FIRST OIL & GAS APPLICATION OF A HYBRID POWER PLANT INTEGRATING: SOLAR PV - ENERGY STORAGE – CONVENTIONAL POWER GENERATION (GTG)

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Abstract - A hybrid Power Plant solution integrating Solar PV, Energy Storage and conventional Power generation (i.e. Gas Turbine Generators) is applied for the first time to an Oil&Gas facility.
An existing Oil&Gas Plant fed solely by conventional power generation is being upgraded with the installation of Solar Power Generation and Battery Energy Storage. The integration of these new systems has allowed the Operator to obtain gas savings and reduction in CO_2 emissions.
This paper provides insights into the project presenting the technical challenges and selection process that have been followed during project development and a technical overview of the configuration selected.

Index Terms — Renewables, Energy Storage, Hybrid Power Plant.

I. INTRODUCTION

The project described in this article falls under the Eni green investments initiatives to develop innovative energy solutions with a low environmental impact. The aim is to promote the development of renewable energies, stimulating technological research and supporting their spread in the countries in which Eni operates. Eni has explored the possibility to integrate renewable resources to existing Oil&Gas facilities in order to both reduce CO_2 emissions and increase gas valorization while maintaining the overall Plant availability unaltered. Eni has decided to conduct a “Pilot” project on a mature field of medium size in order to evaluate its feasibility, time, cost, adverse events, and improve upon the study design prior to investing in a full-scale project. Various scenarios have been evaluated (i.e. Full, Minimum, Hybrid) from both technical (e.g. battery technology and configuration selection) and economical point of view (e.g. battery cost, gas savings). This paper presents in detail the selected option with particular focus on the BESS (Battery Energy Storage System) configuration.

II. INTEGRATION CONVENTIONAL – RENEWABLES GENERATION

A. Conventional Generation: Vendor Engagement

The Plant is located in North Africa in a desert area. The existing main power generation system consists of two Gas Turbine Generators (GTGs) with an available output of about 10 MW @ 15°C (6.6 MW @ 50°C) each. The current maximum power demand is approximately 6.1MW. The current operating configuration is based on one out of two GTGs running (i.e. 1+1: one running and one cold stand-by unit). The loss of one GTG will cause shutdown of the facilities and the loss of production. This is considered acceptable based on the current oil and gas production levels. The first phase of the project has required an in depth investigation on the existing GTGs. After engaging with the GTG supplier, the project team has established two main characteristics of the GTG:

- the minimum generator loading that can be applied continuously without compromising the machines design life. Minimum GTG loading equals approx. to 30% of rating at ISO Condition (i.e. 50% of rating at worst site conditions) that equals to 3.3MW.

- GTG capability to handle sudden load variations. The maximum step load that can be accepted by one GTG is approximately 15-20% of the total power output that equals to approx.1 MW.

The system design has been based on the above values.
The selected standard operating mode of the GTG requires a reduced loading during daylight (i.e. 3.3MW). The gap in the power demand is then covered by the Photovoltaic (PV) system. Stability studies have confirmed that the GTG cannot recover on its own the loss of the entire PV plant (due for instance to sand storms or cloud cover), but with the contribution of a BESS it has been calculated that a full recovery of the system can be achieved within a delta *t* of 10 sec. It is to be noted that the GTG takes the plant full load at night with the exceptions described in the following sections.

B. Renewables System Sizing

The solar system has been selected based on plant location and power requirements.
Global Irradiation of selected site is 5.1-7.3 kWh/m^2 per day, with around 2,300 sunshine hours/year. Maximum irradiation is approximately 100 W/m^2 during Summer season.
Particular attention has also been paid during equipment selection to identify a system could operate in a desert saliferous environment with wide temperature variations between night and day.

Based on the above meteorological conditions and ageing factor, the PV system selected was:

Rating:	**5MWp d.c.**
No. Modules:	**16,200**
Area:	**10.6 ha**
Module Peak Power:	**325 Wp**
Annual Energy:	**8.6 GWh/y**
Cell type:	**Polycrystalline**

The selected configuration guarantees an average power production of 2.8MW.
Based on a technical and economical assessment, the “Night option” has been discarded at an early stage of the design due to the high Capital Expenditure (CAPEX). The “Night Option” is defined as the scenario when the full contribution of the solar plant (i.e. 2.8MW) is replaced entirely by the BESS.

