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Smart Grid Integration for Offshore Oil Platforms

Chibuzo Onumadu
Bachelor of Engineering
Department of Electrical and Electronics Engineering
Enugu State University of Science and Technology

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Abstract: *The successful pilot operation of Equinor's floating Hywind 2.3 MW wind turbine has validated the potential of new technology for capturing wind energy in deep water environments. This innovation shows promise for harnessing the excellent wind resources near offshore oil and gas platforms, where water depths range from 100 to several hundred meters. Offshore oil and gas platforms, which include numerous energy-consuming facilities such as drilling, accommodation, processing, exporting, and injection units, have significant electrical power demands ranging from 10 MW to several hundred MW on the Norwegian Continental Shelf (NCS). As the NCS is a mature petroleum province, energy consumption per produced unit is expected to increase, posing environmental challenges. Currently, most platforms on the NCS generate their own electrical power using gas turbines, which also directly drive compressors and pumps. These gas turbines are responsible for approximately 80% of the total CO2 and NOx emissions from offshore installations. Integrating smart grid technology with renewable energy sources like floating wind turbines could significantly reduce these emissions and enhance the sustainability of offshore oil and gas operations.*

Keywords: smart grid, integration, offshore, oil, platforms

INTRODUCTION

The successful pilot operation of Equinor's floating Hywind 2.3 MW wind turbine has validated the new technology for capturing wind energy in deep water environments. This technology has also shown potential for harnessing excellent wind resources near offshore oil and gas platforms, where water depths range from 100 to several hundred meters. Offshore oil and gas platforms typically comprise numerous energy-consuming facilities, including drilling, accommodation, processing, exporting, and injection units.

On the Norwegian Continental Shelf (NCS), the current electrical power consumption at a platform ranges from 10 MW to several hundred MW. As the NCS is a mature petroleum province, the energy consumption per produced unit is expected to increase. Offshore platforms are encountering increasingly stringent environmental challenges. Most platforms on the NCS generate their own electrical power using gas turbines, which also directly drive compressors and pumps. These gas turbines are responsible for approximately 80% of the total CO2 and NOx emissions from offshore installations.

Three Study Cases

Three case studies comprising wind farms rated at 20MW, 100MW, and1000MWhave focused on(i) the operation benefits of CO2/NOx emission reduction, (ii) electrical grid stability, and (iii) the technical implementation feasibility. The first case (20MW) is the integration of a small offshore wind farm with a stand-alone electrical grid on the offshore oil and gas platform.

The second case (100MW) is the extension of the first case. To utilize more wind power, a 100MW wind farm is connected to five nearby oil and gas platforms by subsea power cables. In order to achieve an economically feasible offshore wind farm, the third case (1000MW wind farm) has been proposed for supplying the wind power both to the oil and gas platforms and to the onshore electrical grid. The description of these three cases is given in Table 1.

Table 1: Three study cases.

Cases description	Objectives
Case 1 *—20 MW wind farm:* Four 5 MW wind turbines generate electrical power in parallel with three gas turbines (each has capacity of 23 MW)	(i) Estimate the long-term operation benefits of wind power integration in terms of fuel savings and CO_2/NO_x emissions reduction. (ii) Determine the electrical grid stability due to the integration of four 5 MW wind power generator units. (iii) Identify the maximum amount of wind power possible to integrate to the stand-alone electrical grid on the offshore platform.
Case 2 *—100 MW wind farm:* 20 units of 5 MW wind turbine are connected to five nearby platforms	(i) Assess the maximum amount of wind power that can be integrated to each platform. (ii) Electrical grid stability in terms of the control strategy and interconnecting grid topology.
Case 3 *—1000 MW wind farm:* 200 units of 5 MW wind turbine are both connected to platforms and to the onshore electrical grid	(i) Design the electrical grid layout. (ii) Calculate the transmission losses. (iii) Evaluate the electrical grid stability.

Simulation Implementation

3.1. Simulation Models for Case 1—20MW Wind Farm. The potential fuel gas saving and CO2/NOx emission reductions due to wind power integration were simulated by a model implemented in MATLAB. The inputs were a series of wind speeds and power consumptions on the platform over time.

The simulated fuel gas consumption and CO2 emissions were compared to the real data from an offshore platform.

