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Integration of Offshore Wind with O&G Platforms with an Energy Storage System

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***Abstract*—Offshore O&G exploration companies are moving to greater depths to access more abundant O&G reservoirs in deeper waters, resulting in higher costs for HVDC power transmission. As such, an integrated system consisting of an offshore floating wind farm and O&G production platforms with a battery energy storage system (BESS) is proposed in this paper. Transient stability results of the proposed system shows a reduction in transient deviation in load power from -19% to +2/-10%, which meets the IEC and NORSOK standards for O&G platforms. In addition, the load power is also maintained close to 1 p.u. during the transient period.**

Keywords*— *Offshore Wind Turbine Generation, Oil and Gas Platforms, Battery Energy Storage System, Transient Stability

I. INTRODUCTION

Throughout the 20th century and today, the number of renewable energy installations have multiplied due to awareness for the environment, increase in fossil fuels' energy price and growth in energy consumption for industrial, transportation and residential purposes. This has led to a worldwide effort from the International Maritime Organisation (IMO) to reduce annual greenhouse gas (GHG) emissions from the shipping industry by at least 50% by 2050 [1]. In the marine and offshore industry, the Norwegian Ministry of Climate and Environment introduced the Norwegian CO_2-tax in 1991, in addition to the EU Emission Trading System regulation, resulting in the oil and gas (O&G) industry paying both CO_2-tax and EU ETS pricing for GHG emissions [2]. Norway has also committed to the UN Framework on Climate Change to reduce GHG emissions by at least 40% by the year 2030 [3].

In the context of the offshore O&G industry sector, traditional O&G platforms are mainly powered by onboard Simple-Cycle Gas Turbines (SCGT). These SCGTs typically have efficiency levels ranging from 25% to 30% with newer models not exceeding 40%[4][5]. As such, they are less energy efficient, compared to the onshore combined-cycle gas turbine, which will produce 50% more energy with the same amount of fuel. In addition to producing more than double the amount of GHG emissions, the installation of SCGT also requires a significant amount of space and cost in building the loading-bearing infrastructure on the O&G platforms. Therefore, there has been increasing interest in exploring alternative renewable energy sources for electrification of O&G platforms [6].

O&G platforms are typically at least 100 to 200 km away from the coast. [7] For distances above 100 km, the High Voltage Direct Current (HVDC) transmission systems are currently most cost-efficient for transmitting energy from the onshore grid to the offshore O&G platforms, as compared to High Voltage Alternating Current (HVAC) transmission systems. Such examples include Troll [8], Valhall [9] and etc. However, with many O&G fields in shallow waters being depleted, O&G exploration companies are moving to greater depths to access more abundant O&G reservoirs in deeper waters, resulting in higher costs for HVDC power transmission. [10]. In addition, other challenges include potential limitations on transmission capacity from onshore power substations, additional infrastructure cost in building an onshore power substation for remote locations, and etc [11].

In recent developments, offshore wind turbine generators (WTG) have been considered as an alternative source of energy for electrification of O&G platforms [12]. Offshore wind installation in deep waters is considerably more expensive largely due to the costly installation of submarine cables to transmit generated energy to the onshore grid. As the cost of WTG power transmission contributes more than half of overall CAPEX cost, there is high cost savings in the power distribution of an integrated WTG to O&G platforms, thereby removing the need for a costly power transmission line to the onshore grid [13].

Based on the latest case studies of integrating offshore wind with O&G platforms, it has been shown to be techno-economical to power O&G platforms using offshore wind energy in deep waters [14]. O&G platforms in Beatrice oil field has been supplied electricity by two 5 MW wind turbine which are installed adjacent in offshore [15]. In order to address the intermittency of wind, on-board SCGTs are required to be on "stand-by" mode, which can be started up almost instantaneously, in the event of a sudden drop in wind speeds. The fuel efficiency of SCGTs reduces drastically under low loads and SCGTs in "stand-by" mode consumes at about 20% of the amount of fuel required in "full power" mode, which contributes towards increased GHG emissions [16].

In this paper, an integrated system consisting of an offshore floating wind farm and O&G production platforms with a battery energy storage system (BESS) is proposed.

