Deploying a Solar Hybrid Technology in a Remote Oil and Gas Production Site

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The paper illustrates a project carried out - between 2012 and 2013 – during which the first eni solar/fossil hybrid power plant - without any grid connection and energy storage systems - has been designed, built, started up and successfully operated - in Egyptian Western Desert - over more than 8000 hours. The purpose of the project was to enhance the efficiency of oil production operation by integrating solar with diesel fuelled power production. A patented Power Management Module (PMS) optimizes power flows among the components of the plant, namely Photovoltaic (PV) panels, Diesel Generator (DG) and sucker rods electric engines. The plant has demonstrated reliability in hostile conditions and capability to save diesel fuel and reduce CO2 emissions up to 12 %. Further optimizations have also been identified, in order to enhance the performance of the whole system.

Key Words

Renewable energy, Solar energy, Hybrid power, Oil&Gas

1. Introduction

1.1 General

Oil & Gas (O&G) plants are often located in remote areas, in many cases lacking grid power connection and/or characterized by high availability of renewable resources. The progressive electrification of these areas - often too remote for grid extension - has mainly been achieved through the installation of decentralized generation units with Diesel Generator (DG). Systems running 100 % on diesel fuel have the advantages of using a proven and reliable technology, ensuring a theoretically dispatchable and on-demand production of electric energy 1). However, in a rural context, the ability to run a genset does not always match the availability of fuel to run the generator. The isolated and sometimes inaccessible conditions in rural areas makes the delivery of fuel very difficult, especially when necessary for a system powering more than 10 households for several hours a day. Local environmental impacts have also to be taken into consideration. For O&G business itself, the main drawbacks of DG technology concerns:

i. operation & maintenance:
   a. possible difficulty to transport and distribute fuel in isolated and inaccessible areas;
   b. very high maintenance cost;
   c. volatile prices of fossil fuel

ii. environment
   a. use of a non-renewable source
   b. Greenhouse Gas (GHG) emissions.

Regardless the relatively low energy intensity of O&G business, the exploitation of renewable resources is one of the most attractive alternative to continued over-dependence on conventional energy sources.

The rapid growth of industrialization and world population, which results in the increase in energy demand, depletion of finite fossil fuel resources, and climate change, has considerably increased the studies on renewable energy resources.

As a result, solar energy has - at least in principle - the potential to provide all of the world's energy demands due to the large amount of insolation available from the sun. Solar Photovoltaics (PV) technology has been considered a promising alternative for electricity supply, being solar

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energy inexhaustible, environmentally friendly – zero Green House Gases (GHG) emissions - and highly abundant in some O&G plants locations, as shown in Fig. 1 ²).

Nevertheless, solar energy presents some downsides, linked to:
- its intermittent availability
- its fluctuant radiation - changing between night and day and from place to place, due to geographic and climatic conditions
- its seasonal change of peak intensity – which is different between warm and cold months and dry and rainy season.

In addition, being solar radiation intermittent by-nature, PV stand-alone systems cannot satisfy load requirement on 24-h basis. Thus power systems running on 100 % renewable energy must rely on a battery to store energy so that electricity is available even when the renewable source is not for short periods of time (from a couple of hours to several days depending on the demand and battery capacity)³).

1.2 Hybrid systems

The constraints of DG technology and renewable energy sources can be partly overcome with the exploitation of both solar and fossil fuel feedstock, by using a hybrid power system ⁴).

A hybrid generation system integrates two (or more) jointly operated energy sources, able to guarantee a stable and reliable solution for serving different loads. Hybrid power systems comprise at least two principal generators: usually a conventional generator powered by diesel and a renewable energy source such as PV, wind, or even PV&wind ⁵).

Hybrid power systems typically rely on renewable energy to generate 75-99 % of total supply. The large share of renewables makes these systems almost independent and lowers the energy prices over the long term, and the diesel genset is used as a backup to assist in periods of high loads or low renewable power availability.

Several studies on the feasibility, performance, and economic viability of hybrid power systems have been conducted in different countries ⁶) such as Denmark, Spain, Germany, United States, China, and India. Hybrid power systems exhibit higher reliability and lower cost of generation than systems that employ only one source of energy.