The dynamic simulation models were implemented in SIMPOW [2], and it included both the platform electrical grids models and the wind farm models. The dynamic simulation models were achieved by modifying the short circuit calculation models of the platforms. Four 5MW wind turbine units were added to the short circuit calculation models. Each wind turbine was modeled using the full power

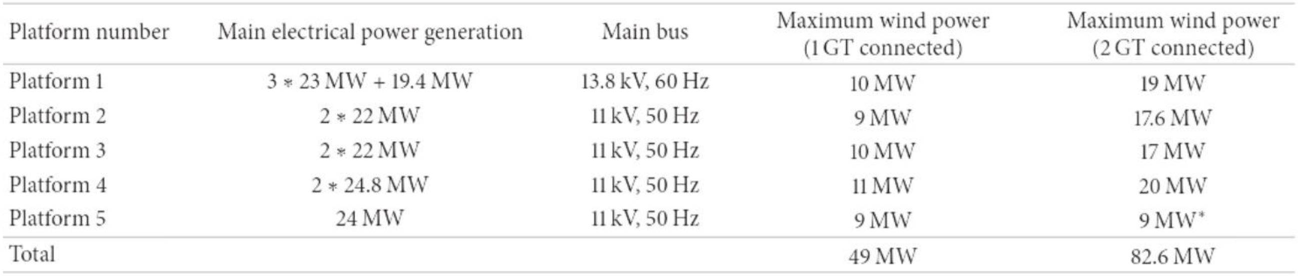
converter wind turbine (FPCWT) model described in the SIMPOW manual [2]. An illustration of the wind turbine model is given in Figure 1. The simulated frequency and voltage variations were compared with the NORSOK standard [4] for power quality requirements on offshore installations. The additional simulations were run to determine the maximum amount of wind power possible to integrate into the platform. The technical limit is defined by the load level, the NORSOK standard of the frequency and voltage variations, and the wind-power strategy during platform operations.

Simulation Models for Case 2—100MW Wind Farm.

The simulation models of the 100MW case have been implemented both in EMTDC/PSCAD [5] and in SIMPOW by two research groups, respectively [3, 6]. The goal of the 100MW simulation model in PSCAD is to identify the maximum amount of wind power for the integration with each platform. The gas turbine, synchronous generator, and the wind turbine models in PSCAD have been tested by comparing the results from the models in SIMPOW [2]. The four main modules in the 5MW wind Turbine model in PSCAD are wind source, wind turbine, wind turbine governor, and generator, all illustrated in Figure 2.

The module of wind turbine has inputs of the wind speed from the wind source module and the wind speed at the hub height, while the outputs are the mechanical torque transmitted to the generator and the power from the wind turbine. The module of wind turbine governor has the blade pitch control. The inputs are the mechanical power of the wind turbine and also the speed of the hub, while the output is the blade pitch angel.

TABLE 5: Maximum wind power for integration to each platform individually.



Platform number	Main electrical power generation	Main bus	Maximum wind power (1 GT connected)	Maximum wind power (2 GT connected)
Platform 1	3 * 23 MW + 19.4 MW	13.8 kV, 60 Hz	10 MW	19 MW
Platform 2	2 * 22 MW	11 kV, 50 Hz	9 MW	17.6 MW
Platform 3	2 * 22 MW	11 kV, 50 Hz	10 MW	17 MW
Platform 4	2 * 24.8 MW	11 kV, 50 Hz	11 MW	20 MW
Platform 5	24 MW	11 kV, 50 Hz	9 MW	9 MW*
Total			49 MW	82.6 MW

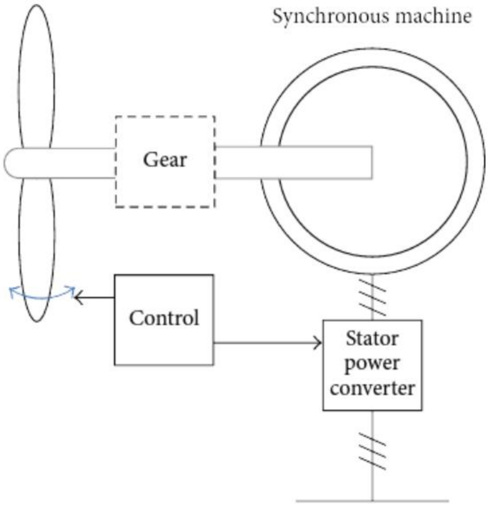


FIGURE 1: Wind turbine model in SIMPOW [2].

