Return of Experience on Renewable Energy Integration in Islands and Remote Locations

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***Abstract*—Since VERGNET was founded nearly 30 years ago, the hybridization of grids on islands nations or remote places has been a major part of the Group's business, leading to an extensive experience in these areas. Focusing on delivering solutions that meet the requirements of the utilities, the consumers and the governments has allowed VERGNET to build hybrid projects integrating various combinations of wind, solar and or battery to existing or new diesel plants on several islands or off-grid systems worldwide. VERGNET solutions have been installed in 61 countries across all continents including Antarctica.**

Installing wind or solar plants in remote areas such as small islands means facing the problem of connecting intermittent renewable energy sources to weak grids. This becomes even more complex today with the integration of various combinations of wind, solar PV, diesel and storage. Challenges went initially from simply making wind turbines connection to the grid acceptable to the utility, to now maximizing renewable penetration/energy share with up to 100% renewable source supported by grid forming Battery Energy Storage System (BESS). VERGNET has constantly increased its know-how/expertise to tackle these challenges and provide turnkey solutions, which led to the development of its real time controller: HYBRID WIZARD. HYBRID WIZARD is able to ensure a smooth integration of renewables on the electrical grid even at higher penetration rates, control of key grid parameters, manage the various generators at their optimum levels of operation and also integrate short term weather forecast to mitigate variability and intermittence of renewables power output.

In this presentation we propose to show insights from design of hybrid systems to field data taken from very different utility or industrial installations all over the world going from Guadeloupe (1.925 MW Wind), Mauritania (Nouadhibou — 4.4MW wind 12MW diesel) to Yap (825kW Wind, 600kW Solar, 2.48 MW diesel). For these projects VERGNET was selected through international tenders, they have in common a pre-existing diesel electrical plant installation to adapt to and industrial or small utility customers seeking to reduce their diesel bill with highest return on investment while keeping a reliable grid.

I. INTRODUCTION

Most islands countries have identified transition to renewable energy as a key priority, majority of the RFP today specify hybridization of power production, but there doesn't seem to be a precise definition of what is an power hybrid system. Everything is not hybrid, connecting a 500kW solar plant to a 5MW diesel grid is not what we call hybridization at VERGNET.

II. WHAT IS HYBRIDIZATION?

We consider an installation to be *hybrid* if for a reason or another a *curtailment of renewable energy* is required e.g

- Thermal gensets operational limits
- Spinning reserve
- RE Power excess (when battery grid forming)
- Voltage regulation
- Frequency regulation
- Grid safety
- Power quality (Harmonics, flicker)

III. ISOLATED GRIDS KEY POINTS

Small Islands grids are often called *weak grids* characterized by a relatively small installed power combined with low spinning reserve and a high load fluctuations:

- Small installed power
- Low short circuit power
- Small spinning reserve
- High ratio $\frac{peak\,demand}{short\,circuit\,power}$

Theses specificities lead to potentially high variations of voltage and frequency in case of grid fault or power producer failure. Due to their unpredictable nature and sensitivity to grid perturbations, wind and solar power have little contribution to grid stability and cannot be used as spinning reserve.

Grid safety becomes an issue, short circuit power can be too low to trip existing protections so specific dynamic grid protections have to be designed and properly set. The protection setpoints at high penetration rated need to consider the required short circuit power that ensures transient stability.

To ensure the grid stability, utilities have therefore often arbitrarily limited the share of renewables power to 30% of the total *installed* power.

IV. EARLY PROJECTS CASE STUDIES

A. *Les Saintes*

Despite the small installed power and low penetration rate, due to the high impedance at point of common coupling the *Les Saintes* 1.925 MW wind power plant (fig 1) experienced connection problems with too high voltage. This was the first time VERGNET encountered hybridization issues and a very trivial form of automatic regulation had to be implemented:

- Automatic active power limitation

- Automatic reactive power regulation at plant level

Fig 1 — Guadeloupe, Les Saintes — Terre de Bas — Commissioned 2007

From this first case with increasing renewable power, more sophisticated renewable energy control systems were developed implementing comprehensive grid studies and dynamic settings with communication with other generators.