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With a BESS, the third SCGT will no longer be required onboard on “standby” mode, resulting in reduced GHG emissions while maintaining the overall output power quality. This paper will present the transient stability studies on the proposed configuration. Subsequently, the results are used for study to compare against the international IEC standards 61892-1 and the NORSOK standard used by Norwegian offshore industry [17] for maximum continuous deviation and maximum transient recovery time, as shown in Table I.

TABLE I. TOLERANCES VOLTAGE AND FREQUENCY FOR O&G PLATFORMS

Operation	Voltage Deviation	Frequency Deviation
Maximum Continuous Deviation	+6 / -10%	+5%
Maximum Cyclic Deviation	+2%	+0.5%
Maximum Transient Deviation	+20%	+10%
Maximum Transient Recovery Time	1.5 sec	5 sec

The outline of this paper is as follows. Section 2 presents the detailed configuration for the proposed system. Four different test scenarios are presented in Section 3. Simulation results of the conventional system for the four test cases, will be shown in Section 4. Section 5 presents the simulation results of the proposed system. Conclusions and future work are discussed in Section 6.

II. PROPOSED SYSTEM CONFIGURATION

The proposed system configuration is as shown in Figure 1. In this section, detailed system configuration for the proposed system is presented as follows.

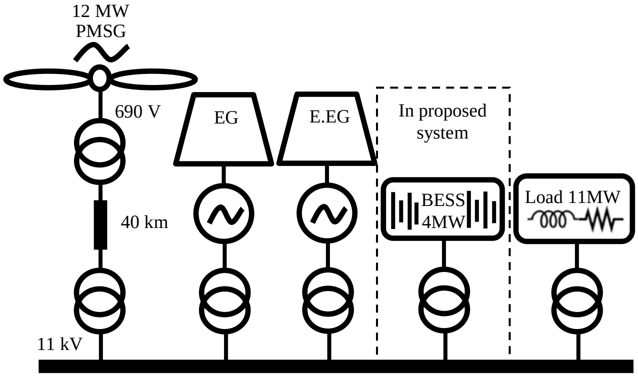

Figure 1. Proposed offshore integrated system

A. *Oil and gas platforms*

Typical O&G platforms are equipped with three platforms consist of a utility and living quarter (ULQ) platform, a processing and heating (CPF) platform and a wellhead (WHP) platform. These platforms are powered by three sets of SCGTs, which are used as EGs and rated to meet the load demand of the platforms. In the conventional O&G platforms, two EGs will always be running and one EG is on standby mode. The EGs burn extracted natural gas from the field under normal operating conditions, which powers the three platforms via three main switchboards that are rated at 11kV. The output voltage is stepped down via integral transformers in distribution panels to 3,3kV and 400V, to power the water injection pumps, gas compressors, drilling unit, utility loads and etc [18].

In the proposed system, the O&G platforms are equipped with 2 x SCGTs (13 MW), where one SCGT acts as an essential generator (EG) and the other serves as an emergency essential generator (E.EG). One of the EG has been removed, which allows integration of the 4MW battery energy storage system (BESS) onboard the O&G platform. The conventional O&G platforms have a fixed load between 10MW, as discussed in [19].

B. *WTG*

The proposed system consists of 2 x 6 MW Siemens (SWT-6.0-154) Permanent Magnet Synchronous Generator (PMSG) floating WTGs connected in parallel, which mirrors the Hywind Park configuration in the North Sea [20]. Each WTG consists of a synchronous generator, DC-link capacitor and back to back converter interfaces. The PMSG operates with variable wind speed and produces a variable AC voltage with variable frequency. The AC frequency voltage is first rectified by AC/DC rectifier. Thereafter, the generator output power is converted from DC link with DC/AC inverter to supply variable frequency and voltage rated at 690V. Finally, a step-up transformer will supply rated voltage of 33kV through a 40km HVAC power transmission cable, which is stepped down to 11kV output on the power bus of the O&G platforms.

