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Offshore Power Generation Using Natural Gas From Remote Deepwater Developments

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Abstract

This paper will explore an alternative technology for the disposition of natural gas from remote deepwater developments. The application of floating production storage and offloading (FPSO) units in the Gulf of Mexico has as a significant hurdle the Minerals Management Service's policy with regard to conservation. In other parts of the world where FPSOs have been operating, gas is reinjected or flared. For an FPSO deployed on the U.S. OCS, these conservation policies require that produced gas be delivered to market.

Remote deepwater locations present significant technical challenges to use of pipelines for export of gas. Gas compression or liquefication technologies present other technical challenges and introduce new risks.

A floating power generation plant will be examined from a standpoint of concept and feasibility. The paper will present a consolidated view developed with input from offshore oil and gas producers, academics, and the electrical power generation and distribution industries. Specifically the paper addresses four primary areas of this technology:

- Generation plant size and configuration
- Electric power transfer systems
- Delivery of gas from production unit to the generation plant
- Submarine Cable Technology

Examination of this topic should encourage discussion and investment in new solutions that will add flexibility to deepwater development options with respect to the disposition of gas, and introduce a potential new source of electrical power generation.

Introduction

The next major step for oil and gas development in the Gulf of Mexico will involve facilities that are well beyond existing pipeline infrastructure. The FPSOs is the probable choice for the next wave of deepwater development. The offshore industry, through the Deepstar consortium, sponsored the completion of an environmental impact statement to identify any issues that might impact FPSOs operating in the Gulf of Mexico.

The conservation requirements[1] established by MMS have the objective of assuring all economically recoverable resources are produced to market. This position precludes two practices commonly employed by FPSOs in other regions of the world, specifically the flaring or venting of produced gas to the atmosphere and the reinjection of produced gas back into the well formation.

FPSOs, by definition, store their produced oil on board for a period of time and export it by means of shuttle tankers. Technologies for the disposition of the produced natural gas include construction of an export pipeline from the FPSO to shore or existing pipeline infrastructure, or compression or liquefication of the gas into a transportable form and the subsequent transport of the gas by some form of shuttle tanker. The conversion of natural gas to a transportable medium requires specialized equipment on the FPSO and specialized vessels for transport. While this technology exists, it is complex, expensive, and poses many new risks not normally encountered or mitigated on offshore facilities.

Natural gas pipeline technology also approaches limits in deeper water applications. The sea-floor topography of deeper waters is more severe and varied, resulting in potential stresses and elevation changes that can promote hydrate formation. Wall thickness and design strength calculations for this hydrostatic environment may tax the current pipeline construction and installation technologies. Additionally, since deepwater developments typically involve large reservoirs, it may not provide sufficient pipeline capacity to connect to existing offshore pipeline infrastructure, which in some cases is already operating close to maximum capacity. This would potentially require new pipelines the full distance to shore.

Currently, natural gas that is delivered to shore is consumed by industrial users, residential services, or power generation. This paper explores the generation of power offshore and the transmission of that electrical energy from the offshore generation plant to the domestic power grid. This option satisfies the conservation requirements, and may provide a viable economic alternative to pipelines, liquefication or compression technologies. The concept is illustrated in Figure 1.

