Smart Renewable Hubs: Multi-Hybridization to Achieve High RE Penetration in Island Grids

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***Abstract*— Deployment of Variable Renewable Energy (VRE) around the world has created concerns about grid stability and energy curtailment; there are on-going studies to evaluate VRE limitations. Decarbonizing the electric sector will require more flexibility and dispatchability from VRE. A special focus is being made in Energy Storage to boost Renewable Energy Sources (RES) integration, but there are requirements to provide backup capacities. Several islands deal with VRE limitations and the burden of energy dependency leading to high electricity costs. Smart Renewable Hubs (SRH) proposed by GRIDSOL project can increase RES penetration in these markets. This paper describes SRH characteristics, assessing the implementation of a SRH (“HYSOL” (CSP+GT), PV, Wind and batteries) compared with other alternatives in an isolated grid, showing how GRIDSOL concept would reduce the system cost in a high-RE scenario.**

Keywords-hybridization; energy storage; VRE; renewable content; dispatchability; firmness; isolated grids

I. INTRODUCTION: SMART RENEWABLE HUBS

A Smart Renewable Hub (SRH) is a flexible hybrid power plant that combines both synchronous and non-synchronous generators, along with energy storage systems, connected to the grid. This kind of Renewable Energy Sources (RES) hybridization presents synergies joining cheap VRE and backup generation capacities in a single power plant, avoiding the requirements of external reserves and providing dispatchability and firmness with a high RE share and low system cost.

The SRH concept is being developed in GRIDSOL, a research project aimed at finding a cost-effective way to significantly increase renewable energy (RE) penetration in the electric system without compromising its stability. The ambitious target of 80% RE content in the energy mix is achieved through the combined action of a coordinated control system (Dynamic Output Manager of Energy – DOME) and a plant design tool (Smart Renewable Hub Modeler – SRH-M).

The SRH-M software includes simple models for a number of generation technologies: PV; wind; Rankine cycle powered by CSP (tower, parabolic trough, and multi-tower), coal, biomass; Brayton cycle using gas, biogas or other fuels; combined cycle, both regular and decoupled through HYSOL. HYSOL is a heat recovery system that allows decoupling the operation of the gas and steam turbines in a combined cycle through the use of thermal energy storage [1].

Besides generation, SRH-M includes models for both Thermal Energy Storage (TES) using molten salts, and Battery Energy Storage (BES) using several technologies: lithium-ion, lead-acid, vanadium flow, etc.

II. THE RELEVANCE OF STORAGE

The main challenge in the use renewable energy as the basis of an electric system is timing: resource availability and consumers’ demand each follow its own, only slightly related trend, so security of supply must necessarily include energy storage. Fossil fuels are, after all, just vectors for solar energy stored in chemical bonds billions of years ago.

Energy storage can come in multiple forms; thermal (sensible heat, latent heat, and/or thermo-chemical), electro-mechanical (pumping-hydro, flywheels, compressed air, etc.) and electro-chemical (batteries, supercapacitors, etc.) are the most common. Sizing the energy storage systems, both in terms of charge/discharge power and energy capacity, is a critical step towards the economic sustainability of the system. GRIDSOL’s SRH-M software uses a multi-variate optimization approach: generation and storage are optimized simultaneously with the target of serving the grid’s requests both in terms of energy demand and ancillary services.

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III. MODELLING OF GENERATION TECHNOLOGIES

Each generation or storage technology is modelled in Matlab, using a combination of first-principles equations and empirical correlations, in order to obtain a sufficient level of detail in the inputs and outputs while staying computationally light enough to carry out full-year hourly simulations in a very short time. This approach makes numerical multi-variate optimization achievable within a reasonable timeframe.

IV. DOME'S CORE: REASONABLY PRUDENT OPERATOR

In order to ensure that the optimization makes sense throughout the year, an automatic regulation system is embedded in the SRH-M software. This regulation system shall be furtherly developed into DOME, an industry-grade plant control suite.

The regulation system emulates, on an hourly basis, the actions of a Reasonably Prudent Operator (RPO), taking into account the information that would be available for said Operator at any given time: status of equipment, weather forecast, demand forecast / programmed production, etc.