C. *Battery energy storage system (BESS)*

There are several types of batteries commonly used in renewable energy systems, e.g. lead acid, lithium, nickel cadmium and etc. In this system, a BESS utilizing Li-ion batteries is proposed, primarily due to its high energy density and declining cost [21]. The BESS offers bidirectional power flow and can be used for control strategy in the event of voltage drop on the grid-connected in renewable systems [22]. The 4 MW BESS is installed onboard the platforms and connected to the 11kV main switchboard on O&G platforms.

III. TEST SCENARIOS

In this section, four test scenarios are described, as shown in Table II.

TABLE II. CONVENTIONAL SYSTEM IN 4 SCENARIOS

Scenario	Event
1	No Wind
2	EG and E.EG are tripped and WTG is turned on
3	E.EG and WTG are tripped and EG is turned on
4	EG and WTG are tripped and E.EG is turned on

These four scenarios are simulated in the MATLAB/ Simulink with SimScape/SimPowerElectronics in Sections 3 and 4. Through the four test scenarios, a constant rated wind speed of 12m/s is assumed. The simulation study is based on the ability of the power system, to maintain electrical power to load when subjected to transient fault such as the loss of a large energy generation source. Usually, the duration of the trip event to study transient stability is around 3 to 5 seconds [17].

For these four test scenarios, the simulation results for the conventional and proposed system are presented in Sections 3 and 4 respectively. The simulation results are compared against the international IEC standards 61892-1 and the NORSOK standard used by Norwegian offshore industry

[17] for maximum continuous deviation and maximum transient recovery time, as shown in Table I. For a fair comparison, the conventional system is assumed to have two SCGTs running onboard, which are the EG and E.EG.

IV. CONVENTIONAL SYSTEM SIMULATION RESULTS

A. *Case 1*

In this case study, the conventional system is started in Scenario 1 and switched to Scenario 2, In this simulation case, WTG is turned on when the EG is tripped and E.EG is not in standby mode. In Scenario 1 where there is no wind, the EG supply electrical power to O&G platforms consistently at about 1p.u.. In Scenario 2, the EG is suddenly disconnected and tripped at 10.8s. At the same time, the WTG is turned on to supply electrical power to O&G platforms at 10.8s onwards. It can be seen from Figure 2 that there is a high surge of output power to the load of 1.14 p.u. between 10.8s and 11.3s, which settled down to 0.96 p.u. after 0.5s. In this case, it is shown that the output load power profile has a maximum transient deviation of 14% and the maximum continuous deviation is +1 / -3%.

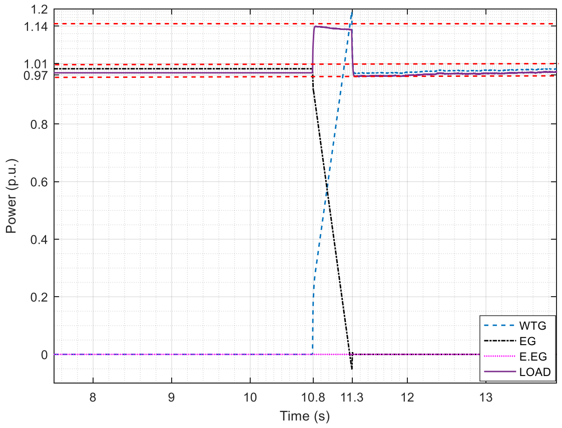

Fig. 2. Power flow in p.u. when EG is disconnected and WTG is turned on (P_{base} =11 *MW*).

B. *Case 2*

In this case study, the conventional system is started in Scenario 2 and switched to Scenario 3, where the WTG is disconnected and the EG is turned on. In Scenario 2, the WTG has been supplying power to the electrified O&G platform consistently around 1 p.u.. There is a trip to WTG at 20.9s and the EG is turned on at this point of time. As shown in Fig. 3, there is a significant drop to 0.81 p.u. to the load. Moreover, the transient recovery time is up to 1.3s. In this case, it is shown that the output load power profile has a maximum continuous deviation of approximately -2%. However, the maximum transient deviation of 19% and a maximum transient recovery time of 1.3s.