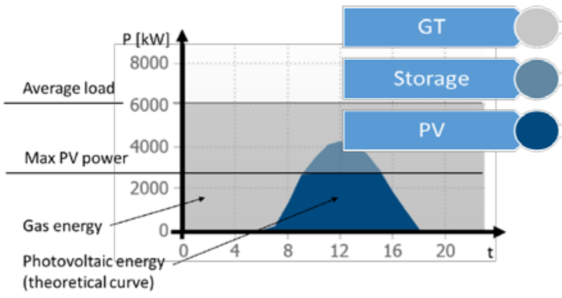

Fig. 1 Power contribution (MW) during the day

The peak a.c. power production of the PV system is approximately 5MW at site solar radiation. However, power production is capped automatically by the new PMS (Power Management System) to limit the power to the Plant to 2.8MW. This value is based on the minimum technical load factor of the GTGs. PMS will control the power generated from the PV system based on load configuration and hence generation load factor. The excess power generated from PV plant is therefore dedicated to the charging of the batteries.
Both PV System and BESS are connected to the main 20 kV Switchgear (refer to Annex A) via DC/AC inverters.
Because the PV plant is not designed to maximize its power output, it is to be noted that a tracking configuration has not been considered.

Configuration of PV power stations and design is based on Eni internal standardization.
The PV plant consists of 3 Power Stations (two Power stations rated 2 MW and one Power Station rated 1 MW).
All Power Stations are connected to a main 20kV Medium Voltage Switchgear located in the Main technical Room. The PV system is then interconnected to the existing Oil&Gas Plant via step-down transformer 20/11kV and cable connection.
PV Modules are collected in string of 20 Modules each; Strings are collected in Arrays and connected to String Boxes.
The Photovoltaic plant, and all relevant components, have been designed to communicate with a SCADA (Supervisory Control and Data Acquisition) System that receives from the nearby plant the relevant operation parameters. The plant is conceived to be operated completely unmanned in a non hazardous area at approximately 2km from the existing facilities.

C. *Transient Analysis*

The PV Plant power production is weather-dependent because solar irradiation can be affected by clouds and sand storms. In the ideal scenario the PV plant power production gently increases and decreases following solar radiation. PV power production during the day is generally represented with a curve which shows PV power production raising until noon and then decreasing. This is shown in Figure 2.

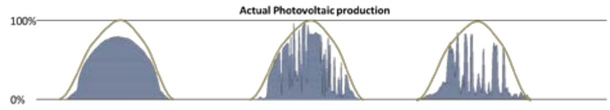

Fig. 2 PV power output vs clouds cover

In the real world, the PV production may be:
- Lower, during winter seasons (i.e. the grey area in the left chart);
- Following the theoretical curve, but intermittent, due to partial cloudy days – i.e. the central chart;
- Severely intermittent, during cloudy days (i.e. chart on the right).

In a «theoretical» day, no battery would be required. However, the real scenario is when clouds or sand storms limit solar radiations causing PV plant power production suddenly to drop; without BESS, if the reduction in PV output is greater than the maximum step load acceptable by the gas turbine generator, the electrical system would shut-down, causing a loss of production.
A battery system is needed to smooth the transient in the PV power output. The removal of large load steps avoids situations of power generation black-out. The BESS selected allows transient load variations to be within system stability envelope.
The graph below describes the worst case scenario where a full loss of PV power input during daylight occurs.

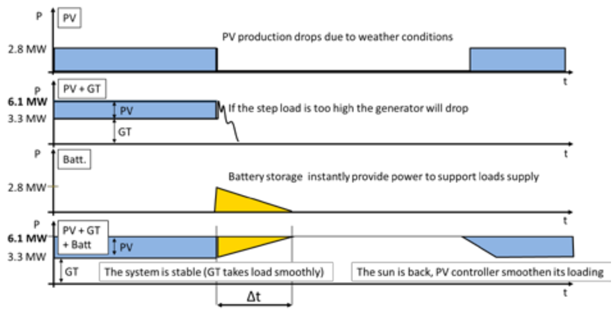

Fig. 3 BESS intervention during PV power output drop.