With this information, operational rules are defined along the following overarching objectives:

- Maximizing renewable content.
- Minimizing curtailment/dumping of primary energy.
- Ensuring firmness, i.e. reaching at least 95% of the target production, 95% of the time.
- Maximizing efficiency

V. ISLANDS AND NON-INTERCONNECTED SYSTEMS

In poorly-interconnected systems, such as islands, the power of a single plant, and especially of a Smart Renewable Hub using several technologies, is a significant fraction of the overall power traded in the grid. This has two main implications:

- The grid can only absorb a certain amount of energy generated by the SRH at a given time. The available niche is capped by the total demand of the consumers in the system, and it has a bottom in other non-dispatchable VRE and must-run units in the grid.
- The available niche is both an opportunity and a responsibility: failing to meet the niche demand could have a negative impact on the stability of the grid.

The demand-based control strategy is applied in this case: under these assumptions, and considering the overarching control principles, all technologies must operate coordinately. A short-term forecast of the expected market demand is used as a target / global set point to be followed by the plant. The control strategy / RPO must decide the hourly individual set points (energy mix) for each technology that will allow the plant to reach the hourly global set point with an optimal use of resources.

VI. CASE STUDY: THE FUERTEVENTURA-LANZAROTE SYSTEM

The Fuerteventura-Lanzarote system (Canary Islands, Spain) has been chosen as a comparison scenario. A SRH using PV, Wind and Batteries in combination with a Decoupled Solar Combined Cycle (DSCC: CSP tower solar field, gas turbine and HYSOL) is compared to an alternative non-CSP SRH (PV, Wind, Batteries and CCGT or Diesel) and the current mix of PV, Wind, and thermal units.

In the SRHs, the installed power of each technology is varied to optimize global system cost. Under comparable conditions, the competitiveness of different SHRs will be analysed.

A. *Current Energy Mix*

Lanzarote and Fuerteventura share a submarine connection, so they have been considered as a single, isolated system.

According to the Canarian government [2], the total installed power in 2015 for the combined system was 464.1 MW, of which less than 10% were renewables (4.7% wind, 4.5% PV, 0.5% biogas). The peak demand reached 246.5 MW and, in terms of energy, fossil-fueled thermal units supplied 1.49 TWh, 95.5% of the total consumption.

The system's energy mix has been simulated in SRH-M, using the hourly demand profile of the system [2] and the Typical Meteorological Year (TMY) as inputs. As shown in Figure 1, generation is mostly carried out with fossil fuels, even in periods with a good solar and wind resource. Curtailment, on the other hand, rarely happens.

The results of the yearly simulation (Table I) show a great similarity, in terms of electricity share of each technology, with the actual system operation results. Differences are likely due to the use of meteorological values from a TMY instead of values for 2015.

This simulation of the current mix will be used in the rest of comparisons, and its estimated LCOE will be used as a base figure for further analysis.

TABLE I. COMPARATIVE PRODUCTION, CURRENT ENERGY MIX (REAL) VS. CURRENT ENERGY MIX (SIMULATED IN SRH-M)

Technology	**Current mix, real**[a]		**Current mix, SRH-M**	
	Installed power (%)	***Production (%)***	***Installed power (%)***	***Production (%)***
PV	4.5	1.5	4.5	2.9
Wind	4.7	2.9	4.7	4.3
ST-CSP	-	-	-	-
GT	90.3	95.5	90.8	92.8
BES	-	-	-	-
Total	100	100	100	100