The 100MWsimulation model in SIMPOW is the extension of the 20MW simulation model [7] by including four more platforms illustrated in Figure 3. The electrical grid stability was analysed based on three different topologies of the five platforms shown in Figure 4.

Simulation Models for Case 3—1000MW Wind Farm.

The 1000MW wind farm case is illustrated in Figure 5. Platform A has current electrical load of 100MW and the electrical power is supplied from onshore via one AC sea cable and two DC sea cables. The electrical load at Platform A will increase from 100MWto 200MW. The new sea cables have been planned in order to provide more electrical power from onshore to Platform A. This 1000MWcase provides an alternative to supply the wind power to Platform A and the surplus wind power to the onshore electrical grid. As shown in Figure 5, there are one AC and two DC transmission lines in existence. There is a plan to build one new AC and two new DC transmission lines in the year

2015. Accordingly, one proposal of the 1000MW offshore wind farm integration is shown in Figure 6. The 1000MW simulation model was implemented in PSCAD [8], and it consists of offshore wind farm, oil and gas platform, HVAC, HVDC, and onshore grid modules.

The simulation results of the three study cases are summarized as follows.

Simulation Results of Case 1—20MW Wind Farm

The simulated yearly fuel consumption and CO2/NOx emissions and the reduction due to wind power are given in Table 2. In the case at average load of 30.6MW, the simulation results show that the integration of a 20MW wind farm to an offshore platform would achieve approximately a 40% reduction in fuel gas and CO2/NOx emissions when one gas turbine can be started and stopped. The yearly case would result in an annual reduction of 53,790 tons of CO2 and 366 tons of NOx. The simulation results also show that the gas turbine start/stop operating strategy would result in a further annual reduction of 6Msm3 of fuel gas, 14,070 tons of CO2, and 96 tons of NOx. This further reduction is due to the gas turbine efficiency increase from 25.6% to 30.1%. The penalty is that the second gas turbine must be switched off and started 543 times during the year, that is, approximately 1.5 times per day. Further study is needed to assess the possible mechanical degradation and lifespan reduction of the gas turbine and the

operational risks due to the additional motor starts and stops. The simulated fuel gas consumption andCO2 emissions agree with the real platform's operation data. The electrical grid stability after integration of a 20MW wind power generator was tested by nine cases under four contingency scenarios listed in Table 3. The variations in frequency and voltage due to wind fluctuations are much smaller than the first three disturbances. The added wind power reduces the voltage and frequency variations during a motor start. The loss of all wind power became critical when the amount of wind power integration is increased, and this scenario was used to identify the maximum limit for wind power integration to the stand-alone electrical grid at the offshore platform.

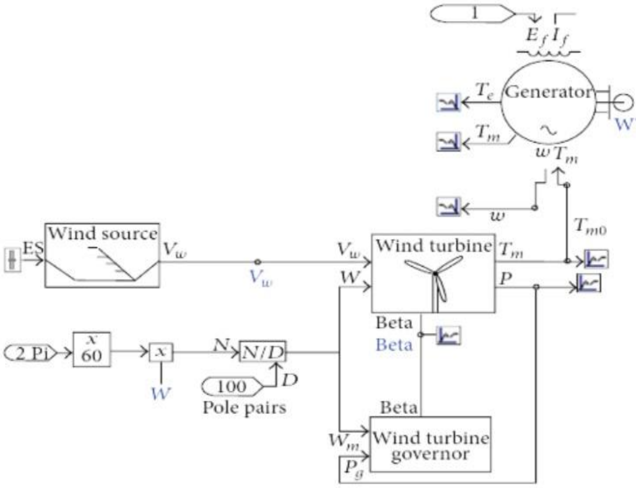
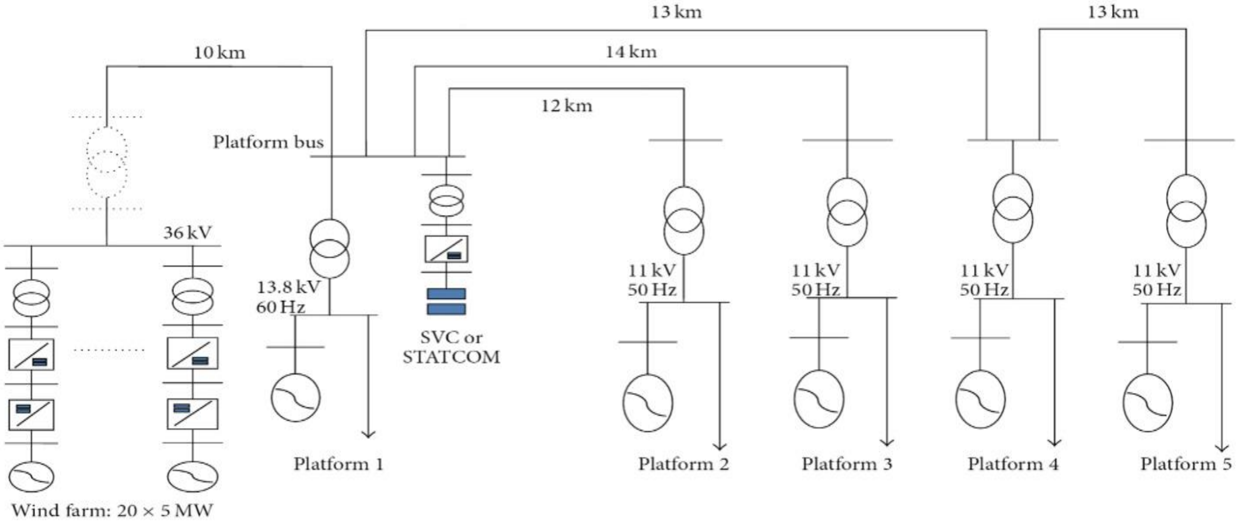