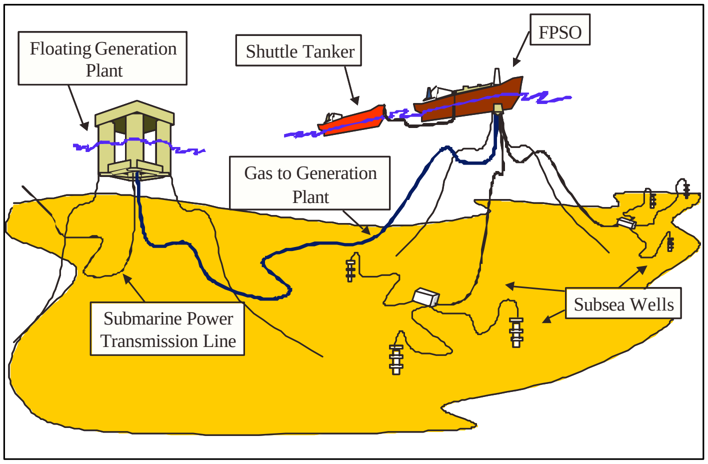

Figure 1: Conceptual Field Arrangement for Floating Generation Pants

The concept of offshore power generation is in its simplest form a consolidation of existing technologies. Offshore production facilities currently generate electricity for their own consumption. Commercial floating generation plants have been employed in various locations, typically near shore or dockside. High voltage electrical power is transmitted by submarine cable. Adapting these technologies for remote deepwater developments involves both technical and organizational challenges. This paper explores some of the answers to both sets of challenges but is not exhaustive. Further research and study in the context of a specific project and a sponsor operator's business practices will identify numerous scenarios that may be equally or more effective.

Technical challenges. The technical challenges of this concept are subdivided into four areas. The basic assumptions associated with each are defined below.

Generation plant size and configuration refers to the physical generation facility, which may be assumed to be either semi-submersible or ship-shaped. The number and capacity of generating sets and the associated voltage control will be based on an assumed availability of gas and the types of equipment in use at land based generation plants that are adaptable for service in the marine environment.

Electric power transfer systems. The electric power will be produced at a voltage substantially lower than that required for transmission to shore. Thus the power must be transformed for movement to the power grid onshore. The differences in electrical operating characteristics between the offshore generation and the onshore power grid requires development of sophisticated electric system tools, equipment, and techniques to insure reliable, coordinated operation.

Delivery of gas from the production unit to the generation plant includes both the metering and transport functions. Under the base case assumption, metering for royalty purposes will occur on the production unit. Gas would be exported by pipeline/flowline a short distance to the generation plant. Provided the plant receives the gas from a single production unit, subsequent metering or allocation systems at the generation plant are not anticipated.

Submarine cable technology. There are proven technologies for transmission of this magnitude of power via undersea cables. However, such technologies have not been applied to the sea depths and distances that will be encountered in an offshore generation project. Research and development will be needed to extend the reliable working depth of high voltage undersea transmission cables. Transmission equipment must be adapted to the offshore environment to allow the produced electric power to reliably flow to shore.

Organizational challenges. The organizational challenges associated with this concept are largely influenced by the sponsoring organization and how they traditionally manage the variety of resources that are engaged in a conventional development project. These will be explored in greater depth later in this paper, but may be summarized by the following questions:

1. Does ownership of the gas change between the production facility and the generation plant?
2. What is the value assigned to the gas consumed in the generation plant?
3. Who owns the transmission cable/system? Where does it begin and end?
4. Should the generation plant be under the control of the production company or a utility?
5. How should the costs associated with the power movement, from the onshore cable terminal into and through the utility grid, be allocated?

Just as a conventional offshore development involves coordinated activity among several participants, the development of a floating generation plant will introduce some new players, such as the power distributor or utility company, the submarine cable fabricator, installer, and operator, and the floating generation plant operator. For the purposes of this paper, the key participants are defined below. In some circumstances, a single company may serve more than one role.

Production Company is the oil and gas interest that owns the rights to the produced hydrocarbons. This is typically also the leaseholder. The production company may also be a joint venture or partnership. The production company may operate the production facility or may contract with an operating company or other production company to operate the production facility.

Generation/Transmission Company. A single company could own and/or operate both the generating facilities and the power transmission facilities. Since they have a common, single purpose, a case can be made for common ownership and operation. However, the required skill sets to construct and maintain these facilities are very different and separation of responsibilities may be more efficient.

Onshore Utility. The operation and reliability of the onshore utility grid will impact the operability of the offshore generation facility. Ultimately, onshore utility system reliability and operations will directly relate to electricity sales revenues. Appropriate contractual relationships must be developed to provide assurance for all parties that the produced power will be moved to market through a system that is both reliable and available.

Operating Company is a company contracted to operate the offshore production facility or floating generation plant. An operating company does not have ownership interest in the facility or commodity.