a. Existing biogas not included

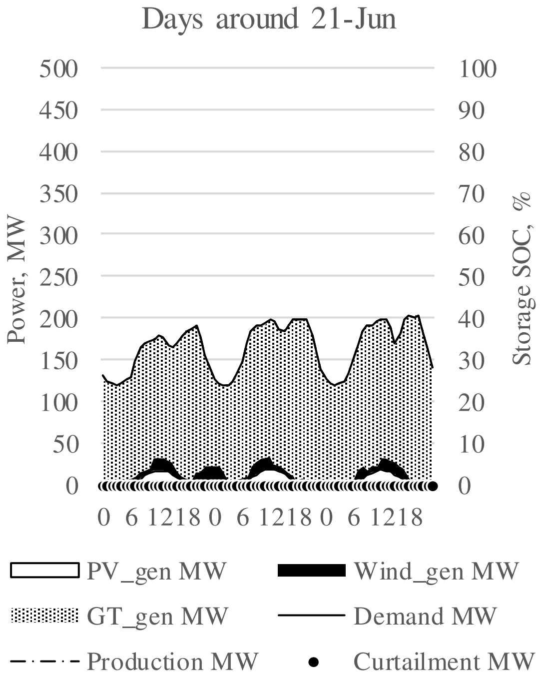

Figure 1. Production profile around summer solstice, current mix

B. Non-CSP solution with SRH

A Smart Renewable Hub is designed using SRH-M, under the constraints of serving the same demand curve as the current mix, with the same TMY. For this design, a target of 80% renewable content is sought, the only storage technology in use are Batteries, and the only solar technology in use is PV.

The combination with the lowest LCOE is determined (Table II). In order to reach a comparable level of demand coverage, this configuration relies heavily on PV and BES; it would require increasing the total installed power in the system by over 70% (over 200% if BES are included) and, despite the Batteries trading 17.6% of the energy generated, around 28% of the gross generation would be curtailed.

TABLE II. COMPARATIVE PRODUCTION, CURRENT ENERGY MIX VS. NON-CSP SOLUTION (BOTH SIMULATED IN SRH-M)

Technology	**Current mix, SRH-M**		**Non-CSP solution, SRH-M**	
	Installed power (%)	***Production (%)***	***Installed power (%)***	***Production (%)***
PV	4.5	2.9	64.8	55.9
Wind	4.7	4.3	24.1	30.1
ST-CSP	-	-	-	-
GT	90.8	92.8	11.1	14
BES[a]	-	-	+77.8	+17.6
Total	100	100	+70	+28

a. BES are excluded from base installed power and production

Figure 2 shows the energy management carried out by the embedded control strategy. The excess energy from the large Wind and PV is stored in the BES system for further use during the night.

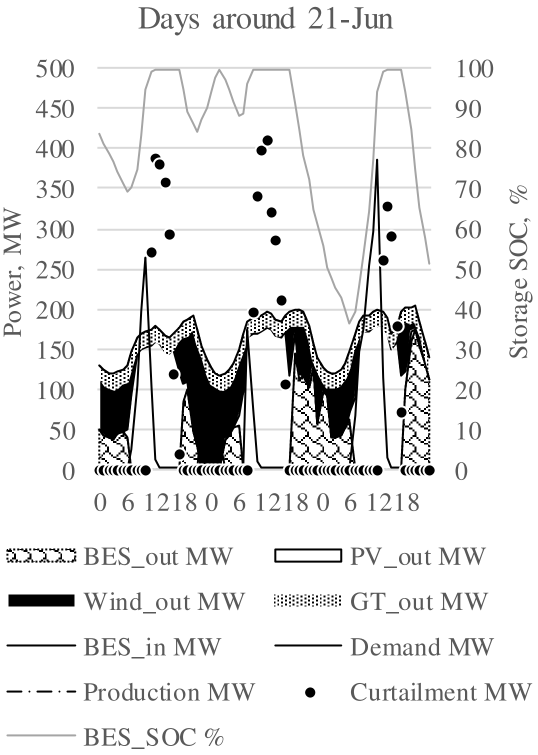

Figure 2. Production profile around summer solstice, non-CSP solution with SRH

C. CSP solution with SRH

Another Smart Renewable Hub is designed using SRH-M, under the constraints of serving the same demand curve as the current mix, with the same TMY. For this design, a target of 80% renewable content is sought, and all generation and storage technologies are forced into the mix.

The combination with the lowest LCOE is determined (Table III). This solution also includes a large portion of PV in the mix but, thanks to the CSP's extended production and the TES combination with HYSOL, the total installed power of the system would only increase by 42% (94% with BES) and, with a similar participation of BES in the market (17.5%), curtailment would not exceed 8%.

