Solar Power for Sustainable Offshore Petroleum Exploration and Production in Africa*

Samuel Tawiah[1], Solomon Adjei Marfo[2], and Daniel Benah Jnr[2]

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[1]Department of Petroleum Engineering, University of Mines and Technology, Tarkwa, Western Region, Ghana (stawiah@umat.edu.gh)
[2]Department of Petroleum Engineering, University of Mines and Technology, Tarkwa, Western Region, Ghana

Abstract

A substantial percentage of Africa's upstream petroleum activity occurs offshore in high risk environments with attendant environmental concerns. Power demands on offshore rigs are met principally through the use of diesel engines and gas turbines. This adds to the already high safety hazards and environmental threat through greenhouse gas emissions, heat, and noise generation. Additionally, petroleum generated power is an expensive venture that can have significant impact on oil and gas project economics. Moreover, some of these offshore locations are so remote that accessibility to petroleum fuel may be challenging. As petroleum exploration and production pushes steadily into deeper, farther waters especially in sub-Saharan Africa, safety, environmental, and logistical security may be key for sustainability. Situated almost entirely within the tropics, Africa is a very suitable place for solar energy applications. This study assesses the potential of solar power for offshore oil and gas operations in Africa to mitigate the issues associated with the use of fossil fuel thereby ensuring sustainability of the upstream petroleum industry in Africa. The size of the solar power system that may meet the power requirement of a sample floating storage and production vessel (FPSO) in offshore Angola was estimated. Appropriate areas and extent of potential solar power application on this sample rig were also assessed. This was followed by some cost analysis to compare the two sources of power economically. It was found that solar power can currently provide only a small part of the power needed on offshore rigs primarily due to lack of space and weight restrictions.

Introduction

Most offshore rigs are mainly powered by internal-combustion diesel engines and gas turbines. Thus the energy supply for offshore oil and gas operations is based mostly on hydrocarbon energy sources, which lead to high levels of ecological footprints. For example, in Africa, oil and natural gas production emitted 89 million metric tonnes of CO_2 equivalent of greenhouse gases (GHGs) in 2012. The global offshore GHG emission from oil and gas production stood at 146 million metric tonnes of CO_2 equivalent (OGP, 2013). The sources of greenhouse gases in offshore petroleum production are varied but power generation forms a substantial part. Offshore operations, by nature, are prone to GHG emissions due to limited access to energy sources and infrastructure for produced associated natural gas. Greenhouse gases in the atmosphere contribute immensely to global warming by trapping heat. This calls for the need to shift power generation on offshore rigs to more environmentally friendly and renewable energy sources to remedy the situation for an industry whose product is largely blamed for global warming.

Solar energy is one of the most developed and widely available forms of renewable energy. The amount of electricity produced by a solar panel does not only depend on solar cell efficiency and solar panel size but also on factors such as the sun's intensity and amount of sunlight directly hitting the panel. Output power gained via the sun's radiation at any point on the earth depends on the day of the year, the time of day, and the latitude of the point (Hankins, 2010). Africa, being almost entirely in the tropics, receives very high intensity and prolonged duration of sunshine. It therefore follows that solar energy is very appropriate for the tropics.

Offshore production accounts for a large percentage of oil and gas production in Africa. An estimated minimum of 100 billion barrels of oil lies offshore Africa yet to be discovered (KPMG, 2013). West African offshore production grew from 58.9% in 2001 to 78.3% in 2011 and the trend is expected to continue. East Africa is sharing in the glory as exploration and production (E&P) in Africa advances into deeper waters (Energy and Corporate Africa, 2013). From these, it can be seen that offshore E&P in Africa will go well into the future and any attempts to combat GHG emissions in the petroleum industry, especially in Africa, must include offshore.

Solar energy utilization for offshore rigs will not only reduce its carbon footprints but may also decrease the drilling cost and aid in job generation thereby contributing to the economy (Halabi, Al-Quattan, and Al-Otaibi, 2015). In an already risky environment, using solar power can reduce heat production from power engines which may reduce the risk of fire on offshore rigs. Furthermore, the use of solar energy may reduce noise pollution around offshore oil rigs and also help meet energy demands in locations where conventional fuels, such as oil and natural gas are limited.

This work studied the possible use of solar energy for power generation on offshore rigs in the tropics.

Energy Requirements on Offshore Rigs

Offshore rigs need 1000 – 3000 horsepower (hp) as total power requirements. The energy needed is usually supplied by diesel engines. These engines typically use 20 – 30 m^3 of diesel per day, depending on the operations performed (IPIECA, 2013). Figure 1 shows an image of an offshore rig.