Generation plant size and configuration

The offshore power generation plant may be developed on board of a semi-submersible or on a ship-shaped facility.

Floating ship-shaped design. The incorporation of generation equipment on board a ship-shaped facility must be appropriate to the consumption of the expected gas production offshore. A typical deepwater development could provide between 100 and 500 million cubic feet of natural gas per day. It is estimated that a small to medium-sized ship could house the turbines and generators needed to process this volume of gas. The facility could be purpose built or converted from an existing tank ship, freight ship or mobile offshore drilling unit. A preliminary estimate of the plant size and design options is conducted below. This preliminary estimate uses consumption of approximately 500 MMCF of natural gas per day.

The first design consideration is to examine the option of using a single ship plant or multiple ships. The advantages of a single ship are lower capital cost, smaller crew, and lower costs. The disadvantage is that the full generation capacity will not be effectively utilized when the natural gas supply wanes on a specific site. To mitigate this problem, multiple ships can be considered to provide more flexibility to accommodate varying supplies of natural gas. Multiple-ship designs can also offer benefits for relocation of excess capacity and other diversified operational options, and thus offer a better overall utilization of assets over time.

While multiple generation facility designs are considered, comparisons of overall economics between single and multiple ships is beyond the scope of this paper because it depends on the specific examination of each site and requires optimization and detailed analysis. To provide a preliminary analysis, this paper only assesses the physical viability of a single ship plant option using a converted tank ship approximately 900 feet long, 120 feet wide, and 40 feet deep. It is assumed that gross displacement would be in the 75,000-ton class. The net available "cargo" capacity was estimated at the 45,000-ton range. In addition, it was estimated that the available space for the power plant would be approximately 560 ft by 105 ft within a 30 ft hull depth. Using a Frame-7 F or G gas turbine simple cycle generation system, it was determined that 12 individual sets would require 500 MMCF natural gas per day to generate approximately 2.3 GW power with an overall plant efficiency of 36 percent.

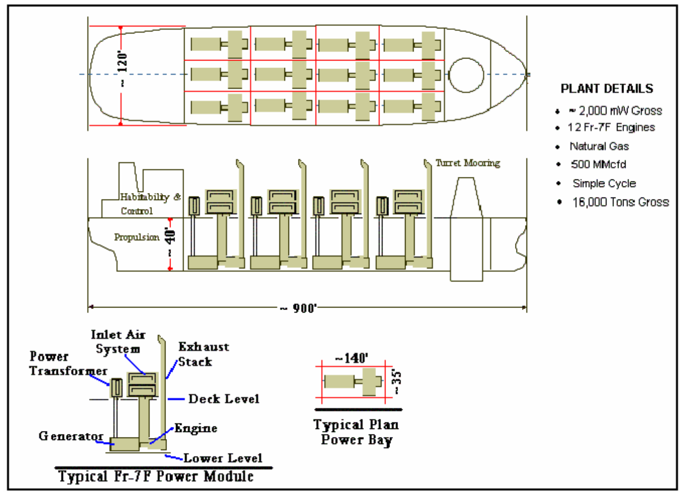

Figure 2: Conceptual layout of 12 Frame F gas turbine systems in a ship

Weight considerations for the entire 12-generator plant with all auxiliary and support equipment associated with the power plant would be in the estimated 20,000-ton range. While the designated ship can sufficiently support the weight of power generation systems, physical dimensions of these 12 plants present some challenges, especially if they were to be laid out in their typical land-based configurations. One potential solution is to design a multi-level plant design that could minimize footprint requirements to 140 ft x 35 ft for each power bay (see Figure 2). Considerably more work is required to design this multi-level layout which must provide for adequate engine access and meet manufacturer warranties as well as operational and safety considerations.

The ship-shaped unit may also be either permanently moored or may be arranged to disconnect and relocate for periodic maintenance or storms.

