ELECTRICAL CONTROL STRATEGIES FOR INTEGRATION OF HIGH VARIABLE WIND FARM IN INDUSTRIAL MICROGRID

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Abstract - In this contribution, it is proposed a distribution control system solution for the achievement of the electrical stability and optimized energy management for an isolated microgrid powered by Gas Turbine Generators (GTG), Battery Energy Storage System (BESS) based on Lithium-ion batteries and renewable power from a wind farm, in a location that presents high-speed resources and large wind speed variability. The system operation is attached to specific load demand conditions from process (scheduled everyday), wind power resource forecasting (daily and intraday), BESS lifetime degradation and operative constraints of the distribution system The proposed methodology was validated with simulation models, which were fed with field data, achieving to verify a significative reduction of the power generation-related CO_2 emissions, due to gas combustion, as well as the verification of the advantages of flexible management of the energy storage assets. The proposed methodology is indeed applicable to similar decarbonization projects around the world.

Index Terms — Decarbonization, Energy Storage, Integration Of Renewables, Energy and power management.

I. INTRODUCTION

Nowadays the efforts for decarbonizing the global energy needs have been accelerated to achieve Net Zero (NZE) greenhouse emissions by 2050, for limiting the global warming between 1.5 and 2.0ºC [1, 2]. According to the most recent global energy outlook [3], investments in low-emission power sources, along electricity grid and battery storage and energy efficiency are considerably superior to such in oil and natural gas; confirmed for a less increasing trend in natural gas and a growing trend in solar and wind power projects.

For the industrial facilities microgrids, replacement of thermal generators by renewable power options, supported by flexible energy storage and optimized power and energy management, accompanied by energy efficiency assessments for both, the process and the distribution system are the common approaches in this sector. However, replacing the fossil generators which provide mechanical inertia to the microgrid and thus robustness against load variations becomes a challenging task when considering variability of the renewable energy sources, particularly when analyzing the safe supply of electricity and its quality for the whole microgrid including operational and critical conditions (i.e generation trips, activation of high apparent power loads, maintenance events, etc) [4].

When performing the planification of these microgrids to achieve grid stability and optimized performance, different timeframes are considered, especially due to the dynamical performance of the electrical variables [4 – 5, 7] (they may vary according to the context):

- **Very Short-term (below 1 second):** required to stabilize the power system against faults, load rejection or disconnection of energy sources. The droop-control strategy needs a new power/voltage reference to maintain the grid frequency at acceptable values with the sudden change of apparent load. This action is typically implemented the primary controllers [6,7].
- **Short-term (below 1-5 seconds):** required to stabilize the power system against load and renewable production variations. The primary controllers are also typically responsible for overseeing these tasks, or it might be done in a secondary control level [6,7].
- **Mid-term (between 1 minute to 1 hour):** period in which the spinning reserves and backup units can be turned on to ensure the generation and storage margins to follow up a microgrid load requirement and following up also a mid-term renewable production forecast.
- **Long-term (between 1 hour and 24-48 hours):** based in the daily scheduling and renewable resource forecast, a planification can be done to set-up daily constraints for the storage assets and fossil generators that allows to reduce the fuel consumption while increasing the renewable energy penetration and avoiding the degradation of storage elements.

According to the time frame, the actions are taken by the Energy Management System (EMS) which optimizes the energy reserves for long terms periods, or the Power

Management System (PMS) oriented to stabilize the microgrid [4]. The schedule proposed by the EMS, which serves to provide constraints to the PMS in terms of power limits and energy stored, for example, is typically updated based in the process behavior and the updated renewable resource forecasting along the day, ensuring a robust and adaptive operational philosophy.

The specification of the functional requirements for each strategy was the main contribution that is presented in this paper, for an industrial microgrid installation in where Gas Turbine Generators (GTG) provide the electrical power, which will be partially replaced by renewable power provided by a wind farm (WF); along with a Lithium-ion Energy Storage System (ESS) complementing the ensemble. In this work, two main elements were treated:

- The setup of the primary controls strategies and required energy reserves to achieve power system stability under variations of the wind power generation, avoiding strong variations from the GTG [4-5, 7]
- The specification of the energy management solution considering 10-minutes period resolution for the wind and load power datasets. The ESS state-of-charge should be preserved, and activation of backup generators are considered in case of strong wind power resource shortage.

This paper is presented as follows: Section II describes the microgrid, load and wind characteristics and description of the operational modes and ESS minimum required capacity; Section III describes the PMS and EMS system solutions, including some performance characteristics of each solutions; Section IV is dedicated to examinate the most relevant and identified Key Performance Indicators (KPI) for this application to highlight the different gains with the inclusion of the renewable source and energy storage. Finally, Section V presents some conclusions and future works.