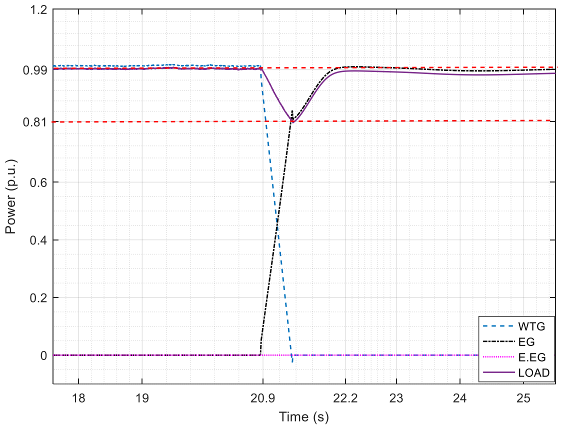

Fig. 3. Power flow in p.u. when WTG is disconnected and EG is turned on (P_{base} =11 *MW*).

C. *Case 3*

In this case, the transient stability of the load power is studied when the EG fails and the E.EG is turned on. In Scenario 3, the EG has been supply electrical power to load on O&G platforms continuously. In this simulation case, the EG is disconnected at 30.8s. The E.EG is then turned on to supply electrical power at rated level. It can be seen in Fig. 4 that there is similarly a significant drop to 0.81p.u. to the load. Similar to Case 2, it is shown that the maximum transient deviation of 19% and a maximum transient recovery time of 1.3s. This is expected as the EG and E.EG are modelled with the same specification. In both Scenarios 3 and 4, the EG and E.EG are supplying power to the same load, which explains the same transient response observed in Cases 2 and 3.

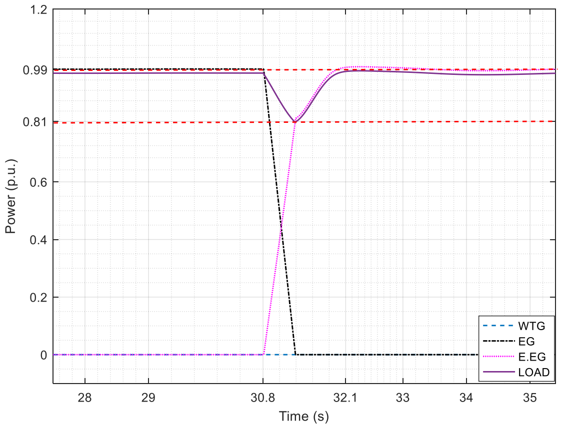

Fig. 4. Power flow in p.u. when EG is disconnected and E.EG is turned on (P_{base} =11 *MW*).

V. PROPOSED SYSTEM SIMULATION RESULTS

In this section, a similar study is conducted on the proposed system with BESS. Two separate BESSs are used in this simulation study, namely BESS 1 (3MW) and BESS 2 (1 MW).

A. *Case 1*

In this case study, the proposed system is started in Scenario 1 and switched to Scenario 2, where the EG is suddenly disconnected and WTG is turned on. BESS 1 is switched on in between Scenario 1 and Scenario 2. In

Scenario 1 where the EG is supplying power to electrified O&G platform, as shown in Fig. 5. It is observed that when the EG is tripped and WTG is turned on, the maximum transient deviation in load power is 10%. This is a reduction of 4%, as compared to the conventional systems in Fig. 2. In addition, the load power is maintained around 1 p.u. after the transient period.

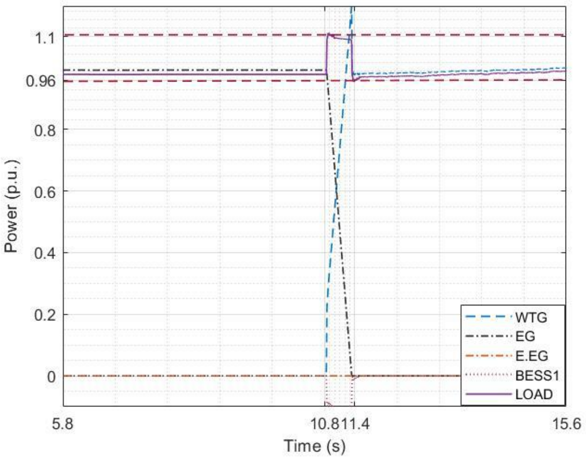

Fig. 5. Proposed System: Power flow in p.u. when EG is disconnected and WTG is turned on (P_{base} =11 *MW*).

