Review of Renewable Energy Technologies Utilized in the Oil and Gas Industry

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Received: 26.10.2016 Accepted:22.12.2016

Abstract- In this study, applications of renewable energy technologies in the oil and gas industry were analyzed. A number of photovoltaic systems were investigated as applications for providing electric power to production facilities (i.e. the oil fields of Midway-Sunset, Kern River and Louisiana Bayou in the United States). Wind power systems were studied in the oil fields of Suizhong 36-1 (China), Beatrice (UK) and Utsira Nord (Norway). The geothermal power systems studied included the oil fields of Rocky Mountain (USA) and Fort Liard (Canada). Moreover, solar thermal systems in the oil fields of Mckittrick (USA), Caolinga (USA) and Amal (Oman) were examined as applications for providing thermal energy to production facilities. From the results, this study revealed that a variety of renewable energy technologies are currently used in the oil and gas industry. In particular, solar thermal systems are being actively studied for provision of the thermal energy required to enhance oil recovery.

Keywords Oil and gas industry, Photovoltaic system, Solar thermal system, Wind power system, Geothermal power system.

1. Introduction

Even during the current period of low oil prices, worldwide interest in renewable energy technology has failed to diminish. This is due to problems regarding greenhouse gas emissions and conventional energy production technologies threatening environmental safety, which are tied to the Paris Agreement. Currently, eco-friendly renewable energy technologies that are sustainable, such as solar thermal energy, photovoltaics, geothermal energy, tidal power, wave power, wind power, hydropower, and biomass energy are being widely used in every industry. Renewable energy, along with fossil fuel energy and nuclear energy, has come to provide significant amounts of energy that help sustain the energy supply to our society [1].

From a conservative point of view, renewable energy is a competitor to fossil fuels. However, recently renewable energy is being used to extract and produce fossil fuel resources, which makes it more difficult to view them as clear competitors. The mining industry, which extracts fossil fuel resources like bituminous coal, is applying renewable energy technologies to supply electricity to mines operating in remote areas and to cultivate alternative industries using the land abandoned by exhausted mines. Choi [2] meticulously studied cases in which renewable energy technologies were applied in the mining industry. Furthermore, many studies have been done within the country to evaluate the potential of renewable energy resources obtainable around exhausted mines [3-9]. Furthermore, studies were done on applying photovoltaic (PV) systems to supply electricity to run treatment plants for mine drainage [10].

In the oil and gas industry, renewable energy technology is being used to resolve problems of supplying electricity for offshore production and to supply the thermal energy required for the enhanced oil recovery (EOR) technique [11]. PV systems have been applied at several oil and gas fields such as the Midway-Sunset, Kern River and Louisiana Bayou in USA. A few applications of wind power systems were also identified at the oil fields of Suizhong 36-1 in China, Beatrice in UK and Utsira Nord in Norway. In addition, several applications of geothermal power systems have been found at the oil fields of Rocky Mountain in USA and Fort Liard in Canada. Solar thermal systems were installed at the oil fields of Mckittrick in USA, Caolinga in USA and Amal in Oman.

Recently, Halabi et al. [11] reported study results on solar energy (PV and solar thermal) technologies being used in the oil and gas industry. A study by Halabi et al. [11], however, had limitations because it only considered solar energy technology, among the many renewable energy technologies that are being used in the oil and gas industry. Therefore, it is also necessary to analyze cases in which other renewable energy technologies, such as wind power and geothermal power, are being applied.

The purpose of this study was to research and analyze cases in which renewable energy technologies are being applied at oil and gas production sites. Cases were analyzed according to their purpose: PV, wind power, and geothermal power technology applications had the purpose of supplying electricity; whereas the application of solar thermal technology had the purpose of supplying heat.

2. Photovoltaic Systems

2.1. The Midway-Sunset Oil Field in the United States

Chevron Texaco built a 500 kW PV system and is now operating the system at the Midway-Sunset oil field in California (USA) (Table 1). The Midway Sunset oil field is the largest oil production area, and was discovered in 1894. The electricity produced from the PV system at the Midway-Sunset oil field is used to power the oil production plant. It supplies about 5% of the total electricity demand. At this location, 4800 modules were used in the PV system [12] (Fig. 1).

