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Power Supply Options and Suitability Assessment for Remote Oil and Gas Production Installations

F. E Idachaba[1], H. E Orovwode[2], J. O Olowoleni[3], O.O Oni[4]

Department of Electrical and Information Engineering, College of Science and Technology, Covenant University Ota. Ogun state, Nigeria

***Abstract*— This paper is aimed at analyzing the possible power options and configurations for remote locations in the oil and gas industry with the view of proposing a cost effect power supply option suitable for the different operational requirements at these remote locations. It reviews the different power options available and presents selection criteria for the optimum choice of power generation technology, transmission links and the generation topology. The extremely high reliability and availability requirement of power supply at oil and gas production installations, the remote nature of these locations and the high power requirements of these sites make it mandatory for the power supply system to be able to deliver power to remote locations with the required reliability and availability, minimal maintenance and high mean time between failures in a cost effective manner. Different power generation options and topologies were reviewed and the use of renewable energy sources was also considered. The combined cycle gas turbine due to its high capacity, high reliability, reduced footprint and maintenance cost, configured in a distributed generation topology was found to be the optimum option.**

***Keywords*—power generation, gas turbine, reliability, maintenance, safety.**

I. Introduction

Oil & Gas is one of the world's most diverse industries, often operating in hazardous, severe, remote environments and conditions. In the face of these challenges remains the unremitting need to operate reliably with the utmost in safety and security [1].Oil and gas production facilities including flow stations, gas gathering plants, compressor stations, booster stations etc are often times located in remote locations are not easy to access. This location challenges coupled with the very high power supply reliability and availability requirements makes the extension of public utility supply to these areas uneconomical and also unsuitable due to the possibilities of vandalization and illegal connections of settlements along the power line transmission paths. Industrial processes require that the power supply be free of interruption or disturbance. A recent study in the USA has shown that industrial and digital business firms are losing $45.7 billion per year due to power interruptions.

In industrial automatic processing, whole production lines can go out of control, creating hazardous situations for onsite personnel and expensive material waste also resulting in long downtime, as well as many hours of recovery operations that may take weeks to resolve [2]. Many power problems originate in the commercial power grid, which, with its thousands of kilometers of transmission lines, is subject to weather conditions such as hurricanes, lightning storms and flooding along with equipment failure, traffic accidents and major switching operations. This paper is aimed at analyzing the possible power options for offsite locations in the oil and gas industry with the view of proposing a cost effect power supply option suitable for remote locations. It provides a review of the different power options available and presents selection criteria for the optimum choice of power generation technology, transmission links and the generation topology. The very high reliability and availability of power supply at oil and gas production installations, the remote nature of these locations and the high power requirements of these sites make it mandatory for the power supply system to be able to deliver power to remote locations with 100% reliability and availability with minimal maintenance in a cost effective manner.

II. Selection Criteria For Power Supply Options For Remote Locations

The nature and site specifics characteristics of oil and gas production sites make it mandatory for the power supply systems deployed in these areas to have the following features

(1) Proven reliability (continuous operation in extreme conditions): The cost implications and convenience of sending maintenance personnel to these remote locations is usually high due to the logistics costs which in some cases require dedicated helicopter flights.

(2) Low Total Cost of Ownership (CAPEX and OPEX including installation costs): The fluctuating price of oil in the international market makes it mandatory for operations to be done in the most cost effective manner to reduce both the CAPEX and the OPEX.

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(3) Multi-fuel capability (Utilization of flared gas is a major advantage) The need for greater fuel flexibility to allow the unit to switch from natural gas to distillate, to cope with variability in Liquefied Natural Gas (LNG) composition and Wobbe Index, or to consider syngas or hydrogen from an Integrated Gasification Combined Cycle (IGCC) option, in the face of natural gas price volatility.

(4) Low environmental impact (Emission Content). The environmental impact of the power supply especially the emissions content of the power supply systems should be kept at the barest minimum to protect the environment.