The optimization of the hybrid solution is targeting the minimization of life cycle cost while guaranteeing reliable system operation, by governing the complexity given by uncertain renewable supplies, load demand and non-linear characteristics of components ⁷).

1.3 State of art of PV/diesel hybrid systems

The fluctuation of solar radiation and the continuous
O&G, which power request do not match on a 24-h basis. The use of a specific PV/diesel hybrid system makes it possible to accommodate seasonal resource fluctuations and reduce fossil fuels consumption.

A typical PV/diesel hybrid system consists of

- a PV component – equipped with inverter
- a DG
- a battery bank
- a connection to a grid.

The last two components are not always simultaneously present but almost one of them is included. Photovoltaic (PV) hybrid mini-grid systems are used to provide grid quality electricity to small islands and rural areas - where the grid extension is difficult and not economical - as the benefits and advantages of each technology complement each other. PV provides most of the electricity, while the genset balances the production when fluctuations of solar resource occur. PV hybrid mini-grid systems have unique environmental characteristics not found in other PV power systems, such as solar home systems (SHS) and grid-connected systems, because of the combination of PV, other power generation technologies, and energy storage. Integrating PV into a small diesel mini-grid power system can significantly reduce the system's greenhouse gas (GHG) emissions. GHG emissions reduction of a diesel power system when combined with PV are attributed to eliminating inefficient use of diesel generators, avoiding dump load, and supplementing diesel power generation with PV-generated power when conditions allow. PV/diesel minigrids have attracted significant attention also thanks to the mitigation of the fuel price volatility plus an expected operating cost reduction. The service quality offered by a hybrid system is higher than the quality obtained with traditional single-source generation systems. Many PV/diesel hybrid systems have been installed in African countries - well known for the high availability of solar radiation. Due to the fluctuations in the availability and maintenance of production sources - that invariably lead to a shortfall in supply - access to a reliable and stable supply of electricity is generally been low in those regions. Currently around 1.5 billion people worldwide live without access to electricity; and without a concerted effort, this number is not likely to drop. An estimated 80% of these people live in rural areas (see Table 1). Most of the projects implemented in recent years were pilot projects, mainly small hybrid systems in the range of 5 to 30 kWp. Senegal has been one of the most active African countries in the implementation of hybrid technology: about 25 hybrid power plants have been implemented (mostly in remote areas and islands in the Saloum Delta) and about 52 more plants are planned. In Rwanda, since 2007 several PV/diesel hybrid systems have been installed in 50 remote health centers while in Uganda various hybrid systems in the 5 kWp range have been implemented at rural district headquarters and a few industries; in the latter case, the deployment of this technology is still at the infant stage. In 2011, a PV/diesel hybrid power plant was implemented in Kenya and in 2012, two PB-based hybrid systems were implemented in Burkina Faso. Larger projects are also emerging, in particular in Mali. Starting from the implementation of a 216-kWp plant in 2011, numerous projects are planning to implement PV arrays in existing diesel power plants in some localities. The current status of the development of PV/diesel hybrid technology in Africa is schematically summarized in Table 2.

Members of the Alliance for Rural Electrification (ARE) have been involved in the implementation of hundreds of mini-grid projects around the world. The lessons learned from these projects provide insights on the key issues that must be considered to devise sustainable, replicable models for the scale-up of hybrid mini-grids. Implementing

| Country           | Population without access to electricity | 2006 | 2030 |
|-------------------|------------------------------------------|------|------|
| Angola            | 12.9                                     | 88   | 18   |
| Cameroon          | 14.2                                     | 78   | 17   |
| Chad              | 10.1                                     | 97   | 18   |
| Congo             | 2.9                                      | 78   | 4    |
| Cote d’Ivoir      | 11.6                                     | 61   | 14   |
| Equatorial Guinea | 0.4                                      | 73   | 0.4  |
| Gabon             | 0.9                                      | 70   | 1.2  |
| Mozambique        | 18.6                                     | 89   | 22   |
| Nigeria           | 76.6                                     | 53   | 66   |
| Sudan             | 26.9                                     | 71   | 30   |
| Total             | 176.9                                    | 65   | 191  |
The following objectives were pursued within the project:

(i) insert the concept of hybridization into O&G business, as a way for reduction of the emissions from process operations;
(ii) validate hybridization between photovoltaic technology and fossil power generation;
(iii) test PV performance in harsh environmental conditions (high temperature & dust);
(iv) reduce the fossil fuels energy intensity of the production activities.

