Powering the Petroleum Frontier: The Hidden Costs of Electrifying Remote Oil and Gas Operations

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Electricity costs of upstream oil and gas facilities including oil and gas well stations, pipelines, and cathodic protection stations, due to their distance from urban areas and power plants, are a significant concern. These facilities have varying electricity consumption and usage durations, often leaving equipment unused after its service life. The objective of this research is to examine and compare the technical, economic, and environmental aspects of electrifying upstream oil and gas facilities using a solar system versus overhead power transmission lines. This study calculates the average cost of electricity generation through air transport lines of different lengths (5, 10, and 20 km) for oil and gas wells stations, resulting in costs of 0.622, 1.228, and 2.438 USD per kilowatt, respectively. The cost of electricity generation using 30 kW diesel generators is 0.72 USD per kilowatt, which includes carbon tax. On the other hand, producing the oil wellhead with 14.6 kwh/d of electricity using solar panels with support for three cloudy days amounts to 2.545 USD per kilowatt and for gas wellhead with 38.04 kwh/d with support for three cloudy days amounts to 2.49 USD per kilowatt. Although solar panels may not be the most cost-effective option, they offer a reasonable alternative considering the absence of environmental pollution.

**Keywords**: Electricity Costs; Oil and Gas Facilities; Solar Energy; Environmental Impact; Power Transmission

* 1. Introduction

Upstream oil and gas facilities, encompassing oil and gas wells, cathodic protection stations, and line break valve (LBV) stations, are typically situated in remote and hard-to-access regions, far from urban centers and centralized power infrastructure. As a result, the cost of providing electricity to these facilities is significantly higher compared to other operations. Despite their relatively low electricity consumption, particularly when contrasted with energy-intensive downstream processes like separation and desalination, the operational demands and critical nature of these facilities necessitate a reliable and stable power supply. This requirement is often addressed through the use of overhead transmission lines to ensure continuity and reliability. However, the lack of nearby dependable power supply sources poses additional challenges, further complicating the energy supply to these facilities.

Once the power supply center and transmission route are identified, the mapping process begins, during which critical landmarks and necessary information are documented. Challenging terrains, including valleys and mountainous regions, often necessitate the use of aerial surveys via airplanes or helicopters, significantly increasing the cost and time required for mapping. The design of the transmission line, including the optimal route, wire type, and other specifications, must align with the characteristics of the selected power supply center and local environmental conditions. In certain scenarios, additional infrastructure, such as bridges over rivers and valleys or pathways through rocky areas and forests, may be required.

A crucial consideration in supplying electricity through overhead transmission lines is ensuring accessibility for maintenance. Where access roads are absent, constructing passable routes through deserts or mountainous areas can be prohibitively expensive. Furthermore, the finite lifespan of upstream oil and gas reservoirs adds another layer of complexity. Once production ceases and facilities are relocated, the electricity transmission infrastructure is often abandoned, leaving significant quantities of copper and galvanized iron in remote areas. This not only results in financial losses but also poses serious environmental concerns, contributing to pollution in ecologically sensitive regions.

Despite the high costs and challenges of electricity supply to upstream facilities via transmission lines, the relatively low power demand of these units offers an opportunity to adopt more sustainable and cost-effective solutions. Implementing modern, eco-friendly power generation systems, such as solar energy, can mitigate many of these issues. Solar systems, in particular, provide flexibility by enabling redeployment to new fields after the decommissioning of a well, thereby minimizing capital waste and reducing environmental pollution. Such alternative energy strategies represent a promising avenue for enhancing the sustainability and efficiency of upstream energy operations.

A solar energy system incorporating a storage unit, low-temperature solar collector field, organic Rankine cycle, and absorption refrigeration system has been proposed to generate electricity and refrigeration with competitive energy costs and reduced CO₂ emissions (Martínez-Rodríguez et al., 2022). Technical and economic assessments have highlighted the feasibility of utilizing renewable energy, including solar and wind power, on offshore oil and gas platforms (Soleimani et al., 2021). Further studies on photovoltaic power plants and solar energy applications in southern Iran have demonstrated significant potential for integrating renewable energy in upstream oil and gas operations (Azizkhani et al., 2017; Bahrami et al., 2013; Heidari et al., 2017).

