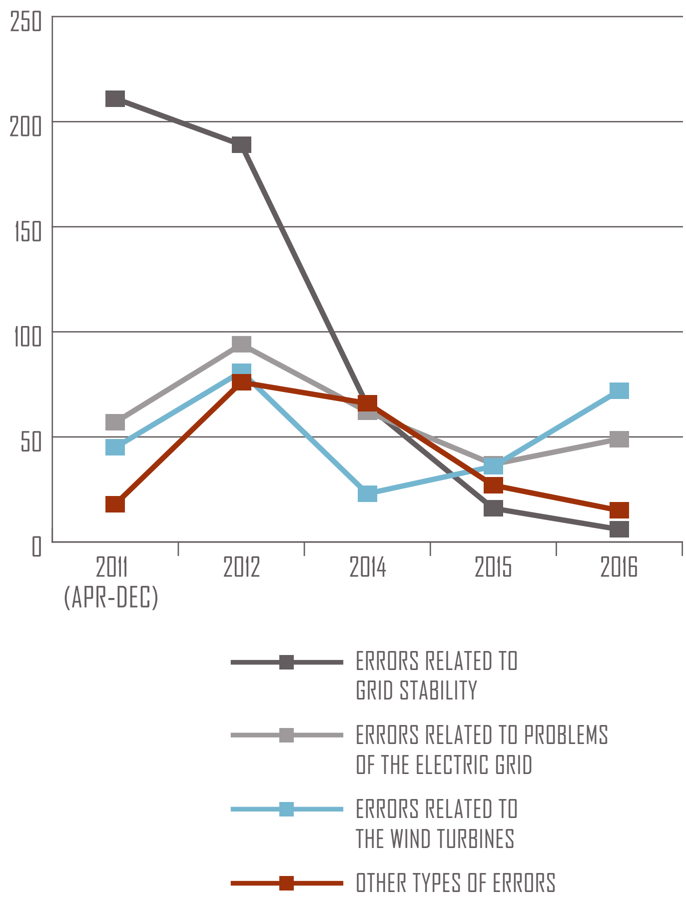
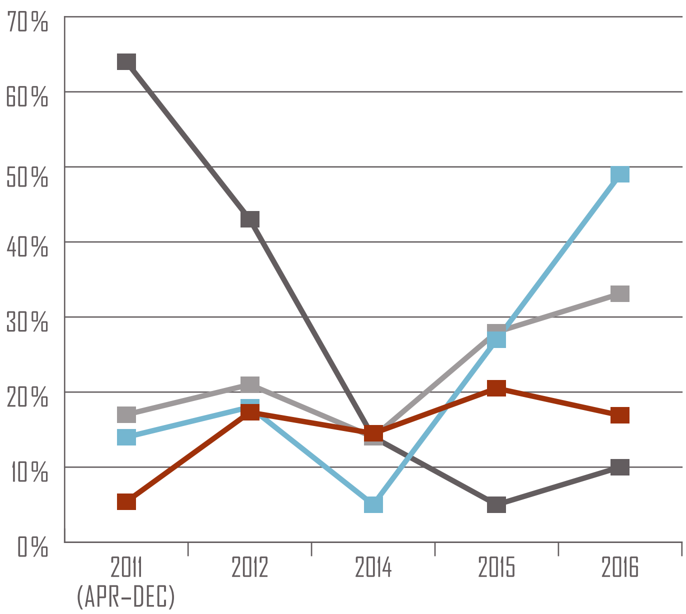


Figure 11: Distribution of errors per type



Planned extension of the project

The second phase of the project, the erection of another 2 × 250 kW wind turbines, is expected to be implemented in 2018, and no technical constraints are foreseen.

The current peak load of the whole island (year 2016) is around 2,800 kW and the base load around 1,500 kW. For the period 2019 to 2021 the average wind power penetration is expected to increase again to a value around 20% as a result of the commissioning of phase II of the *Electric Wind* project. Probably, during the period 2019 to 2021, there will be the need for wind power curtailment during periods of high wind speeds in order to avoid that instantaneous wind power penetration exceeds 50%.

A monitoring system will be installed at the diesel power plant, allowing remote access to the panel board of each wind turbine unit for online information and timely management decisions. The system will be able to control the wind park remotely, but this should be done only in very specific situations to be agreed between both parties. Also a grid analyser will be installed at a selected point of the electric grid to collect appropriate data for evaluation of the impact of wind farm operation on the public grid, especially in terms of frequency variation.

Finally, a power flow study will be carried out to evaluate the contribution of the wind farm for reducing power losses and voltage drop in the grid.

If it is found that an average penetration rate of 20% to 25% can be achieved without noticeable disturbance of the electric grid, a higher new target can be proposed to the Government in the framework of a new project.

FINANCIAL **VIABILITY**

The financial viability of any wind farm project depends on various factors, especially the total financial investment and the amount of energy delivered to the grid.