(5) High power output capacity. Oil and gas installations make use of high capacity pumps and compressors coupled with heavy motors. These are all high power equipment. The power supply should be able to cater for this power requirement with the sufficient spare capacity.

(6) Scalability. In most oil and gas installations, the deployment of new wells and system upgrades occur in the life time of the plant. This make it necessary for the power supply to these sites to be scalable so that the power supply can grow as the plant load increases without any significant change in the plant configuration in terms of CAPEX.

(7) Ease of decommissioning and Scrap value. When the power supply systems reach end of life, they should be easily decommissioned without any negative adverse effect on the environment and should not require special experts to carry out the decommissioning as in the case of nuclear plants. The systems should also have a high scrap value.

(8) Safety: The systems must be designed for safe operations in the areas of installation. They must be designed to conform to the right ingress, ATEX and hazardous area specification ratings.

III. Current Electric Power Generation Options

The function of an electricity generator is to transform one form of energy (e.g. chemical energy in fuels or kinetic energy in wind) into electrical energy as efficiently as possible. As such, the choice of generation technology is strongly dependent on the primary energy supplies available at the point of generation [3].

The current power generation technologies include

(1) Coal Technologies: The existing technologies under this category, include

(i) Pulverized fuel steam plant
(ii) Circulating fluidized-bed combustion (CFBC) plant
(iii) Integrated gasification combined cycle (IGCC) plant

The integrated gasification combined cycle (IGCC) facilitates the production of electricity from coal with low greenhouse gas (GHG) emission rates via pre-combustion capture of CO_2 and CO_2 storage in geological media. A coal IGCC plant with carbon capture and storage (CCS) typically becomes competitive with a coal IGCC plant with CO_2 vented when GHG emissions are valued at a price ~ \$100 per tC [4] .The coal technology is currently limited by the scarcity of coal feed stock and the high GHG emission content of coal when used in power generation [5] [6] [7]

(2) Natural Gas plants: Under this category we have the following plants

(i) Open cycle gas turbine (OCGT) plant
(ii) Combined cycle gas turbine (CCGT) plant

Natural gas burns at a higher temperature and higher efficiency. In the combined cycle turbines the hot gas pushes the turbines and after doing that the spent gas is used to heat steam which is used to drive another set of turbines. This gives the combined cycle turbines a higher efficiency than the single cycle operations like the coal fired plants.

Micro turbines are smaller versions of the gas turbines used for larger cogeneration plants. Developed largely as military power plants for tanks and missiles, they have typical power outputs of between 10 and 250 kW. The compactness of micro turbines makes these units ideal for small businesses or households and will offer new opportunities for peak shaving and cogeneration at a very localized level [3]. Gas turbine maintenance costs vary significantly depending on the quality and diligence of the preventive maintenance program and the operating conditions. Maintenance costs can triple for a Gas turbine that is cycled every hour versus a turbine that is operated every 1000 hours or more. In addition, operating the turbine over its rated capacity for significant periods will dramatically increase the number of hot path inspections and overhauls required [8].

(3) Nuclear power plants: Prominent under this category are the small modular designs for less than 300MW.Examples of these include the pebble bed modular reactor being developed by Eskom in South Africa, the helium reactor being developed by General Atomics of the US and smaller reactors under 50MW are also currently being developed around the world. The high security risks of nuclear reactors and the safety concerns associated with its handling and decommissioning is a very strong drawback to its global utilization [9].

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(4) Fuel cells: These are cells that utilize hydrogen in the generation of electricity. They are efficient and environmentally friendly but are prone to explosion due to the explosive nature of hydrogen and oxygen combinations. The technology is available but is not yet fully implemented due to its very high cost [10].

(5) Reciprocating and fossil fuel engine: This is mainly the diesel engine generator. It is a very popular approach at generating electricity for offsite locations. Its limitations include the fact that it contributes a high amount to environmental pollution among other factors.