During the Front End Engineering Design (FEED), a comprehensive dynamic stability study has been carried out in order to select the optimal solution. Various scenarios have been evaluated covering the most significant perturbances the system could be subject to. Figures 4, 5 and 6 show the model output of the stability study for the worst case scenario.

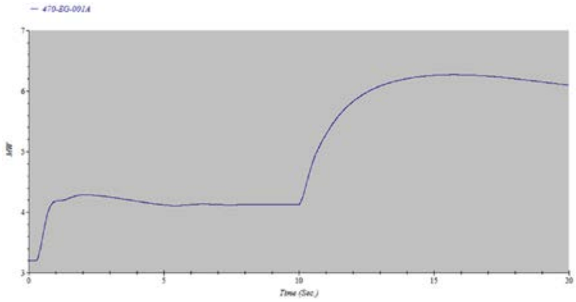

Fig. 4 GTG Power output

The governor system of the GTG is able to provide the required mechanical power to ensure stability. First step is limited to 1.2 MW by the presence of the BESS. Second step shows when the Battery Storage is disconnected.

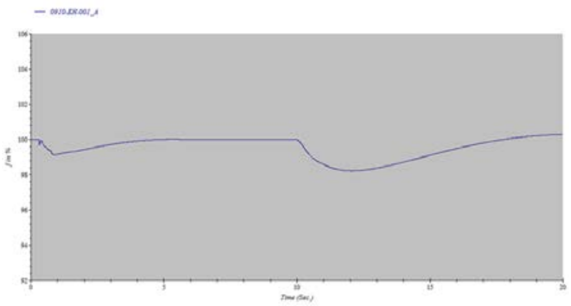

Fig. 5 GTG Frequency

The system frequency during the transient is within the admissible ±2% variation, preventing the frequency protections to trip, as per figure 5.

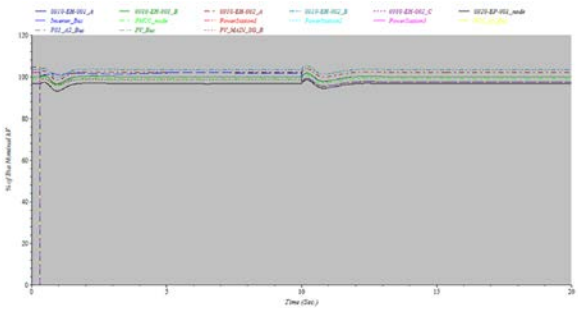

Fig. 6 Bus voltages

All main bus voltages are maintained within ±10% of their rated voltage.

D. Battery Technology Selection and Sizing

The Storage System has the objective to cover the power variations of the PV plant in order to reduce the step load of the gas turbine generator and ensure Plant electrical network stability.

During daylight, the irradiation cannot be considered constant due to clouds cover, sand storm etc. These phenomena can cause load steps larger than those acceptable by the GTG.

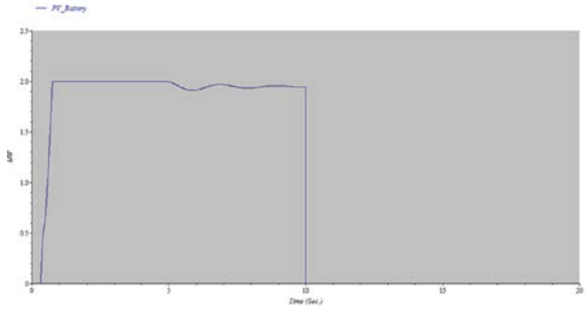

Fig. 7 BESS Power output during transient.

In order to maintain network stability, the gap in PV power generations are to be compensated by the contribution of a BESS system.

Figure 7 shows a typical BESS power output during a loss of PV system output. Peak generation is about 2 MW within 0.5 s, then power supply is disconnected after 10 s since stability is already achieved, saving battery charge.

The selected battery technology for the battery system is Power Intensive type. This is due to the fact that a very short response time (0-100% in 200 ms) and high energy release is required. Figure 8 shows the selection diagram for the battery type. Li-Ion Batteries have been selected.