Semi-submersible design. One of the advantages of semi-submersible design is that there are fewer restrictions on the size and layout of the power plant. The semi-submersible design can easily accommodate a fleet of 12 gas turbine systems. It will provide easier access for maintenance and plant retrofitting, for example, to install an absorption inlet cooling chiller system to effectively use the waste heat.

A semi-submersible facility would be permanently moored, and may not utilize its full generation capacity after natural gas supply wanes at a specific production location. Large producing facilities address the problem of diminishing throughput by seeking new sources of production through further drilling and development tied back to the production unit or "hub." Similarly, to maximize the use of a generation plant, sustained development through continued exploration in the offshore area would provide stable long-term volumes of gas required.

Ship shaped facilities may be designed to remain on location or disconnect and abandon the location during storms.

The ship design allows easy transfer of the entire plant to new drilling sites, whereas the semi-submersible may involve a more complex and costly process for relocation. During severe storms, most offshore facilities in the Gulf of Mexico are abandoned with all the crew being sent back to shore. In some cases, the production facility may continue to operate. Evacuation and operational considerations must be coordinated to apply a consistent standard of safety for crewmembers and to manage interruptions in gas production during evacuations.

Potential exists for gas turbine systems being damaged on board an abandoned facility during storms. Rotating equipment installed on a ship-shaped facility would have to be designed to handle the increased motion and acceleration loads. It is presumed that a semi-submersible design would cost less than a ship-shaped design, but the comparison of costs and economics cannot be made without conducting a specific in-depth analysis for each production site. Additionally, if conversion of an existing vessel is being considered, the availability of units such as single-hulled tankships that are phased out of transportation service due to OPA 90[2] may offer opportunities that make the ship option more attractive.

Electric power transfer systems

The generators of the offshore generation facility will produce the electricity at an alternating current (AC) voltage between 13,800 and 24,000 volts at the generator terminals. Such a voltage is too low to be suitable for transmission of the produced power such long distances to shore. Therefore, the power must be transformed to a higher voltage for transmission to shore.

The delivery of the produced electricity from the offshore facility to the onshore power grid will require further development of several power technologies which are common in less demanding situations. While system studies must be performed to evaluate the relative merits of conventional High Voltage Alternating Current (HVAC) transmission and High Voltage Direct Current (HVDC) transmission, HVDC must be considered as the preferred technology for moving such a large amount of power over the underwater distances required. DC power transmission systems enjoy several advantages over AC Systems including lower levels of electrical losses, reduced electromagnetic field effects, greater compatibility with existing cable technologies, and reduced electrical synchronization and power flow problems with the onshore power grid. However, while undersea HVDC systems are in use around the world today, they have not been placed far offshore in remote electricity production facilities, and HVDC cable systems have not been applied at sea depths in excess of 2000 meters. Of concern is the fact that HVDC systems are considerably more costly to install than AC systems and may require more space at the terminal ends to support the specialized equipment required. Therefore, HVDC Systems are cost effective only where large amounts of power are transported for long distances over a period of many years.

Generation-transmission interface. In conventional AC generation and transmission systems, the electric power generated is increased in voltage to HVAC levels up to 500 kV or in some cases 765 kV by the power plant generator step-up transformers in the generating station switchyards. This HVAC electric power is then introduced into the regional electrical utility power grid for delivery to consumers. Since generating plants and their loads tend to be tightly coupled on a regional basis, they will operate in synchronization with each other and load will be shared by the available generation.

Exceptions to this type of operation generally result from the need to locate the generation plant in close proximity to the fuel source when the fuel source is distant from the load centers of consumption. An example of this would be the location of the hydroelectric resources of the Pacific Northwest and the large load centers of the US west coast and major Canadian cities. Due to the large amount of power to be transported, the distances involved, and the need to properly coordinate operation of this remote generation with local power grids and generation, HVDC has been the technology of choice for such high capacity, long distance power delivery.