(6) Renewable Energy Technologies: These are currently being developed as environmentally friendly solution for the provision of energy to off grid locations. Popular technologies under this category include

(i) Solar energy (Photovoltaic systems)
(ii) Wind energy (Wind turbines) and Compressed Air Energy Storage systems (CAES)
(iii) Biomass
(iv) Biofuels
(v) Hydro based

The major limitations of the renewable energy systems range from limited capacity and low conversion efficiency of the solar system to the inconsistency in power output capacity and site specific nature of the wind and hydro based systems.[11] These coupled with high capital intensive nature and the requirement for backup power makes the use of renewable energy systems unattractive for industrial environments where there is a constant need for high capacity and consistent power supply systems.[6][12][13]

(7) Hybrid systems: These are power supply system's realized by the combination of a number of both the conventional and/or renewable power supply systems. This is aimed at maximizing the advantages of each system.

A comparative analysis of the most popular power supply systems is listed in Table 1

Table 1.
Comparative analysis of power supply systems [3]

	Engine Generator	Turbine generator	PV(solar cells)	Wind turbines	Fuel cell
Dispatchability	Yes	Yes	-	-	Yes
Capacity Range	500KW - 5MW	500KW-25MW	1KW-1MW	10KW – 1MW	200KW-2MW
Efficiency	35%	29%-42%	6%-19%	25%	40%-57%
Energy Density (KW/m^2)	50	59	0.02	0.01	
Capital cost ($/KW)	200-350	450-870	6,600	1000	
Opex Cost($/KW)	0.01	0.005-0.0065	0.001-0.004	0.01	
NO_x Emission (Ib/BTU)					
Natural Gas	0.3	0.1	n/a	n/a	0.003-0.02
Oil	3.7	0.17	n/a	n/a	-

The results in Table 1 show the turbine, the engine and fuel cell as the easiest to deploy while the turbine generator has the highest capacity range. The capital cost of the solar system is the highest of all the technologies while its power output is the lowest. A comparison of the operating cost of both the gas turbine and the engine generator shows the gas turbine as having a better energy density, a better efficiency and a much lower operating cost. The green house gas emission is much more for the engine generator than for the gas turbine. The high radioactive emission associated with the nuclear energy systems has been shown to negate its capacity advantages especially for developing countries.

A. Power Distribution Topology

The main topology used in the transfer of electrical energy from the generators to the load is the centralized approach where the high capacity generating stations are located in one place far away from the load center. The generated power is transferred to the load centers using overhead transmission lines and the required associated equipment.

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This topology has its advantages but the cost implication of building transmission lines to remote locations and the associated losses and transformer stations make it uneconomical for the centralized approach. The decentralized (distributed) approach involves the location of smaller sized modular power generating systems located close to the load centers in remote locations which ordinarily have no access to the public grid network. The desired topology from this study is the distributed generation topology. This is due to the advantages highlighted below.

1. Smaller sized turbines can be used and this results in lower installation costs per site
2. Reduced cost for transmission networks
3. Reduced transmission losses due to the shorter transmission lengths
4. Increased reliability since the failure of any one power generation system does not affect the entire system.
5. Higher power quality and increased network flexibility.

Environmental benefits include reduced fuel usage, lower emissions of CO_2 and other pollutants and an increased utilization of renewable power. The evolution to a distributed generation infrastructure is occurring due to existing centralized generator and transmission networks reaching capacity and lifetime limitations, along with the emergence of economically attractive technologies such as natural gas turbine cogeneration plants and advanced information technology based systems management tools [3].The main disadvantage of the system is the fact that it requires multiple installation costs.

B. Transmission system

There are two types of transmission system. These are Overhead transmission: this involve the use of Aluminum cables hung on wooden or concrete electric poles spaced at equal distances from each other. The main advantages of this system includes

1. The ease of installation
2. Low cost cables and installation materials
3. Possibility of higher power capacity due to the possibility for ambient cooling.

The main disadvantages of this system include the fact that it is very prone to vandalization and it also distorts the skyline and environment and also has a need for real estate for the erection of the poles [14].

