Storageless Offshore Hybrid Power Plant

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I. INTRODUCTION

OFFSHORE oil and gas (O&G) platforms are conventionally equipped with local power supply based on fossil fuel, e.g. Gas Turbines (GTs) [1]. The pollution coming from the use of GTs in O&G platforms requires sustainable solutions. One option is to use wind turbines (WTs) as alternative power supply due to a large potential to reduce the fossil fuel use, and thereby the CO_2 and NO_X emissions. There are two main alternatives for WT connection to the platforms: onshore power system via cables and, in case of this article, offshore power production in islanded power systems [2].

Due to the high-level penetration of renewable energy sources (RES), the islanded power systems suffer from lower equivalent inertia and faces several challenges to ensure the stable operation by maintaining the frequency and voltage at nominal value. This high-level integration of RES negatively impacts stable system operation by causing frequency deviations and longer recovery duration when subjected to frequency disturbances [3][4].

The effect of WT integration in O&G platforms needs to be carefully analyzed, since the number of wind turbines and the intermittency of the wind can impact on the stability of system.

This article presents an isolated, storageless offshore system that connects an Offshore Wind Power Plant (WPP) to an Offshore Platform of O&G powered by GT. The strategies of Control for WPP are dq-frame with maximum power point tracking (MPPT) [5], for grid-following (GFL) control, and Synchronverter [6][7], for Grid-Forming (GFM) control. The stability of the system in terms of frequency- and voltage-deviation, and fuel consumption are analyzed with real wind data, measured near the Campos Bay in Brazil [8]. The Controller Hardware-in-the-Loop (CHIL) validation of the system is modelled in a Real-Time Simulator (RTS) HIL 602+ from Typhoon-HIL, and the control strategies are embedded in the Digital Signal Processor (DSP) TMS320F28379D – LaunchPad.

This paper is organized as follows: Section II describes the wind park and oil/gas plataform system description. Section III presents the methodology to develop the system. Section IV shows the simulation results and discussion, and Section V contains the conclusions drawn from this paper.

II. WIND AND OIL/GAS PLATFORM SYSTEM DESCRIPTION

The studied offshore system is shown in Fig. 1. The system consists of a 30 MW wind park (6 WT of 5 MW) connected to a 50 MW O&G platform to supply the 35 MW electrical loads, which includes a Subsea substation and pumps.

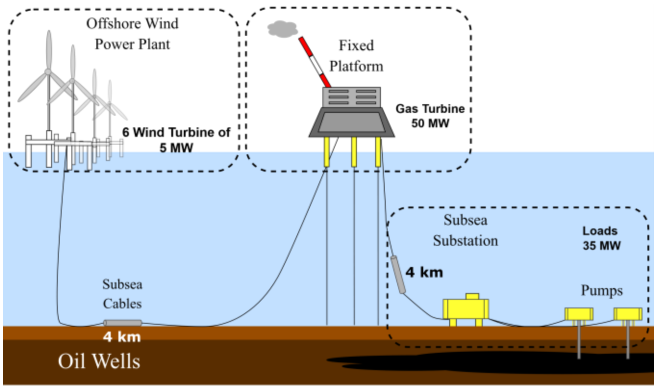

Fig. 1. Offshore Wind Power Plant (WPP) connected to an Offshore Platform of O&G.

A. Wind Park

The wind park consists of 6 Wind Turbines of 5 MW. The wind turbine parameters are found in NREL 5-MW reference wind turbine [9]. An overall configuration of Type-4 WT with conventional grid-following (GFL) control is shown in Fig. 2, which consists of a permanent magnet synchronous generator (PMSG), a back-to-back (BTB) converter including machine-side converter (MSC), and a grid-side converter (GSC), a DC chopper, transformer and grid filters. The main control system includes a pitch controller, a machine-side controller, and a grid-side controller [5].

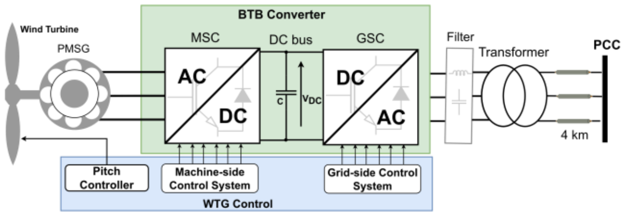

Fig. 2. Configuration of Type-4 wind turbine generator.

For GFL control, the machine-side control strategy is a Maximum Power Point Tracker (MPPT) controller in dq-frame in order to ensure maximum power extraction from wind using optimal power control (OPC) [5].