Conventional HVDC technology requires the generators to first supply a HVAC switchyard that then is connected to a DC converter Station built adjacent to the switchyard. In recent years there has been interest in development of an Integrated HVDC Unit-Connected Generating Station. In this concept, multiple generators are connected in parallel to paired generator step up transformers. The transformers high voltage outputs are connected directly into the series connection of the valve groups comprising the Power Rectifiers. Studies have indicated the economic viability of this approach[3]. There are possibilities for further refinement of such a concept. A recent paper proposes the use of HVDC to interconnect remotely sited generation into power grids using a 36-pulse converter that would allow the elimination of the AC and DC filters at the converter station thereby saving substantial space and cost[4]. The development of an integrated HVAC unit connected station could hold promise for reduction of cost and enhancement of operability of such an offshore facility.

Interconnection with the regional utility grid. The location of remote generation increases the difficulty of maintaining synchronous operation between the offshore generation resources and the regional, onshore load centers. The use of a DC system with a Power Converter at the point of interconnection with the regional grid will help maintain electric system stability and facilitate the continued operation of remote generation during onshore system disturbances. However, the location, type and severity of onshore disturbances and the sophistication of the DC Converter and Offshore Generating Plant control system will determine if the link will continue to operate.

When a large amount of generation is connected to its load center through limited transmission circuits, disturbances on these circuits can require that the generation be shut down for self-protection as well as for system protection. The rotational inertia of one or more large turbine generators creates a sizable source of energy available on an almost instantaneous basis. The continuous firing of gas fuel in the turbine provides a source of potential energy that is continuously converted. The introduction of a fault (short Circuit) in the onshore power grid and/or the opening of onshore circuits will instantaneously change the loading of the turbine generators and cause the remote generation to slip out of synchronization with its load center thereby necessitating the isolation (trip) of the remote generation. Control System Development must take place to create controls capable of coordinated operation of the high inertia, remote, spinning generation, with the regional power grid during normal and abnormal conditions. Such a system will require fast, accurate communication and processing of data, rapid recognition of abnormal events, quick response times, integration with a variety of equipment, and an intelligent operator interface.

Delivery of gas from production unit to the generation plant

The arrangement of the typical remote deepwater location is illustrated in Figure 1. In this example a ship-shaped FPSO exports produced gas to a semi-submersible floating generation plant. While the flowline connecting the two facilities is depicted as being on the sea floor, in situations where the two facilities were in close proximity in ultra deep water, it may be advantageous to use a submerged gas line supported by buoys. For example, figure 3 shows a floating generation plant and FPSO located four miles apart in 10,000 ft water depth. A catenary flowline connection would require approximately 33,000 feet, but a submerged flowline at a water depth of 1,000 feet or less would require approximately 24,200 feet.

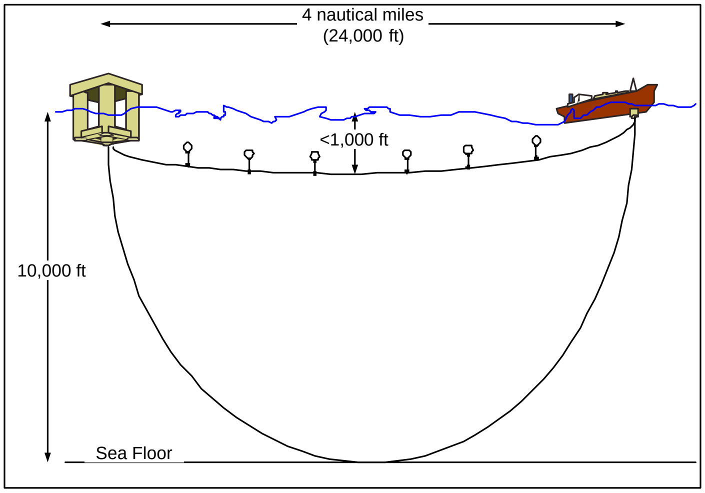

Figure 3: Submerged Flowlines

Metering and royal ties. On a conventional production facility, Minerals Management Service regulations[5] require the metering of produced hydrocarbons to determine the payment of royalties. These rules establish different requirements for hydrocarbons dedicated exclusively to electrical power generation, as compared to products sold or distributed for other purposes. Additionally, where multiple fields are produced at a single location or hub, the production system must provide the means to assess individual well production. This equipment can be complex when different ownership or royalty rates apply. For hydrocarbons exported to shore, the metered production from many facilities is mixed in the transmission pipelines, and metered again when it exits the transmission system. Hydrocarbons that are mixed in transit over great distances in a pipeline are subject to phase changes that ultimately must be reconciled for royalty and ownership purposes. The need for an additional metering of gas at the floating generation plant may be debatable, or may be supportable when a single generation plant, like a transmission pipeline, receives gas from multiple production facilities.