Underground Transmission: This system involves the utilization of specially designed cables buried in special enclosures at specific dept underground. Underground transmission cables (69kV and higher) with XLPE (eXtruded cross-Linked PolyEthylene) insulation have been in use worldwide since the 1960’s. Today, UG XLPE Transmission technology is established worldwide up to 400kV with major projects in Copenhagen, Berlin and other Metro areas and up to 500kV in Japan. Underground transmission cables are typically installed in underground duct banks, invisible to the eye, much like telecom, water, gas or other utilities. Underground transmission lines can be built where there is no space for overhead lines, thus reinforcing the transmission system where it was thought impossible. They can cross cities, and bodies of water. They are extremely reliable and not vulnerable to ice or wind storms, sagging due to overload, tree growth and similar environmental factors. Compared to the older pipe type cable still in use, the XLPE cables are virtually maintenance-free and do not contain any hazardous materials such as lead or oil such as the Self Contained Fluid Filled (SCFF) cables, the Gas Insulated Line (GIL) and the High Temperature Superconducting Cables (HTSC). These cables could leak their insulation materials to the environment and become an environmental hazard. They are currently becoming obsolete. [15]. Power transmission capabilities range from 80MW at 69kV to 500MW at 230kV per circuit [16]. The cables require thicker insulation and some above ground equipment to compensate for the losses. It has the following features

1) It has limited capacity when compared with the overhead cable system. It is estimated that the current capacity of two underground cables is equivalent to the capacity of one overhead cable of the same dimensions.
2) Initial cost for underground cable system is between 5 to 20 times more than that of the overhead systems due to excavation costs, high cable costs installations etc.
3) It requires multiple redundancies due to the high installation cost and replacement or maintenance costs.

The main advantage of the underground system which is the fact that it has lower outage rate but the total cost of ownership is very high and as such its deployment is limited to extreme cases where the advantages accruable by its deployment can be justified. Due to the different electrical characteristics of underground construction, the actual amount of power a buried line can carry is significantly lower than the amount of power an overhead line can deliver.

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Underground lines physically store a significant amount of electrical charge, which means that a larger portion of the line is required to carry the power flow. As a result, underground transmission lines must be relatively short or use expensive methods, like shunt compensation, to improve the flow of power. Generally, underground transmission is used in urban areas due to the lack of usable rights of way for overhead transmission. Construction in this environment usually entails installations under sidewalks or under roadbeds. This increases the amount of labor needed to cut roads/sidewalks, trench, refill the trench and repair the surface [17]. Underground cables are much less susceptible to weather-related outages. However, longer repair times for underground cables result in a significant difference in overall reliability performance. Information published by the European Commission for 400 kV overhead lines shows outage statistics of 0.126 hours per kilometer per year for overhead lines compared to 6.4 hours per kilometer per year for comparable underground cables. Using these statistics, assuming a 100-kilometre 400 kV transmission line, the average time where the overhead lines would be out of service is 12.6 hours per year compared to almost 27 days per year for underground cables. These outage statistics take into account both scheduled maintenance outages and unplanned outages. [18]

C. Proposed power supply system and topology for remote locations

The aim of this study has been to analyze the current power options in the oil and gas industry and develop power supply solution which will ensure high reliability at minimal total cost of ownership .The oil and gas industry is an industry with a continuous growth profile and this means that the power technology deployed must be scalable and as such it should grow as the load grows, it should be modular for ease of transportation and commissioning and should require minimum maintenance, have long life span and have minimal green house gas emission.

D. Topology

The topology of oil and gas production facilities shows a spread of sites across the Niger Delta and with this type of configuration the centralized power supply topology with one central station will require extensive cabling regardless of the transmission system utilized. This is why at most locations generators are used to provide power.

The decentralized approach still remains the best option but the use of generators leads to an increase in the generator footprint, an increase in the quantity of spares, green house gases, and the overall total cost. Thus the decentralized topology has to be combined with an efficient power supply technology.