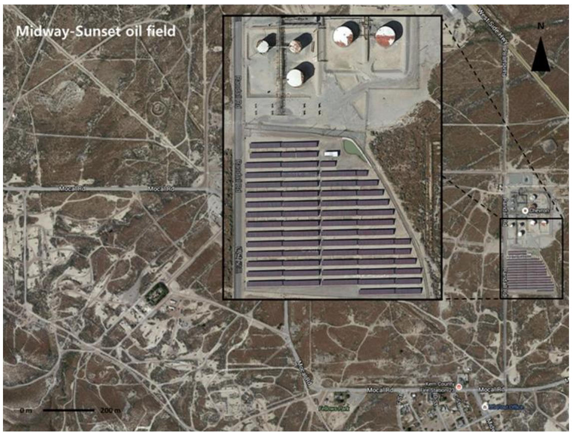

Figure. 1. Arial view of the 500 kW photovoltaic system installed in the Midway-Sunset oil field, USA (image source: Goggle map, http://maps.google.com).

2.2. The Kern River Oil Field in the United States

Chevron Texaco operates the Kern River oil field in California (USA). From its discovery in 1899 through 2006, the oil field has had cumulative production of close to two billion barrels [13]. Currently, a 750 kW PV system is operating at the Kern River oil field (Table 1). Approximately 7700 flat PV modules including six different makes of thin-film PV, plus one type of traditional crystalline silicon PV, and several different makes of racking systems and inverters make up the PV system. The electricity produced by this system powers 40 oil extracting pump jacks. Chevron Texaco is considering building an additional PV system for powering more oil extracting pump jacks [14].

Table 1. Summary of photovoltaic systems applied to oil fields.

Site	Midway-Sunset Oil Field	Kern River Oil Field	Louisiana Bayou Oil Field
Country	USA	USA	USA
Peak capacity	500 kW	750 kW	17.85 kW
Operator	Chevron Texaco	Chevron Texaco	Kyocera Solar

2.3. The Louisiana Bayou Oil Field in the United States

Kyocera Solar is operating 7.7, 3.9 and 6.25 kW PV systems at the Louisiana Bayou oil field in Louisiana (USA) (Table 1). The PV systems include PV modules, mounting structures, controller (with integrated solar charge regulation), storage batteries, system enclosure, installation /wiring kit and instruction manual [15]. The electricity produced from the PV system is used to prevent the oil pipeline from corroding using the cathodic protection technique (Fig. 2). The results from recent studies indicated that corrosion of transport pipes significantly affect the production and transportation of oil and gas. As a solution to these corrosion problems, Popoola et al. [16] proposed a cathodic protection method that incorporates a PV system.

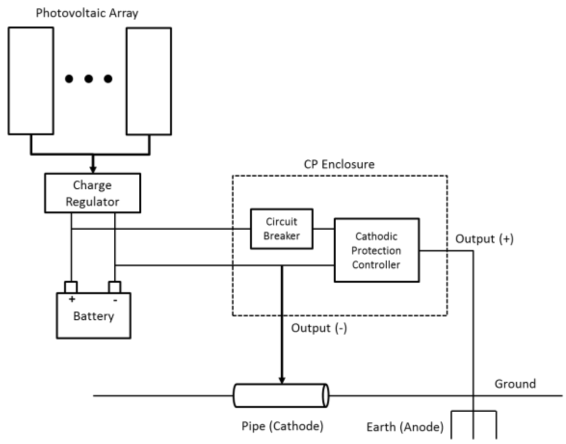

Figure. 2. Schematic diagram of the cathodic protection system for pipelines with photovoltaic systems (modified from Popoola et al. [16]).

3. Wind Power Systems

3.1. The Suizhong 36-1 Oil Field in China

China National Offshore Oil Corporation (CNOOC), the biggest oil company in China, is operating the Suizhong 36-1 oil field, which is located in Liaodong Bay in the Bohai Sea (Table 2). The Suizhong 36-1 oil field was discovered in 1987 and started producing oil in 1993. This is the largest oil field in the Bohai Sea and has over one billion tons of oil reserves. The Suizhong 36-1 oil field has many offshore steel jacket-type platforms. These platforms are approximately 20 years old and need either to be demolished or reused for a different purpose. In 2007, for the first time, CNOOC reused an abandoned 36-1 SPM jacket as a foundation on which to build a 1.5 MW wind turbine [17]. The electricity produced by this wind turbine supplies the production plant at the Suizhong 36-1 oil field. It has reduced the emission of greenhouse gases by 5300 tons annually [18].