Offshore pipeline transmission companies charge a tariff on the hydrocarbons transported. This cost could be deducted for the gas exported to a floating generation plant, lowering its unit cost. Such gas also would not incur any further processing or distribution costs. Regardless of the ownership issues (discussed in greater detail under organizational challenges) these cost savings represent a cost advantage to the generation company.

Floating generation plants should be designed with the ability to support the management of gas supply from multiple sources, in terms of space for appropriate metering equipment and the conceptual approval of the process by which consumption records would be maintained.

Submarine cable technology

Oil impregnated cables. Present undersea power cable technology allows the installation of circuits operating at 500 kV DC with power capacities up to 2800 Amperes or 2800 MW of DC transfer capability utilizing a bipole (positive and negative conductors) circuit. A recent installation, reported in Japan, utilizes a cable constructed with Propylene Laminated, Oil Impregnated Paper Insulation (PPLP). This installation has been the subject of two IEEE papers[6]. The use of PPLP insulation apparently allows reductions in insulation thickness while improving overall mechanical and dielectric strength of the cable with a life expectancy comparable with conventional kraft paper cable insulation. While such a cable would have the necessary current carrying capability, the planned installation is over a distance of 70 km with a sea depth of 73 meters. This oil-impregnated cable requires a center oil duct that must be continuously fed or pressured. The total cable length is limited by the maximum feeding length of this center oil duct. These parameters are far short of the distance and depths required for Offshore Power Generation in Remote Deepwater.

Other solid, oil impregnated, paper insulated cables, not requiring pressure feeding of the oil, have been installed over distances similar to the requirements of this project. However these cables have significantly lower power transfer capabilities, thereby necessitating multiple cables, and none have not been applied in sea depths greater than 200 meters.

Solid dielectric cables. The cable systems discussed in the previous section utilize either oil or a synthetic fluid to impregnate the paper insulation to provide high electrical dielectric properties. A solid, synthetic cable insulation, cross-linked polyethylene, has been improved to make it suitable for certain 500 kV DC applications. This cable does not utilize any oil or liquid medium, however, the overall thickness of the insulation limits conductor size and power transfer capability. Furthermore, this insulation is relatively soft and its applicability in deepwater projects is unproven.

Cable splicing. Since these cables must be transported to the work site and installed using a ship specially suited for the purpose. However, there are size to length limitations as to the length of cables that can be manufactured and transported to the job site. Many cable sections must be spliced together during the installation process to complete the required length. Research and development will be needed to extend undersea cable splicing technologies to make them quick and easy to install and reliable at these water depths.

Technology development for undersea high voltage power cable systems. Development of Offshore Power Generation will require further development of these existing cable technologies. Longer cable lengths will require development of new approaches to maintaining insulation impregnation. Greater depths will require new developments in the armoring and protection of such cables from the hydrostatic pressure of these depths. Improvement in splicing and laying technologies will be required to facilitate installation at these depths. The basic elements of the necessary cable technology for deepwater generation are in place today. However, they must be brought together in an undersea cable system that matches the current and voltage ratings of PPLP cables and which can be laid very long distances at water depths nearly twice that of present applications. The development of power cables, capable of operating in this hostile environment, will provide many opportunities for the development of needed power resources both in the Gulf of Mexico and in other remote parts of the developing world.

Organizational Issues

In order to address the organizational issues associated with an offshore power generation project, it is helpful to review and compare the relationships that are typically encountered in the power generation and offshore production industries.