E. Power supply technology

From a review of the power options, the combined cycle gas turbine is the power supply technology of choice and this is due to its advantages which include the ease of deployment, the availability of natural gas among others. Gas turbines have more power-generation cycle air per unit size and weight of machine than reciprocating engines and, consequently, are lighter in weight and more compact. These advantages have a potential of reducing gas turbine cost relative to reciprocating engines. The characteristics of gas turbines include clean emissions, good efficiency in some models, high reliability, low noise and vibration, compact installed footprint (sq ft/kW), a good match with exhaust-fired steam generation boilers, and infrequent maintenance and overhaul.

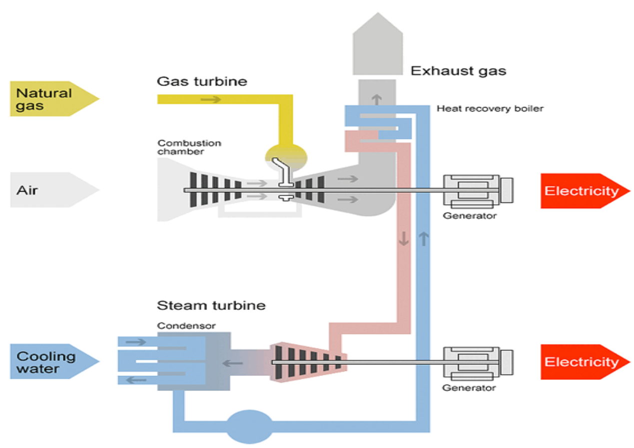

Fig 1: Combined Cycle Gas Turbine

Large turbines present a large single-shaft risk in the event of a failure. Multiple smaller gas turbines are often preferred because power supply availability is still high in the event of a failure of any one of the smaller turbines. Newer and larger gas turbines have also been known to have significant failure rates which results in the preference of older gas turbine models which may be available in the aftermarket [19]. Very small gas turbines, 3 MW or less, have been observed to be higher priced per kilowatt than competing reciprocating engines, due principally to low production volumes and low commonality of parts among multiple turbine models..

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In the 3-5 MW size range, gas turbines are manufactured in greater volumes, and their compactness and high power density begin to make them more economically competitive. In sizes above 5 MW, gas turbines have an inherent economic advantage over reciprocating engines in that they process more air per unit volume of machine, and their power generation efficiencies begin to approach those of reciprocating engines.

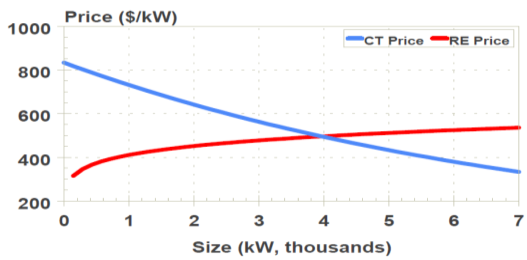

Fig 2: Capital Cost Comparison of Small Gas Turbine Products with Reciprocating Engine Products

Figure 2 shows the comparison between the capital costs of the small gas turbine (CT) with the reciprocating engine (RE). The data shows that the reciprocating engine has a price advantage over the gas turbine, this advantage is at small power output sizes but as the power output capacity increases the gas turbine outperforms the reciprocating engine generators [20].

F. Transmission Systems

The optimal transmissions system will comprise of both the underground and the overhead system. The configuration will be defined by the specific details of the location with more emphasis being laid on the overhead transmission and underground transmission being deployed where there is a high risk of overhead cable vandalization.

IV. CONCLUSION

A decentralized approach at supplying power to remote locations where locations close to each other are fed from a combined cycle turbine located in one of the facilities eliminates the need to have generators located physically on each site and it reduces the foot print, the green house gases and improves the overall reliability of the system as the modular nature of the turbine makes it possible to implement the redundancy and provides for rapid scalability.

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