II. DESCRIPTION OF THE INDUSTRIAL MICROGRID

A. System Configuration

In **Fig. 1** is shown the configuration of the industrial microgrid, including the wind power plant and the ESS, due to space restrictions. The system is composed by two sites, *Site A* and *Site B* connected by a 30 km 240 mm^2 power line. (Alu –XLPE) 50 Hz 20 kV level and characteristics

$$R_L = 0.16\frac{\Omega}{km}; X_L = 0.102\frac{\Omega}{km}.$$

The number of GTGs is four (4): one considered as the main generator of the microgrid, located at Site A and with capacity of 9.5 MWe (Power Factor: 0.85) and three (3) more generators that are considered as backup generators: GT A at site A (5.6 MW); GT A and GT B at side B with capacities of 4.6 MW and 4.2 MW, respectively. A complete list of parameters for the generators, including the main features of their governors and voltage regulators [5] are included in Table A.I

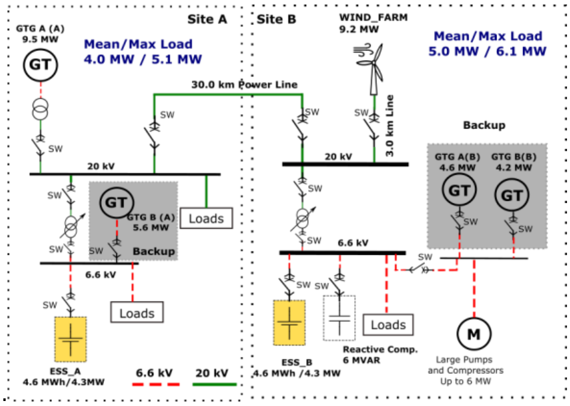

Fig. 1 Single-line diagram of the hybrid microgrid

The wind farm is in Site B, connected at 20 kV through a 3.0 km power line. The wind farm can deliver up to 9.2 MW at the connection point at unitary power factor. Each side has also a Lithium-ion batteries-based ESS with capacities 4.6 MWh/4.3 MW (see section II.C for more details about the ESS dimensioning criteria).

The system is backed-up by a 6 MVAR Reactive Compensation system (SynCon), located at Site B with the objective of getting a stable voltage at the end of power line, as well as a balanced power factor around 0.85-0.95 lagging of the plant, especially when important reactive loads are activated at Side B.

B. Load and Wind Resource Characteristics

In terms of load behavior and wind power characteristics, the system will supply three different load configurations during the 17 years period, considered as project lifetime, according to the operation year (Years 1-7; Years 8- and Year 9-15), which are shown in **Table I**. It is seen that a process optimization along the project lifetime, in which is expected a reduction of the emissions and a more profitable renewable power availability. The process load was obtained locally via Supervision Control and Data Acquisition (SCADA) measurements with 1-Hz sampling rate resolution.

TABLE I
LOAD DESCRIPTION (VALUES IN MW)

Site	Period					
	Years 1-7		Years 8-10		Years 11-17	
	Mean	Max	Mean	Max	Mean	Max
A	4.0	5.1	4.2	5.3	3.4	4.5
B	5.0	6.4	3.0	3.8	3.0	3.8
A+B	9.0	11.2	7.2	9.1	6.4	8.3

The wind resource at the plant location is considerable stable and long-term wind power production forecasts are based in the resource heatmap shown in **Fig 2**. In general, the mean wind speed is close to 10.3 m/s with relatively weak winds during June and July.

The wind power profile was obtained adapting the model of the Type IV wind turbine as in [8], for two eolian generators of 4.5 MW, including availability and AC power conversion and losses. The extrapolated meteorological data considers a 20-years period with sampling period of 10-minutes. Finally, it was assumed that the wind farm will be injecting optimized active power production [9,10]. **Fig. 3** shows the histogram of the mean hourly wind power production for the site and project duration.