Although economic limitations and industrial constraints may pose challenges to solar energy adoption in certain regions, decision-makers must weigh the costs, operational timelines, and long-term benefits of solar systems. For example, while the installation of an overhead power transmission line typically requires approximately one year—encompassing design, mapping, land acquisition, administrative approvals, and permitting—a solar system can be deployed in just one week to ten days, roughly 3% of the time required for a transmission line. Beyond its logistical efficiency, solar energy offers significant environmental benefits, including reduced pollution and greenhouse gas emissions, contributing to the mitigation of global warming. Despite inherent challenges, there is substantial potential to develop cost-effective solar energy strategies tailored to the specific energy demands and geographical contexts of upstream facilities (Zamani et al., 2024).

The primary objective of this study is to assess the feasibility and practicality of adopting solar power as an alternative electricity source for upstream oil and gas facilities located in southern Iran. Given the current dependence on traditional air transmission lines for power supply, the study compares the costs and implications of three distinct electricity supply options: diesel generators, air transmission lines, and solar panel systems. The analysis prioritizes a comprehensive evaluation of economic factors, while also addressing the environmental impacts and time-related considerations inherent to each approach. This multifaceted assessment aims to provide a robust framework for decision-making in transitioning toward more sustainable and efficient energy solutions for the oil and gas sector.

**2. Technical and economic evaluations**

To calculate the present cost of investment and operation of electricity production over the project's life-time, the equalized cost of electricity is used as an economic indicator (Zamani et al., 2024).

2.1. Power generation using diesel generators

Diesel generators are inappropriate for continuous operation in remote and inaccessible locations. Apart from all the issues of consumption of fossil fuels and greenhouse gases, the cost of repair and maintenance of diesel generators is high. Furthermore, due to the limited capacity of their fuel tanks, they require continued refuelling. On the other hand, the price of fuel and environmental pollution taxes are continually rising. Since the present study was conducted to compare different conventional electricity supply scenarios, the employing of generators in 30 kilowatt (37.5 KVA) was investigated.

2.2. Power generation through air transmission lines

The electricity demand of oil and gas well stations, being located in remote areas away from industrial hubs, necessitates the purchase of power from the nearest source, leading to significant concerns for such projects. Key considerations include proximity to a power supply centre, ensuring sufficient capacity to meet electricity needs, and the possibility of establishing new power splits. Overcoming these challenges allows for the procurement of taxed electricity. Subsequently, land acquisition becomes essential for constructing transmission lines, with a requirement of a 10-meter area for a 20-kilovolt airway, necessitating the purchase of land that ideally belongs to the Natural Resources and Environment Organization. The process involves detailed mapping of the Earth to calculate mechanical forces, determine line entrances, and place support bases. Costs associated with mapping vary depending on factors such as terrain type (plains, hills, mountains), vegetation, proximity to facilities, and distance from city centres. In complex terrains involving valleys, rivers, or high mountains, aerial surveying using planes or helicopters may be necessary, potentially impacting project costs. (Kabeyi et al., 2022; Pavicic et al., 2021)

2.3. Power generation by a solar system

Solar systems present several significant technical advantages for the oil and gas industry, including rapid design and installation, system reusability, and flexibility in the application of solar equipment across varying capacities. These attributes enable oil and gas companies to quickly adapt to changing energy demands while minimizing environmental impacts. The swift deployment of solar technology allows for efficient integration into existing operations, enhancing overall energy management. Additionally, the ability to repurpose solar systems contributes to sustainability efforts, as these installations can be tailored to meet diverse operational requirements effectively.

3. Results and Discussion

3.1 Utilization of solar energy for electricity demands in oil wellhead facilities

This study evaluated the power supply for equipment utilizing solar systems equipped with 2-volt, 3000 Ah batteries, accounting for the energy needs during three consecutive cloudy days. The proposed system is designed to meet all electrical requirements, including an area lighting system for an oil wellhead station covering a 50x100 meter area. This lighting setup consists of four 100W LED projectors operating for 14 hours per day, resulting in a total energy consumption of 5.6 kWh per day. Additionally, the system includes two intermittently operated explosion-proof fluorescent lights and two 20W LED fixtures. The guardhouse requires energy for lighting, a television, a refrigerator, and a solar heating and cooling system, amounting to 8.98 kWh per day. Table 1 provides a detailed overview of the recommended equipment for a station with a total energy requirement of 14.58 kWh per day.