FIGURE 2: Wind turbine model in PSCAD [3].



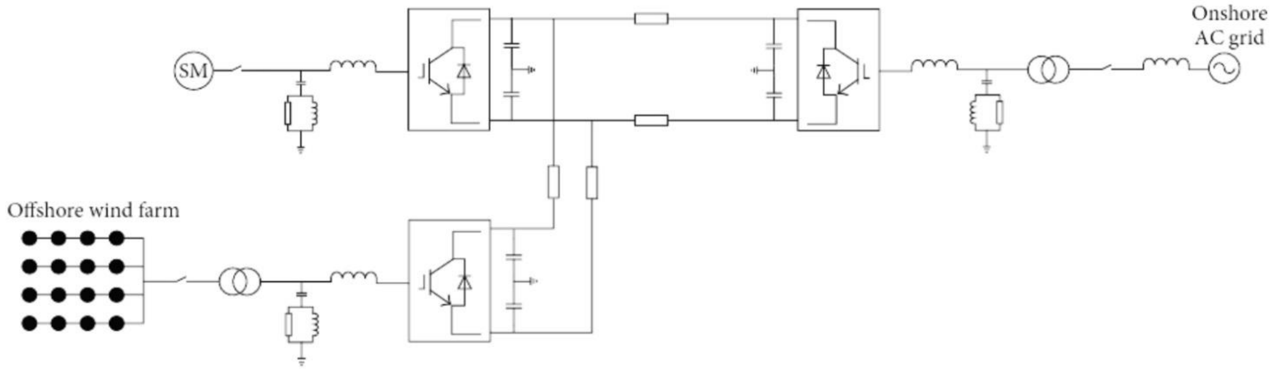
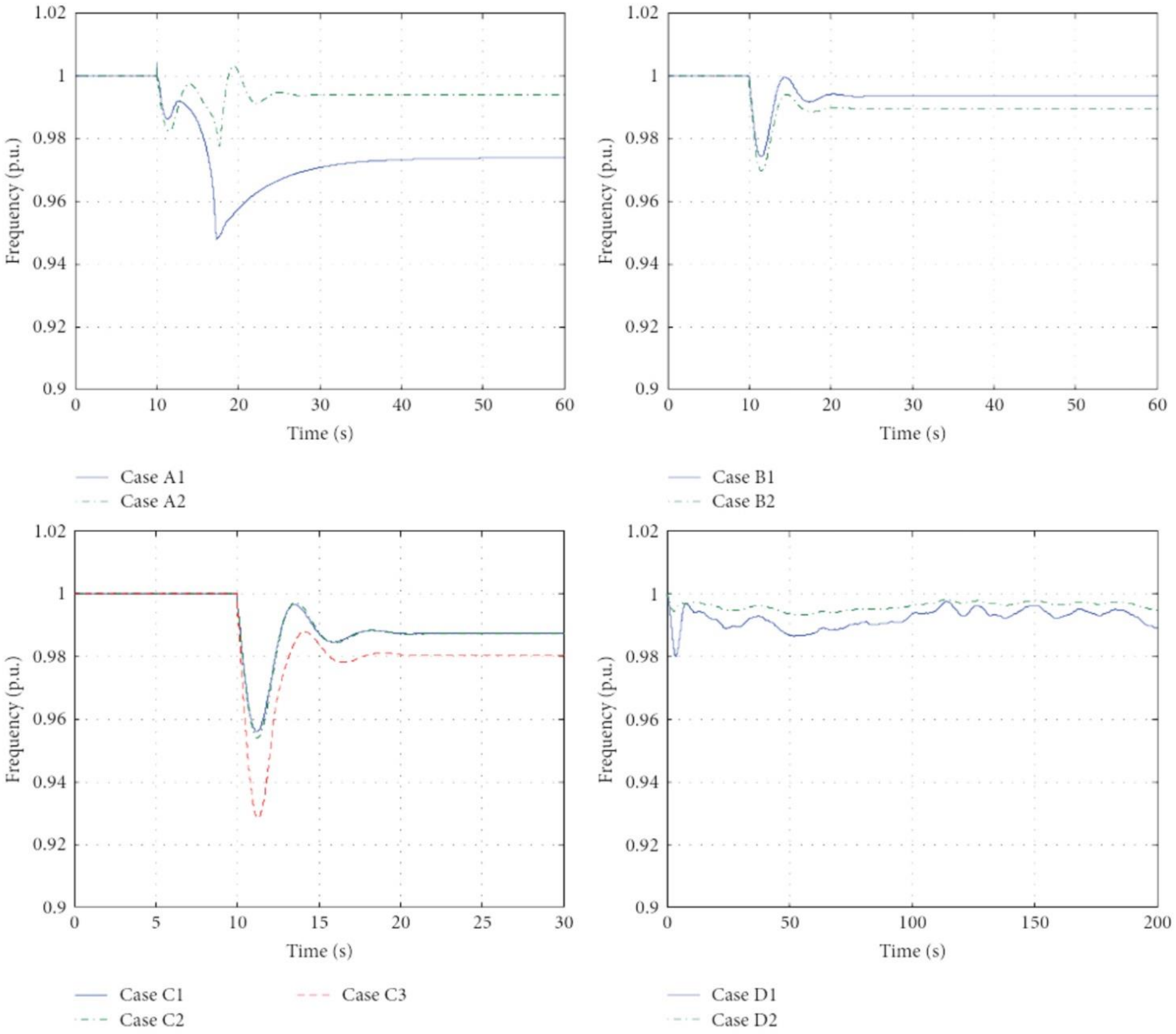