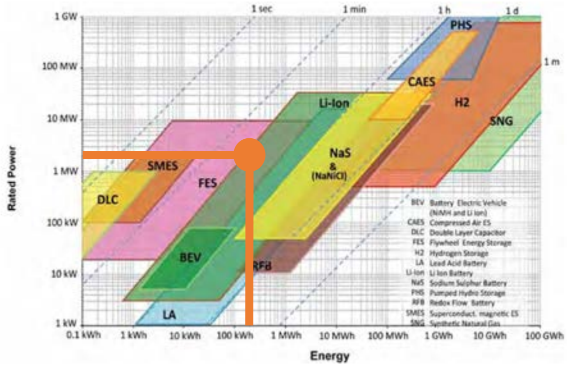

Fig. 8 Battery Selection Chart

The BESS selected rating is: 1 MW/1.7 MWh (2.8 MW for 30 minutes); Number of Cycle: 5000 at Depth of Discharge = 90%.
Further details are given in Section III.

III. SELECTED HYBRID SCHEME

E. System Functional Description

The functional scheme of the Hybrid system is shown in Figure 9.

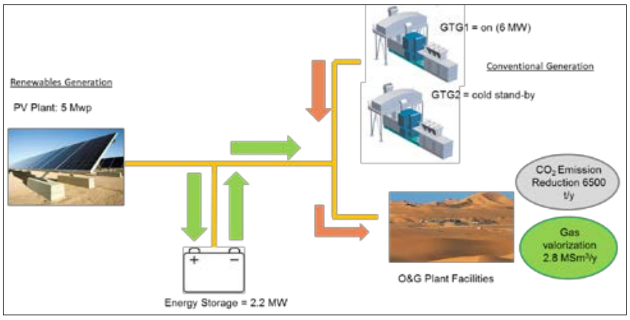

Fig. 9 Hybrid Concept

The system has been designed for a design life of 20 years. The main new sub-systems are now presented here below:

1) *PV Plant:*

The PV plant has been designed in order to:

- Facilitate a defined amount of active power flow (from PV source) to Plant electric users while the remaining of the power is generated by the GTG with a load factor higher than 50%
- Avoid any destabilization/trip of existing plant facilities
- Avoid harmonic resonances with existing electrical distribution

Based on the above objectives, the PV Plant has been sized to have an installed peak capacity of 5 MWp and an estimated average annual energy output of 8.6 GWh/y.

It includes about 16,200 PV panels (polycrystalline silicon type) facing southward with a fixed tilt angle of 30°. PV panels configuration is fixed-mount.

PV plant is directly connected to the existing Oil&Gas plant, which is electrically isolated (not connected to any external electrical grid).
Electrical power is generated by the PV plant at 20 kV. Voltage level is then reduced via a Step-down Transformer to 11 kV and delivered through an underground cable (length 1,500 m) to an existing 11 kV Switchgear. The existing 11 kV Switchgear includes a spare incomer which has been dedicated to the PV Power Plant connection.

The selected layout of the PV plant is shown in Figure 10.

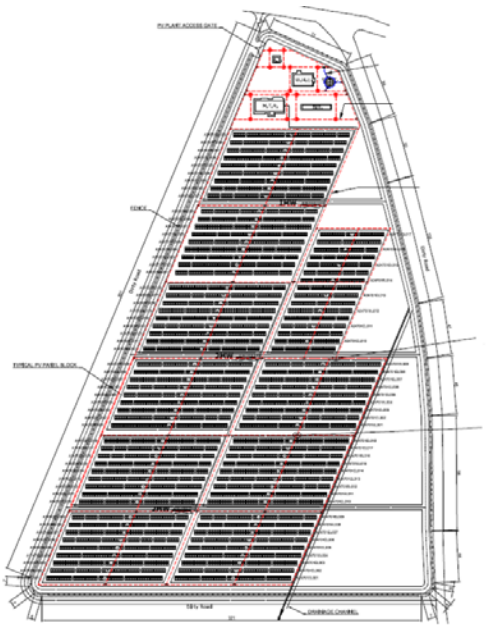

Fig. 10 PV Plant Layout

PV system main components are:

- PV Modules
- Arrays
- String Boxes
- Subarray
- Field Power Stations
- Main Technical Room
- Transformers.