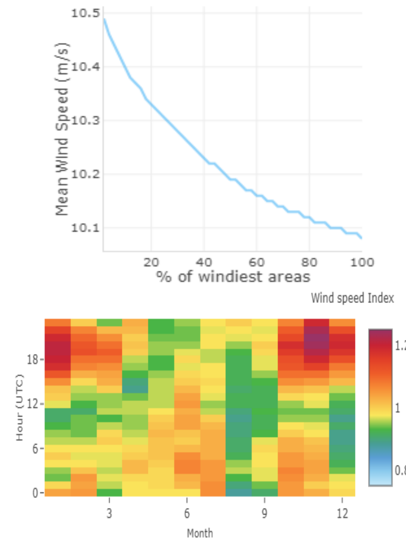

Fig. 2 Mean Wind speed and hourly vs. Monthly Wind Speed Index for the wind resource

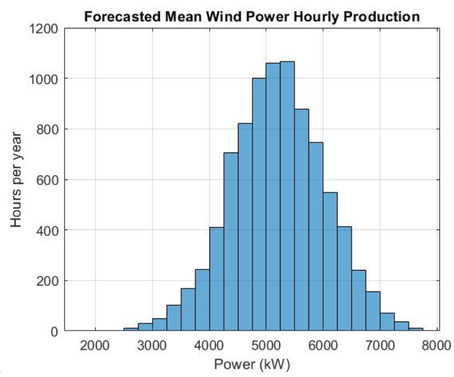

Fig. 3 Forecasted mean wind power production

C. *Operational Configuration of the Hybrid Microgrid*

In total, four (4) operational configurations were identified for the microgrid, according to the generators that are ongoing and the grid status. A resume of actions per generator and storage status is shown in **Table II** for a fast track of the different elements. Details regarding the sizing of the energy storage solution are detailed in section II.D.

TABLE II
OPERATIONAL MODES AND GENERATION AND STORAGE UNITS' STATUS

Operational Conf.	GTG Site A		GTG Site B		Wind Farm	ESS
	A	B	A	B		
OC 1	GFO	S	S	S	MPPT	GFL
OC 2	GFO	S	GFO	S	MPPT	GFL
OC 3	OFF	SU	SU	S	OFF	GFO
OC 4	GFO	S	GFL	GFL	OFF	OFF

GFL: Grid Following; GFO: Grid Forming; S: Support (Backup); OFF: Not Available; SU: starting-up; MPPT: Maximum Power-Point Tracking

The configurations are described as follows:

- **Operational Configuration 1(OC1):** GTG A, at Site A is on duty, assuring the grid forming features. The wind farm injects energy in optimal production mode (Maximum-Power Point Tracking – [9-10]) and might curtail part of its production according to the PMS actions. A portion of the ESS capacity is dedicated to support the grid frequency control caused by strong load variations and/or fast wind power shortages (more details of this capacity are shown in Section II.D.

- **Operational Configuration 2 (OC2):** This configuration is an alternative to OC1. This condition is used when there are forecasted too many wind power shortage events during consecutive hours and/or when the process consummates additional load (especially on-site B). Here, the GTG A of Site B is activated until the wind power forecast and the load profile are both in ideal conditions. The system can be taken back to OC1.

- **Operational Configuration 3 (OC3):** This is a configuration after a faulty state when functioning in OC1 or OC2. Here, an automatic load-shedding system reduces the power demand at both sides down to approximately a maximum of 3.5 MW at the distribution system (covering critical loads and auxiliary supply).
  The system will operate only with the energy storage systems in grid forming mode, after the trip of the GTG A from the Site A (main GTG). The battery provides support for 90 minutes approximately, which is the timeframe for starting up and synchronizing the backup generators (marked as SU in **Table II**). For avoiding possible load balance inconvenient, the wind farm power injection is automatically stopped. Once the backup generators are online, the system can operate with normal load and wind power injection (OC1 or OC2).

- **Operational Configuration 4 (OC4):** This is a configuration in which the wind farm and the storage units are not functioning, due to maintenance, for example. Moreover, this is the system configuration before adding the wind farm and storage. At both sides, there is the GTG A ongoing and on-site B, the GTG B is turned on permanently during the 3rd quarter of the year due to process requirements.

In all cases, the reactive compensator in site B will help to reduce the voltage difference between the nodes and moreover, the reactive power needs. The stabilization of the distribution system for each configuration is done by the PMS, whereas the transition to one mode or other is done by the EMS, while considering wind power forecast inputs and process load scheduling from the operators. These aspects will be detailed in Sections III and IV.

D. *Energy Storage Capacity sizing and services*

The energy storage system was initially chosen to supply the requirement of 3.5 MW for 90 minutes (5.25 MWh), that was introduced as OC3 in section II.C. For reliability reasons, this energy should be available for whole lifetime of project (December 31st of year 17).