The energy generated on a rig is mostly consumed by the hoisting and fluid circulating system in their operation, other rig systems like the rotary system, well control, and monitoring system have much smaller power requirements (Broni-Bediako, 2011).

Energy use on offshore rigs covers a range of activities such as:

- Driving pumps to extract hydrocarbons and to reinjection water;
- Heating the output stream to allow separation of the oil, gas and water;
- Gas reinjection for enhanced oil recovery;
- Powering compressors and pumps for transporting oil and gas through gathering pipelines to processing plants; and

- Driving turbines to generate the electricity and heat needed for on-site operations and living quarters.

Energy and Cost Analysis

An FPSO located offshore Angola was chosen as a sample rig. The energy requirements of this FPSO as provided by Macdonald (2014) were adapted for use in this work. The energy requirements are grouped according to purpose into that for the living quarters and that for production (machinery). The production platform by far requires the most energy, with electrical needs for lighting and safety systems adding to the machinery loads of the production area. There are additional loads for the separation facilities and equipment required for offloading on deep-sea rigs.

The living quarters on this FPSO allows for 70 person groups to carry out daily 12 hour shifts so the housing requirement is for 140 people. All processes on the working platform are assumed to be functioning constantly but the living quarters is characterised by energy spikes which coincide with regular events such as hot water demand for showers after shift. The hourly power requirement for production machinery is given as 17.1 MWh amounting to 150.6 GWh per year while that for the living quarters is 400 kWh which translates to 3.5 GWh per year. The details of the demand for the living quarters are presented in Table 1.

Figure 2 depicts a 50-man living quarter installation available for sale to offshore rigs.

Solar Panels Required to Replace Fossil Fuels

To be able to estimate the possibility of replacing fossil fuels with solar power, the number of panels required was calculated. Due to the low outputs of solar PV cells, the calculation was made for only the living quarters.

The formula employed is given in equation 1 as:

$$No.of\ PV\ Modules = \frac{kWh\ (per\ day)}{hours\ of\ peak\ sunlight\ (per\ day)*PV\ cell\ rating/1000(kW)} \qquad (1)$$

From Hankins (2010), the peak sunshine hours in the tropics ranges from 3 - 8 hours. This gives an average of 5.5 hours. A 315 W solar PV cell, one of the highest commercial PV power ratings available is used in the calculation. Thus for the living quarters with energy usage of 9600 kWh/day, the number of PV cells needed would be:

$$No.\ PV\ Modules = \frac{9600}{5.5*315/1000} = 5541.13\ Modules$$

Thus at least 5542 solar panels will be required to produce the power needed for the living quarters assuming no losses.

The dimensions of solar panels vary but most are in the range of 1.6 m by 0.9 m giving an area of 1.44 m^2. Thus for 5542 modules;

Space required = 5542 * 1.44 m^2 = 7980 m^2

Therefore 7980 m^2 will be required for the PV modules alone without spacing between them.

Cost Calculations

It is difficult to estimate the cost of solar installation on a large scale as it depends on a lot of factors. Considering the number of cells required, the area and the time dependence of solar power, the total energy requirement of the living quarters on the FPSO cannot be met by solar power. For comparison sake, the laundry unit, requiring 12 kW of power in an hour was chosen. This is because this power range is easily obtainable from solar power and quotes can readily be obtained for it. Also, it can be assumed that the laundry can be reserved for day time without much harm to operations.

Cost of Diesel Power

A Cummins Model 13.5MDKDN marine diesel generator with a power rating of 13.5 kW was assumed to be used to deliver power for the 12 kW laundry system at full load capacity. This generator consumes 4.5 litres of diesel per hour at full load according to the manufacturers' specification (Cummins Onan, 2015). Assuming this rig works in Ghana which is in the tropics:

Price of diesel in Ghana = US$0.89 / litre as at May 16, 2016 (Anon, 2016).
Cost of diesel per day = 0.89 * 4.5 = US$96.12
Cost of diesel per year = 96.12 * 365 = US$35 083.8

Cost of Solar Power

A 12 kW system translates into 8640 kWh of power requirement per month. Getting a quote from a professional solar installer in Ghana within the time frame of the study proved futile. Solar-Estimate, a leading solar power systems calculator quoted an average installation cost of US$286,130 for an 81.18 kW peak solar power system which could deliver 8759 kWh per month when installed in an area that gets 5.04 kWh/m^2 peak sun hours in the US (Solar Estimate, 2016). The US was used because solar energy services are more developed there with detailed online resources. Besides, it is a developed country with a massive petroleum industry and has a lot of places with tropical climate. The rigs used in Africa are built in developed countries with similar economic characteristics like the US. Any retrofitting with solar power is likely to be ordered from these countries, thus using US for a sample solar power cost estimation is reasonable.