The PV Plant has been split in three main sections called Power Stations. The first two are rated 2 MW each, while the third one is rated 1 MW. The typical electrical diagram of a PV power station is presented in Figure 11.

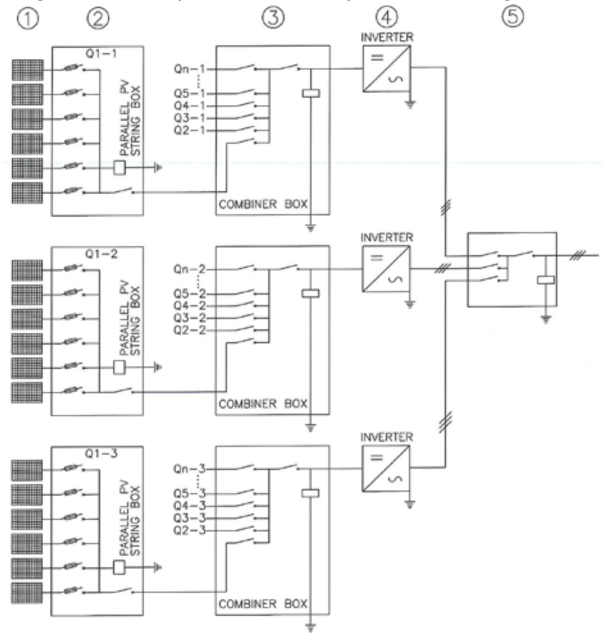

Fig. 11 Typical PV Power Plant Power Station diagram.

Where:

(1)	PV Module
(2)	String Box
(3)	Combiner Box
(4)	Inverter
(5)	Power Station

2) BESS:

The existing Plant electrical infrastructure is not connected to an external national grid. For this very reason, it has been necessary to consider an energy storage system (i.e. batteries) to assist the gas turbine ramp-up in case of sudden drop in PV plant power production. Gas turbines ramp rate are limited and therefore not able to manage big step loads as explained in Section II.

Considering, as worst-case scenario, 20 cycles per day and a number of expected cycles of 14,600 for 10 years, and taking in account battery aging factor, inverter efficiency, etc., the resulting minimum acceptable battery capacity calculated according to IEEE 1115-2014 [3] is 175 kWh, theoretical value that can be obtained with batteries with high rate discharge. The actual battery size is being selected after a cost optimization exercise, where the best compromise between cost and performance has been investigated.

The optimal Storage System capacity has resulted being 1 MW/1.7 MWh (2.8 MW for 30 minutes).

The duration of 30 minutes has been selected based on the fact that batteries can only be recharged by the PV system and recharge cannot be possible for a long period of time. For these very reasons, a conservative approach has been considered to increase system availability.

The Energy Storage System is installed in two packaged buildings. Main equipment components include a vibrated reinforced concrete cabinet, battery system, Power Conversion System (PCS), output step/up transformer and local and remote control and monitoring equipment.

The BESS system is connected to a Main 20kV MV Switchgear located in the Main Technical Room by means of a step-up transformer 0.4/20 kV.

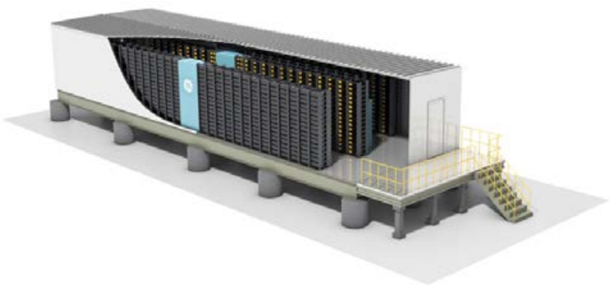

Fig. 12 BESS Module

3) Control System:

The Control System is a PLC (Programmable Logic Controller) based system that is installed to ensure efficient and stable integrated operation of new PV/ BESS systems and existing power generators.