Having in consideration a worst-case scenario for a stationary energy storage system with eventual low depth-of-discharge duties per day [11], the following assumptions allowed to determine the minimum size:

- Mean degradation of ESS based on Lithium-ion batteries: 2.0% per year (respect to previous year)
- Depth-of-discharge (DoD) for battery usage: 92%; being the minimum and maximum State-of-Charge (SoC): 4% - 96%
- DC/AC conversion efficiency (from ESS terminals to AC Point of Connection): 92%

The usable required energy at Beginning of Life (BoL) in MWh at the DC side of the ESS can be computed using the following expression:

$$E_{BOL} = E(k)/g_1(1-g_2)^k \quad (1)$$

Where g_1 is the product between the authorized DoD (0.9) and the DC/AC conversion efficiency (0.92) and g_2 represents the degradation (0.02), k is the year (17) and $E(k)$ the required AC energy (5.25 MWh-AC). According to the expression, **8.75 MWh** of battery DC energy are required. The commercial ESS solution suggested for the project (9.2 MWh/0.9 C-rate) covers the requirement.

Fig. 4 shows the curves of the ESS energy evolution at the end of each project year. A curve of additional capacity per year that is available to provide support to the primary control of the microgrid that can be considered by the EMS to provide such service.

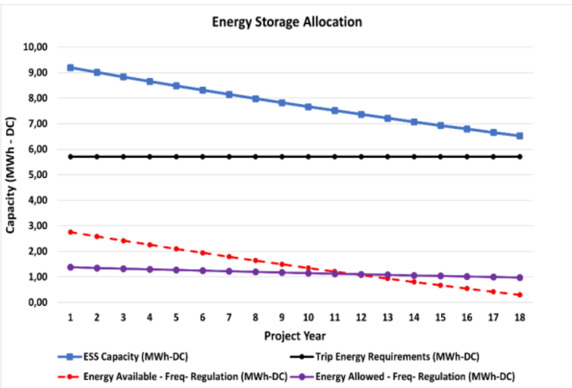

Fig. 4 Energy Storage Solution Capacity Evolution

However, and for preventing a possible accelerated degradation of the ESS [11], it was set down that small cycles are going to be assumed for frequency regulation support (state-of-charge variation 80% and 95% of the ESS - maximum) equivalent to **1.38 MWh** at the end of the first year; arriving to approximately **0.30 MWh** at end-of-life.

The destinated reserve (dedicated DoD) for the frequency regulation can be modified during the project lifetime, considering the battery degradation limits and system behavior. The EMS can manage this feature, as well as the droop gains of the ESS, the GTG and the wind farm, always ensuring the appropriate tradeoff between the energy reserves and the stability limits of the power grid. In the same perspective, the EMS will limit the number or equivalent cycles of the ESS to maximum one per day.

Considering a short-term forecast, it is possible to establish several hours before a wind power shortage or high load request whether a backup generator shall be turned on (i.e passing from OM1 to OM2) according to the state of this reserve. This is highly useful for avoiding constant start-up/shut down events of the backup generators, and thus, reducing the fuel consumption.

To validate the application of backup when the ESS must become the main grid forming device, simulations using the DIgSILENT software [12] where conducted. It is shown in **Fig.5** the simulation results, resulting in an acceptable behavior for the stability of the system.

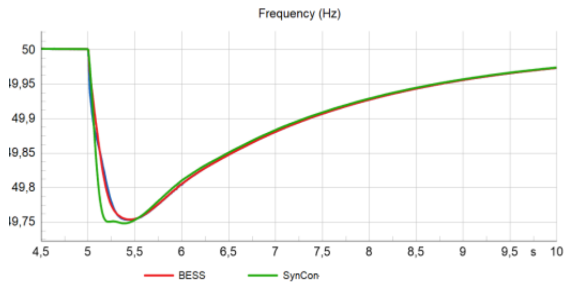

Fig. 5 Frequency during a trip of the main Gas turbine Generator

III. POWER AND ENERGY MANAGEMENT SYSTEMS

A. Control System Architecture

In **Fig. 6** is shown the different blocks that allow to ensure the regulation of voltage and frequency as well as the optimal dispatching of the distribution system.