TABLE III. COMPARATIVE PRODUCTION, CURRENT ENERGY MIX VS. CSP-BASED SOLUTION (BOTH SIMULATED IN SRH-M)

Technology	**Current mix, SRH-M**		**Non-CSP solution, SRH-M**	
	Installed power (%)	***Production (%)***	***Installed power (%)***	***Production (%)***
PV	4.5	2.9	66.7	56.3
Wind	4.7	4.3	13.3	15.7
ST-CSP	-	-	11.1	16.1
GT	90.8	92.8	8.9	11.9
BES[a]	-	-	+36.7	+17.5
Total	-	-	+42	+8

a. BES are excluded from base installed power and production

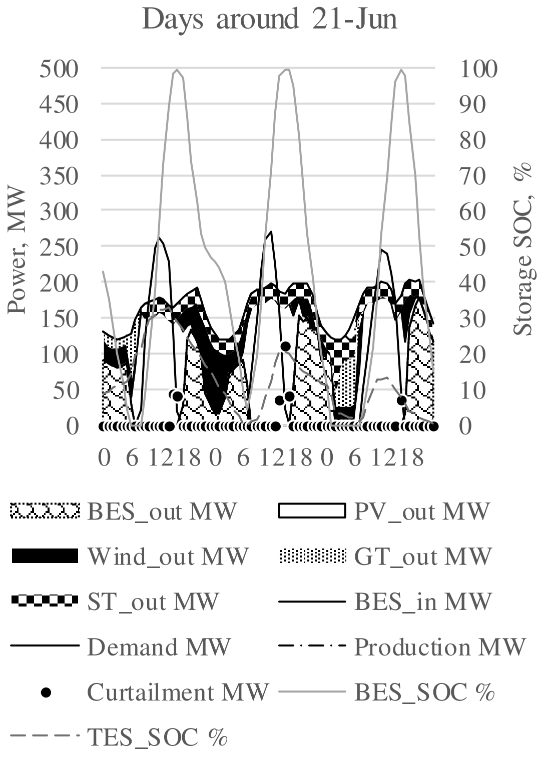

Figure 3. Production profile around summer solstice, CSP-based solution with SRH

VII. ECONOMIC ANALYSIS

Even though the full economic impact of switching the generation mix towards renewables is much deeper, a comparison in terms of LCOE between the different options has been carried out as a preliminary indicator. The average costs used in the comparison are summarized in Table IV.

TABLE IV. AVERAGE INVESTMENT AND O&M COST USED IN THE ANALYSIS

Technology	**Investment cost**	**Operation & Maintenance cost**
	k€/MW	***k€/MW***
PV	750	9.5
Wind	1050	27
ST-CSP[a]	6200	70
GT[b]	850	560
BES	1600	28

a. Considering disadvantages for small plants

b. Investment includes HYSOL, operation includes cost of fuel and CO2 emissions

The LCOE of each configuration has been calculated assuming the following parameters:

- Lifetime: 25 years for all technologies
- Discount rate (real): 5.5%
- Inflation/cost escalation considered: no
- Cost of CO2 emissions: 83.4 €/t

Under these assumptions, the LCOEs obtained for the different configurations are:

TABLE V. LCOE RESULTS FOR EACH CONFIGURATION

Configuration	**Cost of CO2 included**	
	NO	***YES***
Current mix	Base case	+50%
Non-CSP SRH	+5%	-30%
CSP-based SRH	-10%	-40%

These results show that a decided bet for renewables has the potential to reduce the price of electricity even at current costs, and an adequate tailoring of the energy mix can give enough guarantees of grid stability with a minimum requirement for backup.

VIII. CONCLUSIONS

Isolated grids, and especially islands, do not usually tap into their potential for renewable energy supply. Security of supply is identified with fossil-based capacity enough to cover any peak; in this context, renewables are little more than a fuel-saving measure.

Storage technologies are key in mitigating the variability of both renewable generation and consumer demand. Sizing the storage capacity is key for the economic viability of the system, and it is a problem that cannot be solved independently from the generation: the software SRH-M, developed in GRIDSOL, is implementing the tools for this task.

The concept of Smart Renewable Hubs can help cutting down emissions in islands, while reducing the generation cost and maintaining security of supply. A comprehensive regulatory framework and support for pioneering projects can make SRHs a reality before the end of the decade.

REFERENCES

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] was the first . . .”

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

[1] J. Servert, E. Cerrajero, D. Lopez, S. Yagüe, F. Gutierrez *et al.*, “Base case analysis of a HYSOL power plant,” Energy Procedia, vol. 69, pp. 1152–1159, 2015.

[2] Canarian Government, Canarian Energy Yearbook (Anuario Energetico de Canarias), Consejeria de Economia, Industria, Comercio y Conocimiento, 2015.