Before this initiative, the power supply in Aghar field was guaranteed by a 300 kW diesel generator, with difficult and costly fuel supplying. Project scope was the installation of 110 kWp PV plant to support the power supply of a DG (200 kW) to three sucker rods (total power 113 kW). Basically, the previous diesel generator (300 kW) was substituted by a smaller one (200 kW) and the complementary energy supply up to 300 kW was guaranteed by solar photovoltaic panels (110 kWp). Several measurements were performed before the plant start-up, in order to assess the capacity of PV plant and DG. A patented Power Management System (PMS) was customized in order to manage the parallel power production of the two systems, namely controlling and balancing the alternate current (AC) from the DG with the discontinuous direct current (DC) from the PV plant (Fig. 3).

During daily hours the PV plant should supply part of the power required by the pumps while the DG should integrate the energy request; on the contrary, during the nightly hours the DG should supply the total load avoiding the pumps to stop. The expected behaviour of PMS is schematically reported in Fig. 4, where the two curves of PV and DG power productions sum up to supply a constant

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### Table 2: Current status of PV/diesel hybrid installation in Africa

| African Country | N° installed plants | N° foreseen plants | PV (kWp) | Diesel (kVA) |
|-----------------|---------------------|--------------------|----------|-------------|
| Senegal         | 9                   | 16                 | 5        | 11          |
| Tanzania        | several             | 1 + 10             |          |             |
| Rwanda          | ~ 50                | 3 + 6              | 16 + 20  |             |
| Mauritania      | 6                   | 15 + 25            |          |             |
| Uganda          | several             | 5                  |          |             |
| Kenya           | 1                   | 10                 | 80       |             |
| Burkina Faso    | 1                   | 1                  |          |             |
| Madagascar      | 2                   | 7-8                | 12-100   |             |
| Mali            | 216                 | 40                 | 5000     | 17          |
|                 |                     |                    |          | 1000        |

* “kWp”: kilowatt-peak;  
* “kVA”: kilo-volt-ampere;  
* “÷”: in the range
### 2.2 eni PV/diesel hybrid plant

The new designed hybrid fossil/solar pilot plant allows sharing power production between the PV plant and the diesel generator, balancing the AC absorbed by the wells pumping systems and the DC of the PV plant. Solar plant is characterized by:

- Si-Multicrystalline module (EN20/220);
- Module Rated Power: 220 W;
- Module efficiency: 13.44%;
- Peak Power: 110 kWp;
- Solar irradiation: 2210 kWh/m²y;
- Area: 2500 m² (≈ 55mx45m);
- 12 inverters;
- 9.24 kW per array.

Hybrid plant installation and construction was concluded in December 2011 and Start-Up Phase began with the Commissioning activities in 2nd quarter of 2012. PMS – designed to be a simple and friendly tool - is the heart of the system. It is able to properly work in three possible configurations:

- Day Light Configuration, characterized by all PV fields and the Diesel Generator in service;
- Night Time Configuration, characterized by no PV fields and the Diesel Generator in service;
- Emergency Configuration, characterized by no PV fields and the Diesel Generator in service.

Night time configuration means the plant operation during the night; emergency configuration means the plant operation when something goes wrong in PV plant. Thus, the emergency configuration is included in the PMS design in order to ensure a 24-h energy supply. As a result, PMS controls the Diesel Generator engine as a function of the variable solar power generation and the cyclic behavior of sucker rods electric engines. During the daily hours, the PV supplies a seasonal percentage (12-30 %) of the power required. Instead, during the night the diesel generator supplies the whole load. The solar hybrid plant has been successfully tested over more than 8000 hours. The test (2012-2013) has reached the project goal, by validating:

- the energy supply to the pumps in order to have a constant oil production;
- the reduction of fossil fuels energy intensity of O&G production chain;
- Diesel saving;
- CO₂ emission reduction.