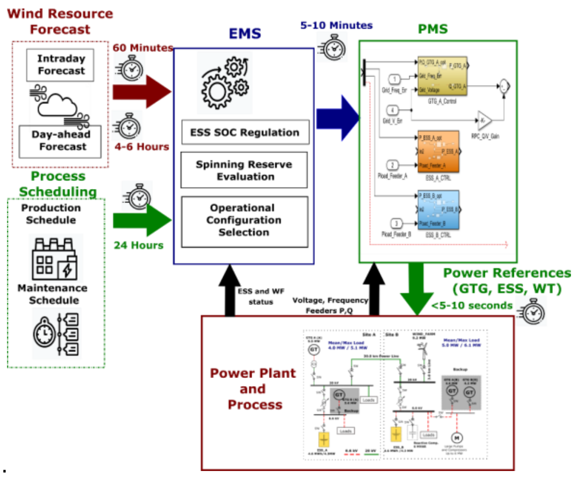

Fig. 6 Control System Architecture

The different blocks are described as follows:

- The **Power Management System** is responsible to provide updates every 5-10 seconds maximum to the generation and storage units. Using measurements from the field (voltage, frequency, power production and main feeders' consumption), it modifies the power reference at each unit, considering an optimized scheduling for the following 5-10 minutes supplied by the EMS. The PMS considers that each generator and storage system have a high bandwidth local controller with local regulation capabilities and thus, behaving as a Level 1 control entity [6].

- The **Energy Management System** will provide optimized references to maintain the energy storage level at the batteries; the spinning reserves from the generators and the modification to the operational configuration that will ensure the best system performance for the following hours. Its behavior is based in either numerical optimization objectives (unit commitment implying technical cost reduction) and/or precise rule-based principles in where are respecting the different operational constraints (see [4] for more details).
  The EMS receives information from the wind forecasting system in short term and long-term forecasts (adjusted intra-day forecasts and day-ahead forecast) as well as the operation plan from the plant operators.
  The optimized sequences for the units are computed every 5-10 minutes (according to the system size and communications constraints), corresponding to the following hours.

B. Configuration Parameters of the Power Management System

For the studied power system, it was adapted the different parameters to achieve the voltage and frequency regulation with the available elements. The main regulation parameters considered at the PMS level (frequency and voltage droop gains for the GTG) are presented seen in Table A.I. The ramp-rate of the GTG was also limited to 0.3 P.U/min (approximately 2.85 MW/min for the GTG A at site A).

In this contribution, this was considered as the worst-case ramp-rate conditions to be compensated, considering that in normal applications, wind turbines below 5 MW might respect ram-rates of about 0.8-1.0 P.U/min [9].

This ramp-rate can be approximated to a second-order low-pass transfer function [13] and will be used to compute the ESS power reference to track the load changes that the GTG cannot take due to its dynamic limitations. In (2) is shown the expression to compute the power that should be supplied by the ESS under load changes and **Fig. 7** shows the ideal behavior of the gas turbine generator and a cumulative battery system under load transients of 0.15 P. U (s denotes the Laplace Operator)

$$P_{ESS}(s) = P_{LOAD}(s).(1 - \frac{4.10^{-4}}{s^2 + 0.04s + 0.04^2}) \quad (2)$$

Finally, to simulate the behavior of the synchronous reactive compensator, it was assumed for this study, a variable gain capacitor bank, with a droop characteristic of -0.05 P.U, for assuring a fast compensation in case of strong load variations, considering again that the system maintains approximately a power factor between 0.85-0.95 lagging.

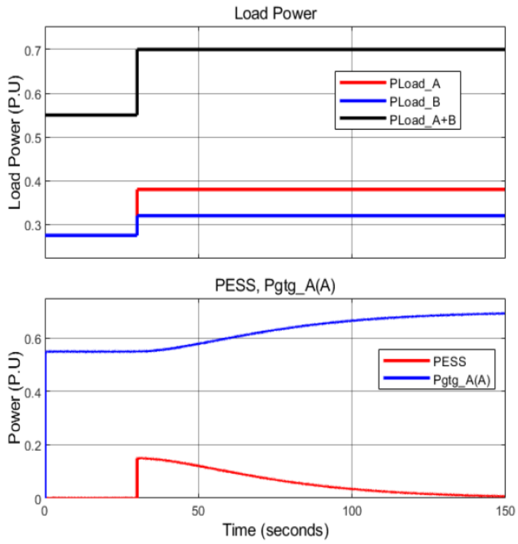

Fig. 7 Expected behavior under load transients (gas turbine generator and battery system)

C. Functional Conditions for the Energy Management System

The energy management system works under a strong assumption: the power management system assures the performance at the low-level elements.