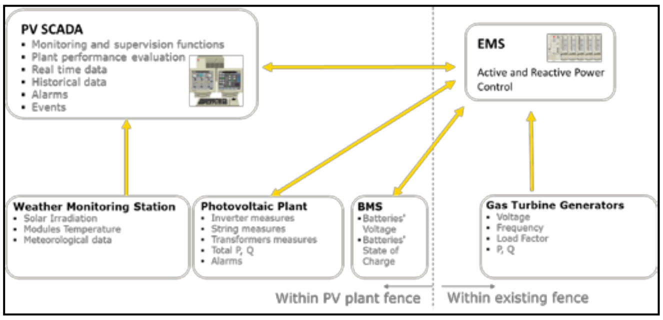

Fig. 13 Control System Architecture.

The Control System ensures the demand-oriented control of the photovoltaic system, dependent on the plant load and generator set characteristics.

Based on the GTG load factor, the PV plant will produce the power necessary to fill the gap in the plant power demand (both active and reactive).

The Power Management System (PMS) will collect data from PV inverters, energy storage system and gas turbine generators Unit Control Panel (UCP), 11 kV main switchgear and existing plant control system (e.g. Distributed Control System (DCS)).

A new HMI (Human Machine Interface) panel is installed for the monitoring and control of the overall plant.

The Power Management System (PMS) will be also connected to the plant SCADA system in order to have all data available globally.

Main system characteristics are summarized in Table I.

TABLE I
MAIN SYSTEM CHARACTERISTICS

PV Plant Power Output	5 MWp peak
PV Panel Type	Polycrystalline 72 Cell > 320 Wp
Inverter Type	1000V d.c. (max. 1500V)
No.of Power Stations	3
Fixed tilt Angle	30°
Number of PV Panels	16,200
Number of PV Modules per String	20
Battery size	1.7 MWh
PV Average Yearly Energy production	8.6 GWh/y
Required Area for PV plant	106.000 m^2
Weight of steel structures	Approx. 1200 t
Site preparation required	Minimal, no grading activities required
Foundations Type	Ballasted
Main Technical Room	Modular, 10 m x 24 m
Power Station	Modular, 3 m x 6 m
PV Power Plant perimeter	1,342 m

IV. CONCLUSIONS

This paper outlines a unique solution adopted to integrate an existing power generation system with a PV/ BESS system. After a long and challenging phase of concept selection, the selected Hybrid concept is regarded as a good optimized balance between cost and performance of both PV/ BESS systems and conventional generation systems. The adopted small scale Hybrid solution provides CO_2 emissions reduction (6,500t/y), fuel gas valorization (saving of approx. 2.8MSm^3/y) and electrical system stability with a reasonable CAPEX investment. It is estimated that the initial investment will be recovered within 10 years. Furthermore, the chosen configuration guarantees the optimal utilization of the existing Gas Turbine Generation system without compromising on its reliability and performance. The project is currently in the process of moving to the Execution phase, where the concept described in this paper will be validated.

V. NOMENCLATURE

BESS	Battery Energy Storage System
CAPEX	CAPital EXpenditure
DCS	Distributed Control System
FEED	Front End Engineering Design
GTG	Gas Turbine Generator
HMI	Human Machine Interface
ISO	International Standards Organization
MV	Medium Voltage
PCS	Power Conversion System
PLC	Programmable Logic Controller
PMS	Power Management System
PV	PhotoVoltaic
SCADA	Supervisory Control and Data Acquisition.
UCP	Unit Control Panel

VI. APPENDIX

The Appendix A shows the Key Single Line Diagram of the Plant.

VII. REFERENCES

[1] IEC 62548 Photovoltaic (PV) arrays - Design requirements
[2] CEI 82-25 Guide for design and installation of photovoltaic (PV) systems connected to MV and LV networks
[3] IEEE 1115-2014 IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications

VIII. VITA

Stefano Fasoli of Eni S.p.A. He graduated from the "Politecnico di Milano" with an Electrotechnical Engineering degree in 1990. He worked as Electrical Lead Engineer in several Offshore and Onshore Oil&Gas projects and subsequently held the position of Head of the electrical Department both in Eni and EniProgetti until the end of 2019. He is currently working in the Technical Authority Department of ENI s.p.a..
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Appendix A

Key Single Line Diagram