B. Case 2

In this case study, Scenario 2 is switched to Scenario 3, where the WTG is disconnected and EG is turned on. BESS 2 is switched on in between Scenarios 2 and 3. In Scenario 2, the WTG has been supplying power to the electrified O&G platform, which is around 1p.u.. At 20.9s, the WTG is tripped and EG is turned on, as shown in Fig. 6. It is observed that the transient deviation in load power is approximately +2/-10%. This is significantly lower as compared to the conventional system, as shown in Fig. 3 and 4, where the transient deviation is -19%.

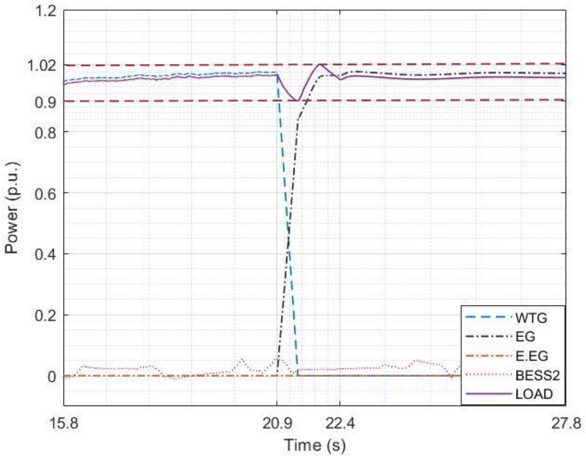

Fig. 6. Proposed System: Power flow in p.u. when WTG is disconnected and EG is turned on (P_{base} =11 *MW*).

C. Case 3

In this case study, Scenario 3 is switched to Scenario 4, where the EG is disconnected and E.EG is turned on. BESS 2 is switched on in between Scenarios 3 and 4. At 30.8s, the EG is tripped and E.EG is turned on, as shown in Fig. 7. It is observed that the transient deviation in load power is approximately +2/10%, similar to Case 2. This is significantly lower compared to the conventional system, as shown in Fig. 3 and 4, where the transient deviation is -19%.

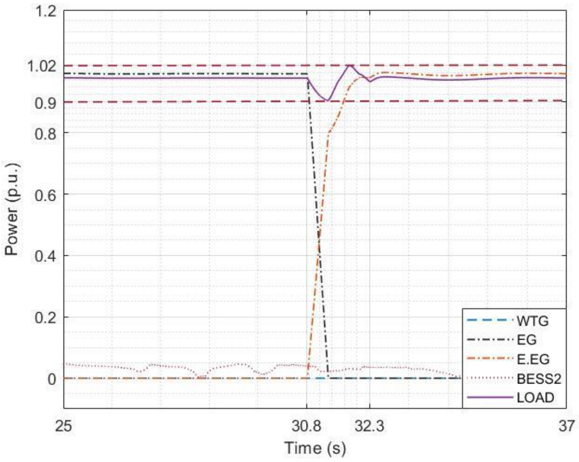

Fig. 7. Proposed System: Power flow in p.u. when EG is disconnected and E.EG is turned on (P_{base} =11 *MW*).

VI. CONCLUSION AND FUTURE WORK

In this paper, an integrated system consisting of an offshore floating wind farm and O&G production platforms with a BESS is proposed. With a BESS, reduced GHG emissions is achieved on the proposed system while maintaining the overall output power quality. Transient stability studies are conducted on the conventional and proposed configurations. It has been shown that the proposed system is feasible for the integration of WTG with O&G platforms and on-board BESS. As compared to the conventional system, the proposed system reduces the transient deviation in load power from -19% to +2/10% during a switch from the EG to the E.EG. When the energy generation is switched from the EG back to the WTG, the transient deviation in load power is reduced by 4%. As such, the proposed system meets IEC and NORSOK standards for O&G platforms. In addition, the load power is also maintained close to 1 p.u. after the transient period.

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