B. Nouadhibou

The SNIM[1] company is operating iron ore mines in Zouerate, region of Tiris in Mauritania. More than $12\,\mathrm{Mt}$ of ore per year is transported by train from the mines to Nouadhibou harbor to be loaded and exported by sea.

Fig 2 — Mauritania, Nouadhibou — SNIM — Commissioned 2013

In order to reduce its carbon footprint and energy production costs at ore treatment facility, the SNIM company issued an EPC tender in 2010 for the construction of a $4.4\,\mathrm{MW}$ wind power plant (fig 2) on his site of Nouadhibou in Mauritania.

1) Site conditions:

- Wind speed $8.78\,\mathrm{m\,s^{-1}}$ at hub height, Weibull 3.63
- Near shore, hot climate, no rain, very high corrosion, sand

[1]Société Nationale Industrielle et Minière

2) Grid: The facility is powered by a $16\,\mathrm{MW}$ diesel plant equipped with $4{\times}4\,\mathrm{MW}$ diesel gensets feeding a $5.5\,\mathrm{kV}$ grid. Only 3 gensets are connected at a time. Consumers are essentially motors for ore conveyors and crushers.

VERGNET proposed a full study to assess and guarantee the achievable wind power penetration according to wind profile, grid load cycles and diesel gensets characteristics while preserving:

- Security of goods and persons
- Availability of the grid
- Power quality

The studies covered the following points:

- On site measurement session to precisely characterize the gensets performances
- Numeric modeling of the whole grid with producers and consumers
- Simulation campaign addressing all possible cases
- Diesel-Wind power plant operating rules definition from analysis of simulation results

3) Measurement campaign: A set of measuring and monitoring equipment was installed in the production facility to record voltage, current, frequency.

Several test cases were conducted:

- 15% load increase step
- 20% load increase step
- 28% load increase step
- load shedding
- Busbar disconnection
- Transformer magnetization

4) Measurement results: The measuring campaign enabled the characterization of the generators for the computer model, the diesel groups time constants were measured, some groups inertias were missing but assumptions were made. The gathered data on diesel groups parameters, speed governors, excitation regulators were sufficient to properly model the groups and optimize parameters by numeric simulation.

The main goal of this study was to define the maximum penetration rate so that grid parameters (mainly voltage and frequency shifts) remain compliant with standards and client's needs during normal and unforeseen transient events. Essentially, the wind power plant must not disturb the diesel power plant in both transient and steady states.

The behaviors of the diesel power plant and wind power plant were checked during both normal and unforeseen transient events like:

- Disconnection of one or several wind turbines
- Disconnection of the whole wind power plant
- Starting of power loads
- Disconnection of loads
- Disconnection of a diesel group
- End of shortcut event

The worst case scenario was computed and found to be the same in any situation of production (1, 2 or 3 groups connected): it is the disconnection of the whole wind power plant.

This case is the one limiting the penetration ratio, it is adjusted in order to always have a correct running state of the diesel plant i.e it is lowered to increase the group power for higher stability.

Following electrical study, a set of operating rules were defined to set the wind power plant power level according to grid state.

5) Penetration rate: We define the penetration ratio r by :

$$r = \frac{P_W}{P_L} \times 100 \quad (1)$$

Where P_W is wind power, P_L is load power, P_W is limited by all the cases listed in section II.

Data in *italic* in table I show steady state penetration ratio r computed from site studies, a "△" represents cases with a blackout risk due to lack of spinning reserve, a "⊖" represents impossible cases.