Table 2. Summary of wind power systems applied to oil fields.

Site	Suizhong 36-1 Oil Field	Beatrice Oil Field	Utsira Nord Oil Field
Country	China	Scotland	Norway
Peak capacity	1.5MW	5MW	6MW
Operator	CNOOC	Scottish and Southern Energy, Talisman Energy	DNV GL of Norway

3.2. The Beatrice Oil Field in the United Kingdom

An English energy company, Scottish and Southern Energy, and a Canadian multinational oil exploration company, Talisman Energy, made a joint investment to build a wind power system at the Beatrice oil field located in the North Sea (Table 2). The Beatrice oil field is located 24 km off the northeast coast of Scotland and started commercial production in 1981. The Beatrice oil field comprises of three offshore platforms. Beatrice Alpha is an oil production plant located in the center of the oil field [19]. Two 5 MW wind turbines were built near the Beatrice Alpha platform (Fig. 3). The electricity produced from these wind turbines supply about 30% of the total electricity demand of the Beatrice Alpha platform [20]. The capital cost (CAPEX) and levelized cost of energy (LCOE) for three different floating foundation types are presented in Table 3.

3.3. The Utsira Nord Oil Field in Norway

DNV GL of Norway is working on the Wind Powered Water Injection (Win-Win) project that builds a wind power system at an offshore oil and gas production plant at the Utsira Nord oil field (Table 2) [21]. The main purpose of the Win-Win project is to build a floating-type wind turbine that produces electricity and supplies this electricity to an offshore platform. Furthermore, Nilsson [22] investigated creating an offshore wind farm with capacity of 288 MW, consisting of 48 wind turbines with capacity of 6 MW at the Utsira Nord oil field. In this study, it was reported that building a wind farm to produce 288 MW would generate 1222 GWh of electricity per year. This is enough to supply 48% of total electricity demand in the neighbouring Utsira High region.

Figure. 3. Photo of the 5 MW wind turbines installed near the Beatrice Alpha offshore plant in the Beatrice oil field, UK (image source: http://www.geograph.org.uk/photo/1988601).

Table 3. CAPEX and LCOE for three different floating foundation types [22].

	CAPEX (MNOK)		LOCE (NOK/kWh)	
Type	Low	High	Low	High
Spar	7031	10213	1.03	1.26
Semi-Submersible	8539	12868	1.19	1.53
TLP	6757	8885	1.00	1.13

4. Geothermal Power Systems

4.1. The Rocky Mountain Oil Field Testing Center in the United States

In the United States, approximately 25 billion barrels of thermal water are discharged every year through oil boreholes [23]. A feasibility study on using discharged thermal water for geothermal power generation was done in 2008 [24]. Furthermore, Blodgett [25] reported to the Department of Energy (DOE), regarding the study results on the feasibility of building a 1 MW geothermal power system using thermal water from boreholes in oil industrial zones in the United States (Fig. 4).

Based on this, a 217 kW geothermal power system that uses thermal water from oil boreholes was built at the Rocky Mountain Oil Field Testing Center located in Wyoming (USA). In an area of 38 km^2, 150 boreholes ranging from 76 m to 1500 m in depth were used, and the thermal water temperature was approximately 65 °C. It was reported that the geothermal power facility generated 1918 MWh of electricity from 109 million barrels of thermal water [26].

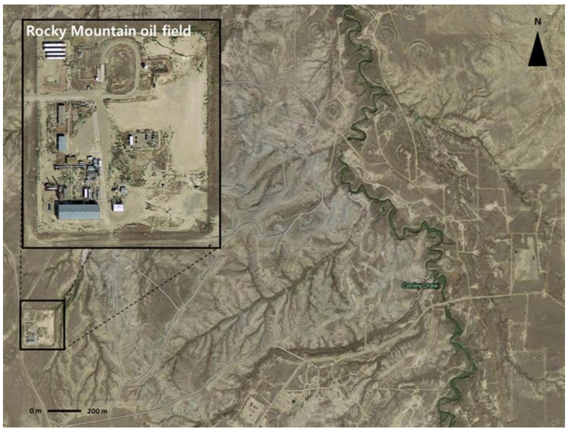

Figure. 4. Aerial view of the geothermal power plant at the test center of Rocky Mountain oil field, USA (image source: Google map, http://maps.google.com).