The total investment of this project was about EUR 900,000, representing an amount of 1,800 EUR/kW. It may be considered a risky investment, taking into account that the expected life time of the second hand wind turbines is only 10 years. The high financial risk was mitigated by a grant from the Government of the Netherlands accounting for 50% of the total investment. The remaining capital was raised through shareholder loans, 25.5% from *Green Energy Services* BV and 24.5% from *Electric,* Lda.

Electric Wind does not benefit from a subsidized price for the electricity injected into the electric grid. The income results only from the power purchase agreement signed with the national electric utility, but this is a win-win project, since the project generated financial benefits for all the interested parties.

During the period 2011 to 2016, the operation of the wind park already allowed financial savings in fuel costs equivalent to 166% of the project investment cost (see table 1). This is a very important macro-economic benefit for a small country that imports around 90% of everything that is consumed internally.

For the national electric utility purchasing power from the wind park operator has been very profitable considering that the purchase price of the wind power electricity fed into the grid has been most of the times significantly lower than the avoided cost of fuel (see table 2).

For the private partners of the wind farm project the financial results have also been positive, since all the private investments were totally paid back in 2016. However, if the private partners had had to mobilize all the financial investments of EUR 900,000

Table 1: Savings on fuel import cost

YEAR	PRODUCTION (kWH)	FUEL SAVINGS (LITER)[1]	FOREIGN CURRENCY SAVINGS (EUR)[2]	AVOIDED GREENHOUSE GAS EMISSIONS (TON CO_2 eq.)[3]
2011	861,759	237,049	203,827	612
2012	1,381,310	389,223	326,714	981
2013	1,527,097	434,277	286,426	1,084
2014	1,841,690	560,857	345,663	1,308
2015	1,687,104	477,867	213,117	1,198
2016	1,445,758	384,006	127,873	1,026
TOTAL	8,744,718	2,483,279	1,503,621	6,209

[1] Fuel savings were calculated on the basis of the specific fuel consumption registered at the diesel power plant.

[2] Foreign currency savings were calculated on the basis of imported fuel cost reported by Agência de Regulação Económica (Economic Regulatory Agency — ARE).

[3] Avoided greenhouse gas emissions based on 0.71 t/MWh.

(phase I), a higher tariff of about 33% more than the current tariff would be needed to guarantee the financial viability of the project.

For phase II of the project, the investment costs will be fully supported by the private partners. Nevertheless, it was found at the planning stage that the expansion will lead to a better financial performance of the whole project. However, a new feasibility study should be conducted, updating costs for second hand wind turbines and including new costs due to changes in the law after the year 2011, such as import taxes for second hand equipment and corporate tax income also during the first five years. Keeping the tariff at the same level of 0.13 EUR/kWh for the next 10 years, and at the same time generating financial benefits to all partners is the final goal of the project.

Table 2: Tariff of wind power versus avoided fuel cost

YEAR	AVERAGE FUEL COST ON THE ISLAND OF SANTO ANTÃO (EUR/kWH)[4]	WIND POWER TARIFF (EUR/kWH)[5]
2012	0.29	0.15
2013	0.24	0.13
2014	0.25	0.13
2015	0.18	0.13
2016	0.14	0.13

CONCLUSIONS

At the planning stage, *Electric's* Santo Antão wind farm was considered a risky project, because there was no experience in dealing with used wind turbines and, additionaly, the wind farm was to be connected to a small grid supplied by an old thermal power plant. After six years of operation the project may be considered a successful case of a small wind farm that is integrated into an isolated and weak electric grid, and some important lessons can be learned from it.

First of all, grid stability (frequency oscillation) can be a challenge in situations of wind power penetration above 50%. Therefore, suitable working rules should be agreed with the electric grid operator, and the control system of the wind turbines should be very well fine tuned according to the existing functioning conditions of the whole electric system.

The monthly average wind power penetration varies widely over the year, reaching peak values between 28% to 38% during periods of high wind speeds. Concerning the yearly average wind power penetration rate, the variation is lower with a maximum value of 25%. These are very significant values for a small to medium size wind farm.

Power curtailment and failures on the electric grid side did not have a strong impact on the financial viability of the project. The first reason is because the average yearly production was correctly estimated, taking into account realistic losses of production caused by turbines faults and electric grid faults. Secondly, *Electric Wind* was able to train a young team of Cabo Verdean technicians who gained the competency to understand and to successfully operate this wind power system that is connected to an isolated and weak public grid.

The financing of the project was facilitated by a very specific program opportunity which made it possible to generate financial benefits for the private partners, the national utility and the country's trade balance, while avoiding greenhouse gas emissions.

[4] The fuel cost values are based on the specific fuel consumption at the diesel power plant on Santo Antão and on price of fuel established by ARE.

[5] The Power Purchase Agreement established a lower wind power tariff after the first 18 months of operation.

FURTHER READING

Graça, Daniel (2012): Santo Antão Wind Project — First IPP in Cape Verde. In: Vilar (ed.), Renewable Energy in West Africa: Status, Experiences and Trends. http://www.ecreee.org/sites/default/files/renewable_energy_in_west_africa_0.pdf

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