The optimal mechanical power (P_{opt}) produced by the turbine rotor is given by equation (1) [5].

$$P_{opt} = k_{opt}\omega_r^3, \quad (1)$$

$$k_{opt} = 0.5\rho\pi R^2 C_p^{max}(R/\lambda_{opt})^3, \quad (2)$$

where ω_r is the WT rotor speed, ρ is the air density, R is the WT rotor radius, C_p is the power coefficient and λ_{opt} is the optimal tip-speed ratio (TSR).

For islanded operation and black-start of wind farm, the turbine controllers are based on the GFM or voltage control [5][10]. The WT with GFM control behaves as a controllable voltage source behind a coupling reactance much like grid-tied synchronous generators, which forms the voltage amplitude and frequency of the local grid [10].

In literature, there are many different control solutions using GFM control, including traditional droop-based power controllers and more complex controls that replicate the functionalities of Synchronous Generators (SGs) like inertial & damping characteristics and frequency/voltage droop. For this article, the Synchronverter control strategy is considered [6][7], which replicates the SG using equation (3) [6].

$$\ddot{\theta} = \frac{1}{J}(T_m - T_e - D_p\dot{\theta}), \quad (3)$$

where θ is the rotor angle (virtual angle), $\dot{\theta}$ is a virtual angular speed, J is the moment of inertia, T_m is the mechanical torque, T_e is the electromagnetic toque, and D_p is a damping factor.

B. *Oil/Gas plataform and loads*

The O&G platform consists of a GT with a SG and transformer, which is connected to wind park through a 4 km cable and to loads (Controllable load and Fixed load) through another 4 km cable, as shown in Fig. 3.

Due to wind power intermittency, the SG has to provide power to the load during low wind speeds and compensate for variations in wind power output [12]. The required level of power supply security is generally high on O&G platforms, and a GT should always be online as backup [2].

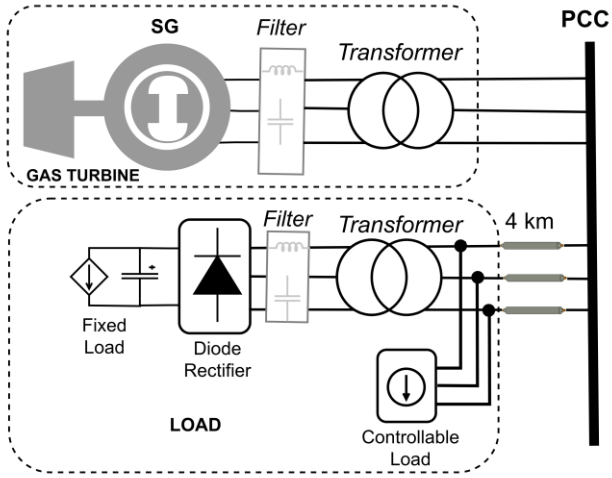

Fig. 3. Oil/Gas plataform and electrical loads.

The efficiency of a GT is not higher than 36% when operating at nominal power, and it decreases significantly at low loads. The fuel consumption during idle operation is approximately 20% of the consumption at nominal power, and operating at low load or idle is undesirable from both a fuel-use and emission standpoint [2].

III. METHODOLOGY

To test control algorithms before field deploy Hardware-in-the-Loop simulations are suitable to validate it in a commercial hardware [13]. This is only possible with RTS because as it runs an simulation in real time the equipment feels that it is interacting to a real plant. Fig. 4 shows the CHIL setup. In the Host PC there's a SCADA Panel for monitoring and controlling the simulation. The simulation is embedded in the RTS Typhoon HIL 602+ which interacts with the controller F28379D Launchpad through an interface board. The RTS sends the measures of the WT through analog outputs pins and receives the respective PWM switching signals through digital input pins, which drives the converters in the simulation. With the Launchpad output pins an oscilloscope can be used to monitor the exchanged signals.

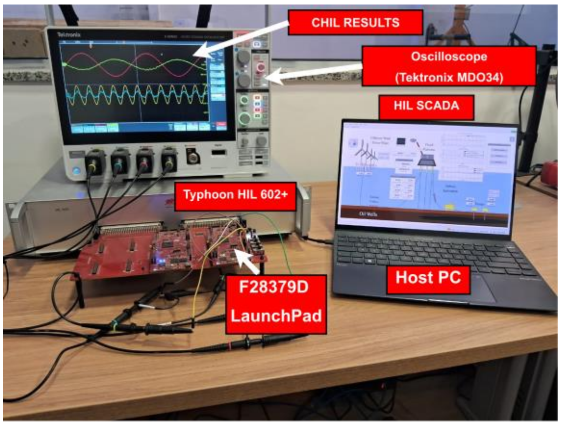

Fig. 4. CHIL Setup to test the WT's controls.