4.2. The Fort Liard Oil and Gas Field in Canada

The Fort Liard oil and gas field located in the northwest region of Canada, produced 1.4 billion barrels of natural gas and 700 million barrels of oil in 2008 [27]. The cumulative production of natural gas until 2013 was approximately 1.6 billion barrels [28]. Currently, the Fort Liard oil and gas field has stopped producing oil and gas. Instead, a geothermal power generation project is in progress, using thermal water from boreholes deeper than 5000 m. Thompson and Dunn [29] designed a 700–1000 kW geothermal power system and it is predicted to produce 2900 MWh of electricity annually (Fig. 5).

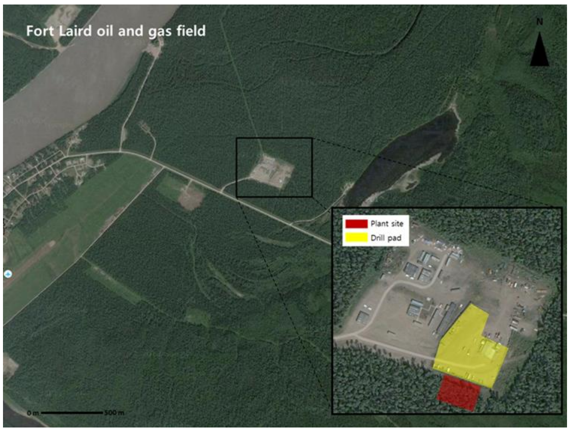

Figure. 5. Aerial view of the Fort Laird oil and gas field, Canada with an approximate footprint of geothermal plant (image source: maps.google map).

5. Solar Thermal Systems

5.1. The Mckittrick Oil Field in the United States

The Mckittrick oil field operated by Berry is located in western California (USA) (Table 4), and produces approximately 1300 barrels of crude oil per day [30]. Berry launched the solar thermal EOR project with Glass Point Solar to apply the EOR technique to the Mckittrick oil field. The main purpose of this project was to install solar thermal collectors approximately 13,388 m^2, at the Mckittrick oil field, to collect sunlight. The sunlight was used to boil water and produce high-pressure steam. The high-pressure steam was used to apply the EOR technique. This project implemented the enclosed trough technique of Glass Point Solar for the first time. The enclosed trough technique allowed installation of solar thermal collectors in oil fields with a lot of sand and dust. An extremely lightweight mirror was installed in the structure and an automatic directing device was mounted on the mirror to focus the sunlight to a designated spot (Fig. 6)

Figure. 6. Photo of the solar EOR facility installed in the Mckittrick oil field, USA (image source: https://en.wikipedia.org/wiki/GlassPoint_Solar#/media/File: GlassPoint_EOR_Kern_County_CA/jp).

Table 4. Summary of solar thermal systems applied to oil fields.

Site	McKittrick Oil Field	Coalinga Oil Field	Amal Oil Field
Country	USA	USA	Oman
Peak capacity	300 kW	29 MW	7 MW
Technology provider	Glass Point Solar	Bright Source	Glass Point Solar
Type of CSP technology	Enclosed trough	Solar tower	Enclosed trough

5.2. The Caolinga Oil Field in the United States

The Caolinga oil field operated by Chevron is located in western California, the United States (Fig. 7). It is the eighth largest oil field in California. In October of 2011, Chevron started the Coalinga Solar EOR project with Bright Source Energy (a company focusing on solar power plants) to install a 29 MW centralized solar thermal system at the Caolinga Oil Field (Table 4). In this project, 3822 2×3 m heliostats (mirrors) were used. The heliostat reflected and focused light on a solar tower (99.7 m high) to heat the water and produce steam. According to the reports, using solar thermal technology instead of natural gas reduced the cost to create steam for EOR by approximately 120 MMBtu/h [31].

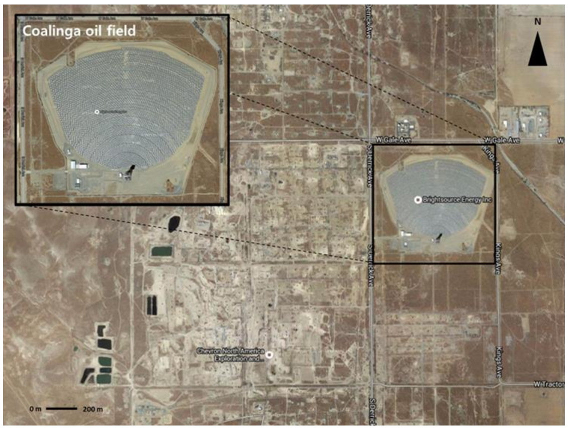

Figure. 7. Aerial view of the concentrating solar thermal system installed in the Coalinga oil field, USA (image source: Google map, http://maps.google.com).