Load (kW)	Nb running groups		
	1	2	3
1000	*20.0%*	⊖	⊖
1500	*46.7%*	⊖	⊖
2000	38.3%	*20.0%*	⊖
2500	30.6%	*36.0%*	*4.0%*
3000	25.5%	*46.7%*	*20.0%*
3500	21.9%	43.7%	*31.4%*
4000	19.1%	38.3%	*40.0%*
4500	△	34.0%	*46.7%*
5000	△	30.6%	45.9%
5500	△	27.8%	41.7%
6000	△	25.5%	38.3%
6500	△	23.5%	35.3%
7000	△	21.9%	32.8%
7500	△	20.4%	30.6%
8000	△	19.1%	28.7%
8500	⊖	△	27.0%
9000	⊖	△	25.5%
9500	⊖	△	24.2%
10000	⊖	△	23.0%

Table I — Achievable long term penetration ratio

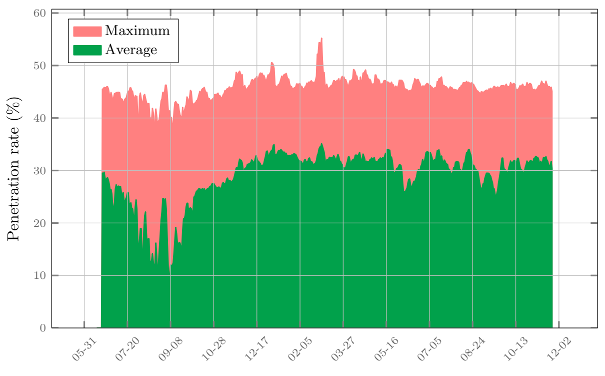

Fig 3 — Mauritania, 1.5 year daily penetration record, 7 days average

Customer did not allow a full automation of diesel Genset so operating values are set by operators, however, very good results are achieved thanks to exceptional site conditions as shown in fig 3 where 18 months of daily maximum and 7 days average penetration rates are displayed. August is a lower wind speed period explaining the decrease of penetration average. Sustained penetration rate is above 30% in high wind periods.

- Wind power plant output: $19\,\mathrm{GW\,h\,year^{-1}}$
- Fuel savings : $4800\,\mathrm{t\,year^{-1}}$
- Pollution avoided (CO_2, NO_x, SO_2): $11\,500\,\mathrm{t\,year^{-1}}$

V. Technology Evolution

Building on field experience, VERGNET developed HYBRID WIZARD, an hybrid controller featuring a *Feedback Loop*, to monitor the grid in real time.

The system auto-adapts to the grid conditions, controls power quality. Grid stability is guaranteed, RE penetration is always maximized to what the grid can accept. Limits are set with the same grid studies as described in previous sections.

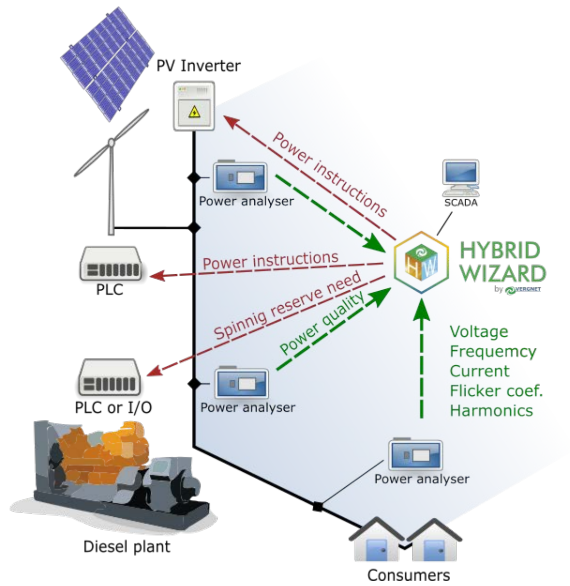

Fig 4 — Hybrid Wizard

- Real-time control of power quality
- RE penetration is always maximized to what the grid can accept
- Grid stability is guaranteed
- Grid safety is guaranteed

VI. Recent Project Case Study

A. Yap Island

The Yap Renewable Energy Development Project's primary goal was to reduce fossil fuel dependence on the island of Yap by installing properly sized diesel generators and integrating a large amount of renewable energy in the Yap power system. The project was launched by an international bid in 2014.

The Yap power system was transformed from virtually no renewable penetration to a high renewable penetration system. The need for a sophisticated control system which automatically dispatches conventional and renewable generation to match power system conditions was recognised early in the project planning.