FIGURE 6: One proposal of the 1000 MW offshore wind farm integration.



The simulation results of the frequency and voltage variations for the nine simulation cases shown in Figures 7 and 8 can be listed as follows.

(i) The motor start resulted in a frequency variation from +0.5% to −1.5%and the voltage variation was +13% to −18%.

(ii) The loss of one gas turbine resulted in a frequency variation of −3% with the final deviation of −1% and the voltage variation was −4% with a final deviation of −0.5%.

The loss of all wind turbine power resulted in a frequency variation of −7.3%and the voltage variation was −1.7% to 5.3% under transient conditions.

The largest deviations in frequency and voltage are observed in Cases A1 and C3. The frequency and voltage deviations during loss of all wind turbines are given in Table 4. This worst-case scenario will be used to identify the Maximum amount of wind power allowable for integration to the stand-alone electrical grid on the offshore platform in the following section. The loss of all wind power became critical when the amount of wind power integration is increased, and this scenario was used to identify the maximum limit for wind power integration to the stand-alone electrical grid at the offshore platform.

CONCLUSION

Three case studies comprising wind farms rated at 20MW, 100MW, and 1000MW show that utilizing offshore wind farm for offshore oil and gas platforms and for supplying the power to onshore grid is a promising alternative to reduce CO2/NOx emissions. One yearly case based on the real load data gave an annual reduction of 40% of the CO2/NOx emissions. The wind power capacity could be further increased by connecting a wind farm to five nearby platforms (100MW case) and further still by using electrical subsea cables to supply the surplus wind power to an onshore electrical grid (1000MW case). All three cases are theoretically feasible based on this preliminary study; further studies are required to overcome many other operational, logistical, and economic problems.

Acknowledgments

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