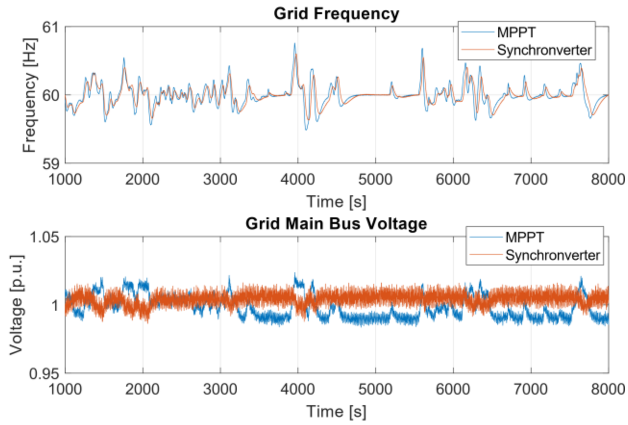

Fig. 6: Resulting Grid Frequency in Hz (upper graph) and Bus Voltage in V (lower graph). Both measured at the Main Bus.

IV. Results and Discussion

The comparison of the control strategies was made applying the wind profile of 43.5% of capacity factor in the input of the WT model. Fig. 5 shows 2 profiles extracted in [8] to give an overview of the variability of the wind.

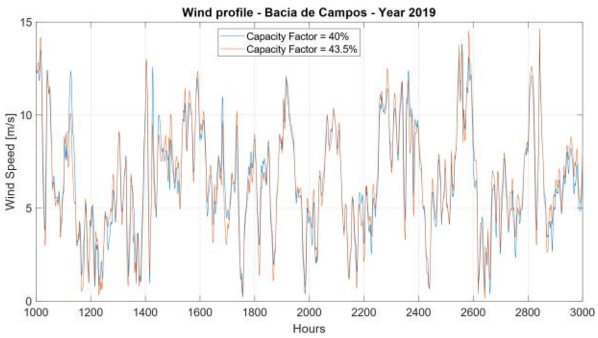

Fig. 5: Wind profile at Campos Basin from the 1000th hour till 3000th of the year 2019. Wind speed from 0 till 15 m/s. Capacity factors of 40 and 43.5%

Fig 6 shows the grid's frequency and voltage respectively and it can be seen that for both graphs the Synchronverter control presents a more stable scenario. For the first, the amplitude of the maximum and minimum frequency are lower than for the MPPT and also smothier changes are present, indicanting the variability of the wind is compensated by the frequency droop present in the control. For the voltage plot, the synchronverter control also presents a more stable operation. This also happens due to a voltage droop loop present in the control which uses reactive power to compensate voltage variations and try to maintain it's value around 1 p.u. as much as possible. The MPPT control does not have voltage droop loops and when the total power changes the voltage drop in the transmission line also changes making the grid voltage reach levels around 0.97 p.u. .

Fig. 7 shows the total active power of the WPP and the generator fuel consumption. For the power graph, the MPPT shows higher levels of energy production and for the fuel graph a lower consumption, which can indicates that it would have a higher descarbonization of the system.

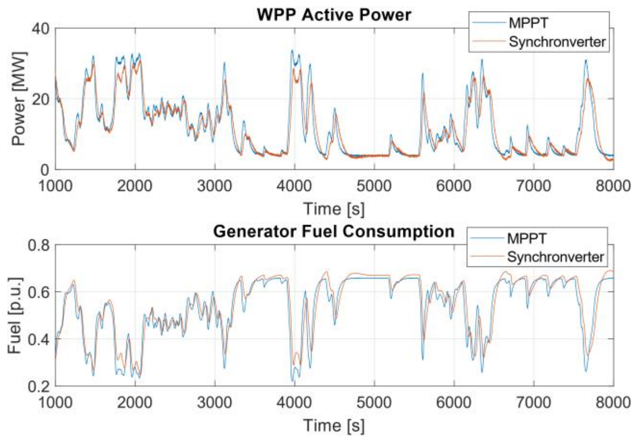

Fig. 7: WPP active power (MW) (upper graph) and Generator Fuel consumption (p.u.) (lower graph).

V. Conclusion

This paper presented the assessment of 2 control strategies to integrate offshore wind turbines with oil & gas platforms through CHIL simulations. The results showed that for the Synchronverter control the frequency and voltage levels presents a more stable operation due to the support control loops. Altough this, this control have a lower efficiency than the MPPT, which in some cases could be a more suitable choice to increase the fuel consumption reduction. In the full version of the article, additional results will be presented.

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