Considering the reduced number of assets and the simplicity of the power system, the preliminary results presented in this work considers an optimized rule-based energy management system that takes in consideration the following elements:

- The main gas turbine generator will be the GTG A, located at site A. As backup solution, it will be used the GTG A at site B.
- The baseload of the gas turbines generators shall be 2.0 MW.
- The energy storage system must always ensure the energy in case of a gas turbine generator trip event.
- The energy storage can be charged only with wind power and having in consideration its participation in the frequency regulation, the reference state-of-charge is set at 88% approximately (middle point of the 80% - 95% zone defined in section II.D.
- Power transmitted between the sites should be limited.
- The EMS receives wind power production predictions in 10-minutes samples. For this contribution, prediction error is ignored.
- In case of predicting a wind power shortage that cannot be covered by the stored energy at the ESS for the frequency regulation, the backup turbine is activated. However, the minimum operation time for the backup generator is 8 hours and cannot be restarted but 48 hours after turning it off.

D. Testing Conditions for the Power and Energy Management Systems

For the different simulations results explained along the paper, it was used MATLAB/SIMULINK [14].

The system behavior was tested after considering a day in where, due to the variability of the wind speed, it might occur a power production drop at the wind farm; either by passing from the Full Load to Partial Load Zone; or approaching the zero-production zone from the Partial Load [9,10] (see **Fig. 8**). Taking in consideration the power production curve for a wind turbine:

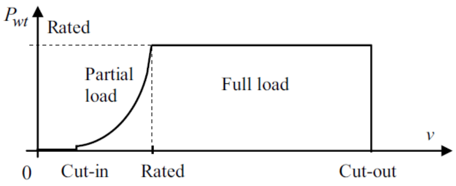

Fig. 8 Typical Power Production Vs. Wind Speed in wind power generators [9]

$$P_{wt}(t) = 0.5\rho\pi R^2 C_p(\lambda,\beta)v_w^3; \quad \lambda = \omega_T R/v_w \tag{3}$$

Where P_{wt} is the shaft power; ρ is the air density, R is the radius of the wind turbine, v_w corresponds to the wind speed and C_p is a polynomial function of λ (the tip-speed ratio that relates the angular speed of the turbine and the wind speed) and β that is the pitch angle, the wind turbine power can be regulated, either by manipulating the pitch angle (if the machine operates in the Full load zone) or by acting over the angular speed of the turbine in Partial load zone (acting in the electrical generator).

Analyzing the wind speed dataset, it was identified firstly the year with the lowest wind power production. Then, for each one of the 365 days it was obtained an approximated gaussian distribution, obtaining an estimation of the daily mean wind speed (µ) and standard deviation (σ) each day. Considering that most of the wind turbines are already producing their rated power for wind speeds over 12 m/s, it was analyzed the obtained locus (see **Fig. 9**) a day in which the wind speed range $\mu \pm 3\sigma$ is good enough to have a representative variability in the dataset. Therefore, the selected date was the day 252 of the year (corresponding to September 9th), in which the mean wind speed was 10.6 m/s and the standard deviation 0.89 m/s.

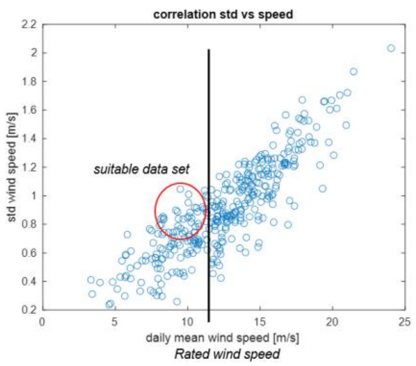

Fig. 9 Set of critical days for the test according to the rated wind speed value and standard deviation

For this same date, it was taken the forecasted load profile, obtaining the following minimum and maximum values for the active (P) and reactive power (Q) per site:

- **Site A:** $P_{SITE\_A} = 3.28 - 4.09\ MW$; $Q_{SITE\_A} = 2.03 - 2.53\ MVAR$
- **Site B:** $P_{SITE\_B} = 3.43 - 5.42\ MVAR$;$Q_{SITE\_B} = 1.13 - 1.78\ MVAR$

In **Figs. 10** and **11** are presented the simulations results for the chosen date, showing the balance between the active and reactive power production and consumption, validating the good performance of the proposed PMS and EMS strategies.