According to design conditions, DG and PV power production are completely complementary from night to day, as shown in Fig. 5. The performance of the hybrid plant in the cold season is reported in Table 3, where the main parameters have been quantified: the diesel saving and the reduction of CO₂ emissions are about 12 %.

### 3. Conclusion and Way Forward

#### 3.1 Conclusion

To our best knowledge, the first solar-fossil hybrid plant to load sucker-rod pumps in a remote location has been successfully installed and operated for more than 8000 h. The test has validated some important properties of the hybrid system, especially its robustness and reliability in a remote, unmanned area, without any grid connection, harsh climatic conditions (high daily temperatures, sudden temperature decreases during night, presence of sand) and without a battery bank. In addition, the PV/diesel hybrid plant has sustained constant oil production with the
reduction of diesel consumption (15,000 liters of diesel saved per year) and CO₂ avoided emissions (40 tons per year).

3.2 Way forward

The demonstration of the system has been successfully concluded and the technology is now ready for further deployment on a worldwide basis. The test has also allowed identifying additional optimizations of the system, currently in the phase of engineering, which are expected to:

- further enhance diesel savings and CO₂ avoided emissions;
- optimize the energy management of the power plant, improving the patented PMS technology;
- better exploit the solar energy;
- optimize the load profile of the DG lowering maintenance and fuel costs (possibly through the installation of a couple of DGs of small size).

Furthermore, the addition of an electric accumulator may be helpful for peak shaving the pumps, thus ensuring a regular power request by the generators. Batteries add stability to the system by storing the energy for peak consumption when there is insufficient production from renewable sources (i.e., to offset lack of solar power during nighttime hours). The most common type of battery used in a hybrid micro-grid is the lead-acid, deep cycle type, although many models are available in the market. SuperCapacitors (SC), also known as Ultracapacitors, seems to be the most suitable storage systems for the specific case of eni PV/diesel hybrid plant in the Western Egyptian Desert.

As showed in Fig. 6, SCs have a Power density higher (1-2 order of magnitude) than conventional batteries. This makes them convenient for our purpose, where high Power values are necessary. The Energy density is lower (1-2 order of magnitude) than conventional batteries, meaning that SCs are useful for the short period (peak shaving) and not for supplying energy during the whole night.

References

1) Alliance for Rural Electrification (ARE), Hybrid mini-grids for rural electrification: lessons learned, http://www.rutalelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf, (2011)
2) Free Download of Solar Radiation Maps: Africa and Middle East - Global Horizontal Irradiation (GHI), http://solargis.info/doc/postermaps
3) Panapakidis, I. P.; Sarafianos, D. N.; Alexiadis, M. C., Renewable and Sustainable Energy Reviews, 16, 551-563 (2012)
4) Adaramola, M. S.; Paul, S. S.; Oyewola, O. M., Energy for Sustainable Development, 19, 72-82 (2014)
5) Barbieri, J.; Simonet, E. Renewable Energy for Unleashing Sustainable Development, 5, 133-161 (2014)
6) Celik, A. N., Energy Conversion and Management, 43, 2453-2468 (2002)
7) Ashok, S., Renewable Energy, 32, 1155-1164 (2007)
8) Report IEA-PVPS T9-13:2013, Rural Electrification with PV Hybrid Systems, Overview and Recommendations for Further Deployment
9) Adeoti, O.; Oyewike, B. A.; Adegbuyega, T. D., Renewable Energy, 36, 155-161 (2001)
10) Afgan, N. H.; Carvalho, M. G., Energy Policy, 36, 2903-2910 (2008)
11) IEC, Recommendations for small renewable energy and hybrid systems for rural electrification Part 4: System selection and design, (2005)
12) Storage wars: batteries vs. supercapacitors, http://www.maxwell.com/search/?zoom_query=supercapacitor