Fig 5 — Micronesia, Yap — YSPSC — Commissioned 2018

VERGNET was selected for the supply and installation of the wind power plant and also the Control System with the implementation of HYBRID WIZARD.

Max Load	2200.0	kW
Min Load	610.0	kW
Average Load	1518.8	kW
Spread	1590.0	kW

Table II — Grid data

Description	Max capacity
Commercial/residential solar plants	300 kW
Solar plants	300 kW
Wind turbines	3 x 275 kW
Diesel generator	830 kW
Diesel generator	1650 kW

Table III — Yap Power plants

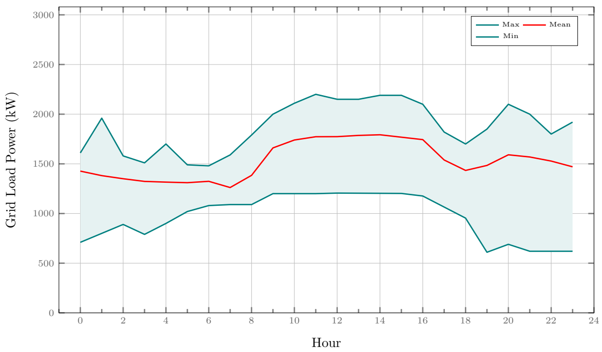

Fig 6 — Yap power curve enveloppe

1) Site conditions:

2) Grid studies: The typical work scope described in paragraph IV-B2 was conducted with the added following points:

- Earthing studies for the purpose of determining quality of the current earthing system.

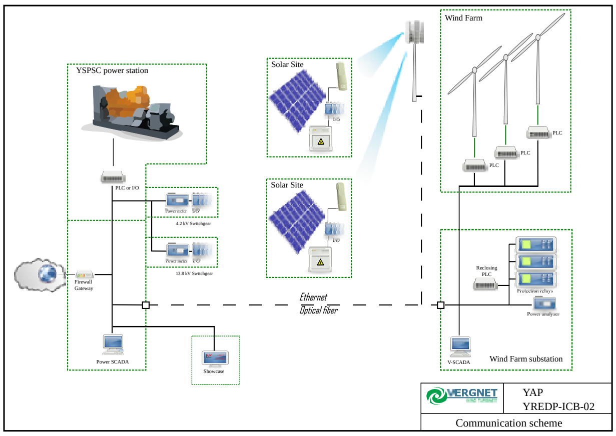

Fig 7 — Yap communication scheme

- Switching studies for distributed solar PV plants.
- Settings specification for solar PV inverters and transformer tap settings (each solar PV generator has its own, dedicated transformer)

Fig 7 shows communication scheme, 5 solar power plants distributed on the island are controlled through radio network, wind power plant, diesel power station and one solar plant are connected with optical fibre.

3) Site conditions:

- Wind speed $6.3\,\mathrm{m\,s^{-1}}$ at hub height, Weibull 2.3
- Near shore, tropical climate, difficult access to site, cyclones

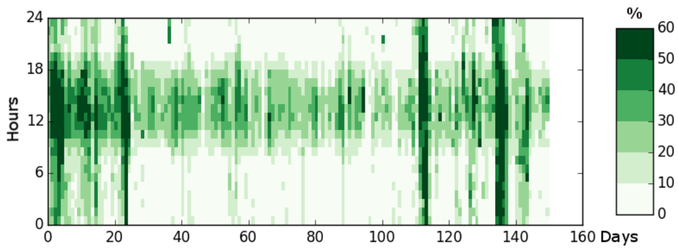

Fig 8 — Yap expected penetration heatmap

4) Expected performances: With minimum load (table II) of 610 kW and total renewable power (table III) of 1425 kW, theoretical maximum penetration ratio is 100%. Taking into account resources, actual load and diesel condition, expected annual renewable penetration at bid time was 20% with sustained penetration ratio of 50% and more. Fig 8 shows penetration ratio taken from grid load flow simulation (x values are days and y values hours).

5) Results: Turbines have just been commissioned and at date HYBRID WIZARD is being tuned but still, first data are inline with expectations, more data to be shown at conference!