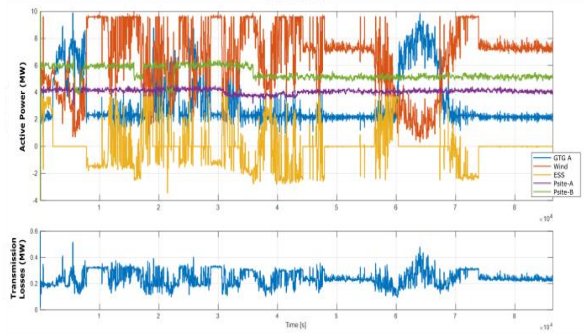

Fig. 10 Active power behavior for the chosen test date

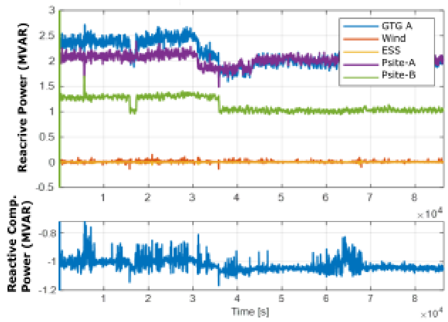

Fig. 11 Reactive power behavior for the chosen test date

At the bottom of Fig. 10 is detailed the power losses at the transmission line; whereas Fig 11. Shows the action of the reactive power compensator located at side B.

IV. PROJECT LIFETIME ANALYSIS OF THE HYBRID MICROGRID

The proposed microgrid configuration, which in normal operation will be alternating between the OC1 and OC2 defined in Section II.C is expected to show superior performance in fossil power consumption and thus, allow the reduction of GHG emissions when the project is in execution (aligned with the several remarks included in [1 – 4]).

For this propose, the following project lifetime configurations were taken for comparison proposes:

- **Configuration #1 (C1):** Full thermal powered system. This corresponds to provide power to the load without any renewable power or stored energy. It was adopted the OC4 for this mode.
- **Configuration #2 (C2):** It is tested a solution in which the ESS is not used for helping in the wind power shortages. Here, it is considered that system will operate alternating the OC1 and OC2,

according to the wind power resource. It was considered that the minimum duty and rest times for the backup generator (GTG A at side B) are considered as 8 and 48 hours, respectively.

• **Configuration #3 (C3):** Nominal conditions hybrid mode. Here, it is considered that system will operate alternating the OC1 and OC2, according to the wind power resource. The following conditions were considered:

- The minimum duty and rest times for the backup generator (GTG A at side B) are considered as 8 and 48 hours, respectively.
- The energy capacity dedicated to the frequency regulation support, and usable for avoiding the activation of backup generators is fixed as 1.38 MWh at BoL, evolving into 0.97 MWh at EoL; the maximum power from the ESS is fixed at 8.3 MW (corresponding to 90% of the full ESS energy at BoL)

For this analysis, it was neglected the maintenance periods that should be done at the generators. This hypothesis will be included in future studies.

The following indicators were used to compare the system performance:

- Total Fuel Consumption (cubic meters of fuel-gas) and CO_2 emissions for the project lifetime
- Mean Renewable energy penetration for the project lifetime. This includes the contribution from the ESS to the load when required (case C3) for not turning on the backup generator.
- Mean Equivalent number of hours of operation of backup generators. This is computed for the first seven (7) years of the project, after reviewing the simulation results and finding that no backup generators are required from the beginning of the 8^{th} year of the project.

TABLE III
PERFORMANCE INDICATORS AND COMPARISONS BETWEEN CASES FOR THE PROJECT

Indicator	C1	C2	C3
Fuel Consumption (Mm^3 FG)	534.8	249.2	245.4
CO2 emissions (kTon CO2)	1156.1	538.7	530.6
Mean renewable energy penetration (%)	NA	53.1	56.43
Mean op. hours of backup generator (first 7 years)	NA	2031.5	1514.3

Relative Difference	C2 Vs C1	C3 Vs. C1	C3 Vs C2
Fuel Consumption (Mm^3 FG)	-53.40	-54.11	-1.52
CO2 emissions (kTon CO2)	-53.40	-54.11	-1.50
Mean renewable energy penetration (%)	NA	NA	+6.27
Mean op. hours of backup generator (first 7 years)	NA	NA	-25.5

Based on these indicators, the following conclusions can be made for the proposed energy management strategy and resources sizing:

- The renewable energy is capable to provide more than 50% of the energy needs for the process. This is already a good confirmation of the outstanding wind power resources at the location and that is profitable with the proposed wind farm sizing.
- In the same proportion, emissions are reduced at least by 53% by the addition of the wind farm.
- Using part of the ESS reserve as first resource in case of wind power shortage, allows to increase the renewable energy penetration by 6.27% of mean value for the lifetime, when comparing the system without this option. Herein, the stored energy allows to stop the initialization maneuver of the backup generators.
- The number of mean equivalent operational hours of the backup generator was reduced by 25.5% when using the ESS based on Lithium-ion batteries. This value highlights the importance of adding a flexible energy reserve that could provide support to short term dynamic perturbations, eliminating the needs of additional thermal power to the system, reducing therefore the emissions, the operational costs and increasing the renewable power penetration to the site.