Comparison of Diesel Power with Solar Power Costs

An installed solar panel lasts for 20 to 25 years with no routine operation costs. However, some cost may be incurred in replacement of damaged or deteriorated PV modules and batteries among other occasional repairs. Assuming this additional cost to be 50% of the installation cost, the total cost of using solar power for the 12 kW laundry system was estimated to be US$429,195.

The cost of diesel for laundry in the living quarters was estimated to be US$35,083.8 per year which will amount US$701,676 in 20 years. This estimation ignores the cost of the generator set, installation, and repairs which are assumed to be small. Comparing the costs for the two power systems, it can be deduced that using solar power instead of diesel will result in savings of US$272,481 (39%) over a 20 year period with a break-even point of 12.23 years. By extension, assuming the same conditions, there could be 39% power cost savings if the entire offshore rig could be solar powered.

Discussion

Ability of Solar Energy Use on Offshore Rigs

The working conditions of solar cells make it possible for them to work on offshore rigs. It may even be safer because no flammable fluids are involved. Solar panels are tested at 25°C but can work within a wide temperature range below and above this value. Temperatures higher than the standard testing temperature of 25°C will only reduce the output of the modules in the range of 0.4% to 0.6% per °C.

One challenge may be a relative quicker deterioration of the solar cells and reduced efficiency due to high water droplets that may usually collect on the surface due to waves and misty air (high humidity). This can be minimised if the panels are installed at higher height. Most PV modules can be added simply and efficiently to the facade of a structure and even integrated as part of the cladding materials of a structure as solar technology has advanced. This allows older structures the ability to make use of new solar power technology without intrusive and vast retrofitting. This is extremely suited to a rig located in sunny waters, where PV solar panels could be rigged onto the living quarters directly to provide a steady and reliable renewable energy contribution towards the energy requirements of that area. To solve the space requirement and heavy retro fitting, solar panels could be floated on the water separate from the rig.

Extent of Fossil Fuel Replacement by Solar Power

It can be seen that, by no means can solar power completely provide the energy demands of an offshore rig. This shortfall results primarily from the lack of space to accommodate the large number of panels required. Another factor is the time and weather dependent nature of solar power which may lead to energy supply deficiencies during long low sunshine periods. However, partial replacements are possible and the extent of replacement will depend on many factors such as the space available for solar panels and the amount of power required by the rig. For example, solar power use may be significant for a simple drilling rig without power requirement for production purposes. As solar cell efficiencies improve in the future greater extent of replacement may be achieved.

Cost of Solar Power versus Fossil Fuels

The cost calculations were also simplified by assuming constant power use. This is however not the case in practise and the diesel generator would not be working when power is not required. This means that the cost of diesel power generation can be far less than the estimated. This can be offset by fact that the 20 year solar panels life is quite conservative. Solar panels can perform well for 25 years and can last even up to

40 years. Again, the maintenance cost at 50% of initial cost assumed for solar power is quite on the high side. Furthermore, the cost of using diesel power only included the cost of fuel and the purchase price of the generator and maintenance were deemed insignificant. While this may be fine for small power systems, it can be significant in larger systems. Moreover, the cost calculations also paid no regards to carbon costs and solar power incentives. Finally, power requirement for laundry can be quite intermittent and require the generator be shut down for a good percentage of the time but other systems require power for all or most of the time. In such instances, cost savings due to non-usage may absent or negligible, making an assumption nonstop power not far from accuracy.

As attested by the results, the use of solar energy may result in a reduction in the cost of power generation. The capital cost of using solar power can be large but in the long term it usually becomes cheaper than fossil fuel. Solar power price trend has been on continual decline and will likely continue to reduce. If this happens, it will be more profitable to use solar power on offshore rigs. Again as efficiencies increase, fewer panels would be required which can also reduce the price.

Environmental Pollution

The use of solar power comes with numerous environmental advantages compared with fossil fuel. There may be reduced noise, heat, and most importantly greenhouse gas emission from offshore rigs if solar power is integrated with fossil fuel power. For example, the laundry represents 3% of energy requirement in the living quarters in the sample FPSO used. If the laundry's power is supplied from solar, it may lead to 3% decline in emissions from power generation for the living quarters. This percentage, though small especially when compared to the emission from the whole rig, it may be significant in terms of greenhouse gas volumes and effects.