Table 1. Proposed solar power system for a 14.6 kWh daily energy requirement

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Amount** | **Unit** |
| Energy required  | 14600 | Wh/d |
| Panel capacity | 250 | Wp |
| Conversion factor | 3.4 | Wh/d/wp |
| Energy generated by each panel | 850 | Wh/d |
| Panel number | 17 | Number  |
| Battery vol. | 2 | V |
| Battery Amp | 3,000 | Ah |
| Ampere required | 7300 | Ah/d |
| Number of cloudy days | 3 | Day |
| Imperative required with cloudy days support | 525600 | Ah/d |
| Battery number | 175.2 |  |

The cost of solar photovoltaic modules has experienced a remarkable decline over the years, decreasing from approximately $105.7 per watt in 1975 to around $0.20 per watt by 2022, according to data from the International Energy Agency (IEA). This substantial reduction can be attributed to competitive market dynamics and continuous technological advancements, suggesting a persistent downward trajectory in pricing. Additionally, the resale value of solar systems is a critical consideration; the capital invested in these systems can be transferred to different locations after the project's operational lifespan, facilitating reuse and allowing for the resumption of operations without incurring excessive time or financial costs. Table 2 illustrates the cost of power supply for a solar system designed to support a 14.6 kWh oil wellhead station, accounting for energy needs during three consecutive cloudy days.

The cost of generating electricity using solar panels, known as the Levelized Cost of Energy (LCOE), is $2.545 per kilowatt for a system capable of sustaining operations for three consecutive cloudy days. In contrast, the price of a solar system designed without this cloudy day support is $55,082, resulting in an LCOE of $1.054 per kilowatt.

Table 2. Power supply cost breakdown for solar systems supporting oil wellhead operations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Equipment** | **Numbers** | **Unit** | **Brand** | **Price ($)** |
|  PV Modules 250W | 17 | NO | TBEA |  | 1,718 |
| Batteries 3000A/h | 175 | NO | NILE |  | 115,632 |
| Charge Controller MPPT80A | 1 | NO | Outback |  | 4000 |
| Inverter 3000W | 1 | NO | MW |  | 1800 |
| Control System | 1 | 1 Set | Niroo Pars |  | 500 |
| Support Structure | 4 | 1 Set | Niroo Pars |  | 240 |
| Installation | 5 | 1 Set | Niroo Pars |  | 4000 |
| Water Heater | 1 | 1 Set | any  |  | 280 |
| **All Cost:**  |   |   |   |  | 128,170 |

3.2 Utilization of solar energy for electricity demands in gas wellhead facilities

The study focused on analysing the power supply for gas wellhead equipment utilizing solar systems, accounting for support during three consecutive cloudy days. The solar system is capable of meeting all electrical requirements, which include an area lighting system for a gas wellhead station covering a 100x150 meter area. This lighting setup consists of six 100W LED projectors operating for 14 hours per day, resulting in an energy consumption of 8.4 kWh per day. Additionally, the system features two intermittently operating explosion-proof fluorescent lights alongside two 20W LED fixtures. Moreover, the processing injection package requires 12 kWh per day, with continuous operation at 0.5 kW over 24 hours. Instrumentation tools demand an additional 7.2 kWh per day, while the guardhouse—similar to that of an oil wellhead—requires 8.98 kWh per day. Table 3 provides a comprehensive overview of the recommended equipment for a gas station with a total energy requirement of 38.04 kWh per day.

Table 3. Proposed solar power system for a 38.04 kWh daily energy requirement

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Amount** | **Unit** |
| Energy required | 38040 | Wh/d |
| Panel capacity | 250 | Wp |
| Conversion factor | 3.4 | Wh/d/wp |
| Energy generated by each panel | 850 | Wh/d |
| Panel number | 45 | Number  |
| Battery vol. | 2 | V |
| Battery Amp | 3,000 | Ah |
| Ampere required | 19020 | Ah/d |
| Number of cloudy days | 3 | Day |
| Imperative required with cloudy days support | 1369440 | Ah/d |
| Battery number | 456.48 |  |

Table 4 displays the power supply cost for a 38.04 kW-hour per day gas wellhead station using a solar system, with support for 3 consecutive cloudy days.