5.3. The Amal Oil Field in Oman

The Amal oil field operated by Petroleum Development Oman (PDO) started producing oil and gas in 1967 (Table 4). In 2012, 920,000 barrels of oil and 2.8 BCF (billion cubic feet) of natural gas were being produced each day. PDO and Glass Point Solar launched the solar thermal EOR project at the Amal oil field and were the first in the Middle East to start such a project [32]. A 7 MW solar thermal EOR plant was built in the Amal oil field in 2012 and the enclosed trough technology of Glass Point Solar was implemented (Fig. 8). Presently, the solar thermal EOR plant produces around 50 tons of steam each day, which is used for implementing the EOR technique. This is approximately 1% of the steam that used to be produced using only natural gas [33]. Glass Point Solar [34] is planning a project to build a 1 GW solar power plant at the Amal oil field by 2017. This project is anticipated to replace 5.6 trillion BTUs of natural gas and supply electricity to approximately 209,000 people using residual latent heat [35,36].

Figure. 8. Photo of the solar EOR facility installed in the Amal oil field, Oman (image source: https://en.wikipedia.org/wiki/GlassPoint_Solar).

6. Discussion

The Midway-Sunset oil field was a case where a PV system was applied to supply electricity to an oil and gas production site. A 500 kW PV system was built to supply a portion of the electricity required at a production plant. Furthermore, at the Kern River oil field in the United States, a 750 kW PV system was built to supply the electricity required to operate pump jacks. At the Louisiana Bayou oil field, also in the United States, 3.9, 6.25 and 7.7 kW PV systems were being used to supply electricity to preventing corrosion of oil pipelines. An overall analysis indicated that PV technology was generally used on small-scale PV systems to supply a portion of the electricity required at oil and gas production or transportation facilities.

The Suizhong 36-1 oil field in China was one of the cases of applying wind power technology. A 1.5 MW wine turbine was built upon elements of an abandoned oil drilling structure. The Beatrice oil field in England had two 5 MW turbines offshore, that provided electricity to an oil production plant nearby (about 30% of total electricity consumption). Last, the Utsira Nord oil field in Norway had a floating wind turbine, which provided electricity to an offshore oil production plant. Overall analysis of these cases showed that marine structures built to produce oil were being efficiently reused as structural elements for marine wind turbines. Furthermore, the wind turbines were supplying a portion of the electricity consumption at the oil production plants.

Cases of the application of geothermal technology were found at the Rocky Mountain Oil Field Testing Center in the United States and at the Fort Liard oil field in Canada. In both cases, the aim was to use the thermal water discharged from oil boreholes to generate geothermal power. At the Rock Mountain oil field, a 217 kW geothermal system was designed and a feasibility test performed. The Fort Liard oil field is also testing for feasibility to build a 700–1000 kW geothermal system. Overall analysis on the cases showed that the geothermal technology was mainly being applied to reuse thermal water discharged from exhausted oil and gas fields.

Cases of applying solar thermal technology to provide thermal energy were found in the Mckittrick oil field in the United States with a 300 MW solar thermal system, the Caolinga oil field in the United States with a 29 MW solar thermal system and the Amal oil field in Oman with a 7 MW solar thermal system. Overall, the solar thermal technology was being used to supply the thermal energy required for applying the EOR technique to oil and gas production sites.

7. Conclusion

In this paper, cases were investigated of international oil and gas production sites at which renewable energy technologies (PV, wind power, geothermal energy, and solar thermal energy) were being applied. Applying renewable energy technologies to the oil and gas industry brings reduction in energy cost and reduction in greenhouse gas emissions. The prolonged low oil price era has somewhat decreased the public interest in reducing energy cost. Yet, the cost of oil could rebound. Furthermore, reducing greenhouse gas emissions remains a major problem for the oil and gas industry. Therefore, the oil and gas industry needs to consider the efficient application of renewable energy technologies to sites producing conventional energy resources.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2015R1D1A1A01061290). The authors thank anonymous reviewers for their critical comments and suggestions, which improved the quality of our manuscript.

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