In general terms, the hybrid project evidences good performance with respect to the full thermal solution. Furthermore, smart use of flexible storage solutions allows to decrease specific operational cost for the generators park.

In an extended version of this document, additional scenarios for the energy storage capacity will be tested to evaluate the correct tradeoff between investment (i.e increasing ESS size) and emissions reduction/renewable power penetration while keeping in mind the distribution system stability.

V. CONCLUSIONS AND FUTURE WORKS

In this paper it was presented the most relevant modeling elements and performance of the electrical control solution at both, power, and energy management levels, for a microgrid that operates with gas turbine generators and will receive wind power from a new installation and will include energy storage units to ensure power backup and frequency regulation support due to wind resource intermittence and shortage.

The methodology can be extended to other type of microgrids, having in consideration the main applications and the different available datasets and operational philosophy, showing interesting achievement of the reduction of GHG emissions and additional thermal to be activated caused by the renewable source variability.

In future works, it will be studied more optimized approaches at the energy management level that allows to study the effect of wind guts and turbulency that may require a finer tuning of the frequency regulation requirements at the energy storage and wind farm instances.

VI. NOMENCLATURE

BESS	Battery Energy Storage System
BoL	Beginning of Life
DoD	Depth-of-Discharge
EoL	End of Life
EMS	Energy Management System
ESS	Energy Storage System
GHG	GreenHouse Gas
GTG	Gas Turbine Generator
OC	Operational Condition
PMS	Power Management System
SoC	State-of-Charge

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VIII. APPENDIX

TABLE A.I
GAS TURBINE GENERATORS PARAMETERS

GTG	Rated Power (MVA)	Inertia (s)	Voltage (kV) / Poles	P/f Droop gain (P.U)	Q/v Droop gain (P.U)
Site A					
A	11.5	1.05	5.5 / 4	0.03	0.03
B	8.5	0.79	6.6 / 2	0.03	0.03
Site B [a]					
A, B	7.0	0.48	6.6 / 2	0.03	0.03

[a] Similar machine considered. GTG B limited at stator level.

GTG	Governor PID Gains (Kp, Ki, Kd) in P.U	Voltage Regulator PID Gains (Kp, Ki, Kd) in P.U and Time constant (s)
Site A		
A	10; 5; 0.2	30; 25; 6; 0.01
B	10; 5; 0.2	30; 25; 6; 0.01
Site B [a]		
A, B	10; 5; 0.2	30; 25; 6; 0.01

[a] Similar machine considered. GTG B limited at stator level.

IX. VITA

John Sandoval-Moreno is graduated as an Electronic Engineering (2008) and owns a MSc in Automatic Control (2011) from Universidad del Valle (Colombia) and received his PhD in Automatic Control (2014) from University Grenoble-Alpes (France). He joined TotalEnergies in 2017 in where he worked 5 years in the R&D division of GRP division as research engineer, supporting the development of techno-economics feasibility tools for multi-energy projects, and co-advising research students. From 2021, he joined the Technical Line of OneTECH division, in where he is currently Electrical Control System Specialist. His interests include modeling and control of electrical systems, optimal distributed control, data-science applied to energy systems sizing and operation and optimization of power production of renewable sources.

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Domenico Di Domenico graduated in Physics in 2002 at the Università degli studi di Napoli (Italy) and received his PhD in Automatic Control in 2008 (2014) from Universita` del Sannio (Italy). He has been working at TotalEnergies since 2021, in OneTech's "Hybrid and Storage" R&D department. He is active in research on modeling and control of electrical systems, particularly in the field of wind energy.

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Moataz El Sied obtained his PhD degree in 2015 (with the greatest distinction) from the university of Caen Normandy, (France). In 2016, he joined the Graduate School of Electronics and Electrical Engineering (ESIEE Amiens, France) as a postdoctoral researcher on research related to Energy management and power converter design in microgrids applications. On March 2018, he joined SAFT, BMM group (Bordeaux, France), research dept as a research scientist. He was leading the microgrid research activities and managing the experimental tests validations at SAFT microgrid lab. Currently, he is leading the power system modeling activities at TotalEnergies/OneTech/RD/ Power department. He is the authors of more than 35 scientific publications and a reviewer in more than 5 international journals. His fields of interest include power electronics, energy/power management strategies, modeling techniques and control systems, smart local grid and renewable energy.