Table 4. Power supply cost breakdown for solar systems supporting gas wellhead operations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Equipment** | **Numbers** | **Unit** | **Brand** | **Price ($)** |
|  PV Modules 250W | 45 | NO | TBEA |  | 4,475 |
| Batteries 3000A/h | 456 | NO | NILE |  | 301,277 |
| Charge Controller MPPT80A | 2 | NO | Outback |  | 8000 |
| Inverter 3000W | 1 | NO | MW |  | 1800 |
| Control System | 1 | 1 Set | Niroo Pars |  | 500 |
| Support Structure | 6 | 1 Set | Niroo Pars |  | 480 |
| Installation | 8 | 1 Set | Niroo Pars |  | 8,000 |
| Water Heater | 1 | 1 Set | any  |  | 280 |
| **All Cost:**  |   |   |   |  | 324,812 |

The cost of generating electricity using solar panels, known as the Levelized Cost of Energy (LCOE), is $2.49 per kilowatt for a system capable of sustaining operations during three consecutive cloudy days. In contrast, the price of a solar system designed without this cloudy day support is $119,721, resulting in an LCOE of $0.90 per kilowatt.

A critical advantage of utilizing solar systems in the upstream oil and gas industry is their flexibility after the oil and gas wells have reached the end of their productive life, typically between 10 and 15 years. Unlike overhead power lines, which often remain unused due to high decommissioning costs, solar systems can be easily dismantled and relocated after the wells are exhausted. This feature allows for the rapid redeployment of solar infrastructure to new resources, effectively enabling subsequent well operations at no additional cost. This aspect represents a significant hidden return on investment for companies adopting solar technology in their operations.

The integration of solar systems in the upstream oil and gas industry presents a significant advantage once oil and gas wells reach the end of their productive life, typically between 10 and 15 years. Unlike overhead power lines, which often remain unused due to high decommissioning costs, solar systems can be easily dismantled and relocated after the wells are exhausted. This flexibility allows for the rapid redeployment of solar infrastructure to new resources, enabling subsequent well operations at minimal cost. Consequently, after a well is no longer productive, the next well can commence operations with virtually zero initial investment. This aspect represents a substantial hidden return on investment for companies that adopt solar technology in their operations.

Solar power not only reduces operational costs but also enhances sustainability within the industry. By transitioning to solar energy, companies can mitigate their environmental impact while maintaining economic viability. As the oil and gas sector increasingly embraces renewable energy solutions, the potential for solar systems to contribute to long-term operational efficiency and cost savings becomes increasingly evident.

Figure 1 illustrates the electricity transmission costs for various consumers based on their distance from the T-off point, indicating that longer distances result in increased transmission expenses. This shows that as the power consumption is increased from the power supply, it will increase the cost of supplying it, while this does not happen when using the solar and diesel generator system. These findings imply that for consumers with low electricity usage, solar systems represent a more economical alternative. Conversely, high-consumption users situated at greater distances would derive more benefits from utilizing traditional transmission lines.



Figure 1. The LCOE for all alternatives for oil and gas wellheads electricity supply with different distances to conventional infrastructure

4. Conclusion

The use of a solar system instead of transmitting electricity through airlines brings the following results:

* The implementation of such plans not only lowers energy consumption costs but also contributes to environmental preservation and aids in mitigating the effects of global warming.
* Based on the economic analysis, for oil and gas wellheads stations are not financially feasible to install an overhead transmission line, particularly if it is located 10 km away from the last split. In such cases, it is recommended to utilize solar systems with the capability to operate for 3 consecutive cloudy days, as it would offer a more cost-effective solution.
* According to results of the present research, for any electrical consumer that have a daily electricity consumption of less than 38 kilowatt-hours and are located over a distance of 10 km, it is economically viable to use solar systems to meet their electrical power needs, considering the cost of 2.49 dollars per kilowatt.
* When considering the use of solar systems for gas wells, it is observed that they offer a highly cost-effective solution for sweet gas (non-corrosive) types. However, for corrosive gas types, the effectiveness of solar systems may be influenced by the electronic technology used in the process systems.
* The installation time for independent solar system supplies is considerably shorter compared to overhead lines, primarily due to reduced physical and paperwork requirements. This leads to a significant reduction in operation time, decreasing it from approximately a year to less than a week, which is only around 3% of the time required for overhead lines installation.
* The utilization of solar systems in upstream oil and gas industries presents a significant advantage in terms of resell back. Traditional power sources for wellhead stations require ongoing expenditure and time investment, but after 15 to 20 years, these facilities become obsolete. In contrast, by using solar systems, it becomes possible to transfer the entire invested capital to another location once the project reaches its end, allowing for seamless continuation of operations without incurring unnecessary costs or delays.
* The implementation of this project encompasses important objectives, including promoting sustainable development, reducing environmental pollution, and harnessing the abundant and free energy from the sun.
* Considering that renewable sources currently account for approximately 19% of the world's total energy supply, while the corresponding figure in the country is less than 1%, the implementation of such plans will require increased engagement with the international community.

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