Conclusions

From the research, it is concluded that:

- Solar energy can be used on offshore rigs.
- Solar energy may only be able to partially replace fossil fuels on offshore rigs. This is primarily due to limited space on rigs and weight restrictions.
- The extent of replacement of fossil fuel with solar power on rigs will be determined chiefly by the size and nature of energy required, space availability among others. The utilization of solar energy on offshore rigs may increase as solar panels become more efficient.
- Solar power use on rigs may initially be capital intensive but can be cheaper as compared to diesel in the long term.

References Cited

Anon, 2016, Ghana Diesel Prices, Litre: http://www.globalpetrolprices.com/Ghana/diesel_prices/. Website accessed February 2017.

Broni-Bediako, E., and R. Amorin, 2010, Effects of Drilling Fluid Exposure to Oil and Gas Workers Presented with Major Areas of Exposure and Exposure Indicators: Research Journal of Applied Sciences, Engineering and Technology, v. 2/8, p. 710-719.

Broni-Bediako, E., and I Addei, 2010, Managing the Huge Expectations of Ghana's Oil and Gas Discovery: International Journal of Economic Development Research and Investment, v. 1/1-2, 7 p.

Cummins Onan, 2015, Power Rating for Marine Diesel Generator: https://power.cummins.com/generator-list. Website accessed February 2017.

Energy and Corporate Africa, 2013, Africa Offshore Basins Expanding from West Africa to East Africa: http://www.energycorporateafrica.com/africa-offshore-basins-expanding-from-we. Website accessed February 2017.

Halabi, M.A., A. Al-Quattan, and A. Al-Otaibi, 2015, Application of Solar Energy in the Oil Industry – Current Status and Future Prospect: Renewable and Sustainable Energy Reviews, v. 43, p. 296-314.

Hankins, M., 2010, Stand-Alone Solar Electric System: The Earthscan Expert Handbook on Planning, Design and Installation: Earthscan Publications, London, 232 p.

Hankins, M., 1995, Solar Electric Systems for Africa, Revised Edition, Commonwealth Science Council, London, United Kingdom, 135 p.

International Association of Oil and Gas Producers, 2013, Environmental Performance Indicators – 2012 Data OGP Data Series, Report No. 2012e, 50 p.

IPIECA, 2013, Offshore Drilling Rigs: http://www.ipieca.org/energyefficiency/solutions/60311. Website accessed February 2017.

KPMG, 2013, Oil and Gas in Africa: Africa's Reserves, Potential and Prospects: https://assets.kpmg.com/content/dam/kpmg/pdf/2014/11/unlocking-potential-africas-NOCs.pdf. Website accessed February 2017.

Macdonald, J., 2014, Providing Scope for Reducing the Carbon Footprint of an Offshore Oil Rig: MS Thesis, University of Strathclyde, Glasgow, United Kingdom, 74 p.

Mayeda, A., 2010, Feds Watered Down Regulations Governing East Coast Offshore Drilling: The Vancouver Sun, June 3, 2010, http://www.sqwalk.com/q/feds-watered-down-regulations-governing-east-coast-offshore-drilling. Website accesses February 2017.

Myre, J.C, 2001, Electrical Power Supply to Offshore Oil Installations by High Voltage Direct Current Transmission: PhD Thesis, Norwegian University of Science and Technology, Trondheim, Norway, 248 p.

OGP, 2011, Petroleum Industry Guidelines for Reporting Greenhouse Gas Emissions: Second Edition, OGP Report Number 446.

Solar-Estimate, 2016, Your Solar Electric Estimate: http://solar-estimate.org/. Website accessed February 2017.

Figure 1. Image of an Offshore Drilling Rig (Mayeda, 2010).

Figure 2. Offshore Rig Living Quarters Module (Macdonald, 2014).

Unit	**Percentage of Total Energy Use**	**Power Usage (kWh)**
Galley (Kitchen)	5	20
Laundry	3	12
Heating, Ventilation and Air Conditioning (HVAC)	50	200
Lighting	13	52
Elevators	5	20
Safety Systems	8	32
Chillers	6	24
Sewage System	4	16
Water System	5	20
Radio Communications	1	4
Total	**100**	**400 kWh**

Table 1. Average Hourly Energy Demands of Sample FPSO in Angola (Macdonald, 2014).