Power generation industry. The utility company that sells power to the consumer is usually part of a large corporation that owns and operates all intermediate business units associated with power generation. This includes the purchase and transport of raw materials, generation of the electricity, transmission stations and lines and the local distribution system.

Offshore energy industry. The offshore energy business is subdivided into three predominant sub-industries that operate with a high degree of independence. Exploration and development is the component that identifies prospects, conducts seismic testing, obtains the leasehold, executes drilling and installs and operates a production facility on the successful discoveries. The exploration and development company is usually one of several major divisions within an oil and gas company. Within the exploration and development sub industry, a myriad of service companies provide virtually all levels of support, hardware and technical expertise. The service companies own large capital equipment (such as drilling rigs, seismic vessels, remote operated vehicles, support and construction vessels), while the exploration and development company owns the leasehold and the permanent production facility.

The next major sub industry is the transmission company, which owns, maintains and operates the pipelines that transport oil and gas from the production facility to shoreside refineries or storage. The transmission companies charge a tariff to production companies based on the volumes of oil and gas transported. While they may also be a major division within an oil and gas company, in most cases they do not exclusively serve their parent company, but transmit product for competing production companies as well.

The final sub industry is collectively referred to as “downstream” and includes the on shore refining, processing, marketing and sales, including the retail gas stations bearing the parent company’s logo. Special subsidiaries such as chemical production, plastics and transportation may also exist within an oil and gas company.

Optimize the model. In considering the floating generation plant, the first question may be who owns it? To some degree that answer is driven by decisions related to the respective ownership of the gas consumed and the power generated. In conventional power generation, the generating company has purchased the fuel and owns the generation plant. In the offshore industries, the oil companies own the gas until it reaches the customer or downstream component, or more accurately, own of a pre-measured quantity of gas contained within a specific pipeline system. Since the floating generation plant is intended to complement a particular production facility, presumably over several decades, the production company would have significant interest in its design and operation. One scenario that may be considered is to consider the export of the gas from the production facility as a point of sale transaction to the power generation company, which owns and operates the floating generation plant.

This arrangement is considered optimal under most circumstances, with the possible exception of a very large oil and gas company that had significant electrical generation or distribution operations within its corporate structure.

Assuming the aforementioned division of ownership, the power generation company and the production company would have to collaborate to some extent on the design and deployment of the unit. This process would parallel the current design procure and construct practices used by most major oil companies in the procurement of specialized drilling or support units.

Other scenarios may include oil company ownership or operation of the floating generation plant. The produced power would be sold to the power distribution company or utility. It is presumed that the transmission lines, offshore substations, and other electrical transmission plant and equipment would be owned and managed by the power generation or distribution company.

Conclusion

The concept of a floating generation plant as a means to make use of natural gas produced from remote deepwater facilities such as FPSOs appears to be economically viable, but requires more detailed study. This indication of economic viability is based on rough order of magnitude estimates for equipment, facility construction, and the challenges associated with deepwater pipelines experienced on deepwater developments over the past decade. However many unknowns still remain. A proposal has been submitted to the Mineral Management Service Technical Assessment and Research Program (TARP) to undertake more specific research with the intention of producing a preliminary design basis for an offshore power generation project. As similar efforts are expended and experience gained in natural gas conversion and transport technologies, more conclusive analysis can be undertaken.

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[1] Mineral Management Service Notice to Lessees (NTL) 2000-N05, *Conservation Information* dated October 1, 2000

[2] The Oil Pollution Act of 1990 requires tanks ships to be converted to double hull or taken out of oil transport service by specific phase out dates related to the vessel's age.

[3] IEEE PA7S Vol.3 No. 4 October, 1988, Manitoba Hydro, pages 1615-1621

[4] IEEE Transactions on Power Delivery, Vol. 16 No. 4, October, 2001, Miguel Villablanca, pages 462-467

[5] Title 30 Code of Federal Regulations Part 202

[6] IEEE Transactions on Power Delivery: Volume 14, No. 3, April 1999, Fujimori et al, pages 43-50 and Volume 11, No. 1, January 1996,Nakiri et al, pages 319-325