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RiPASSO ENERGY

Ripasso Energy
THEnergy
study

A hybrid solution
with concentrated solar power
(CSP)
and fuel
for baseload mining operations

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Content

1 Introduction

Energy consumption in mining is typically high. Approximately 20% of the energy that the global industry consumes and around 10% of world energy consumption is used for extraction and processing of mineral resources.[1] From the mining industry's perspective, energy is also an important cost factor. Normally 20-40% of a mine's operating costs are expenditures for energy. Additional aspects are security of electricity supply, as we see blackouts in the electricity grids of many developing countries and mine outages due to issues with the diesel provision of off-grid mines.

Renewable energy solutions have become increasingly interesting for mines. Falling costs have been a main driver over years for solar and wind energy solutions. One of the main barriers at this stage are intermittencies of solar and wind power plants. Already today there are quite a few examples of mines having integrated electricity from renewable resources into their energy mix.[2] In off-grid contexts, the business case for so called solar diesel hybrid installations is particularly advantageous. One of the main issues is, however, that a high renewable energy share requires storage solutions, which are rather expensive today.

That means for the diffusion of renewable energy solutions at mine sites, that we see some progress, but costs make it very hard for mining companies to run their operations 24/7 fully on renewable energy or with a high share of renewable energy. For mines, which are taken of the grid due to an unacceptable quality of the power from the grid, we see that modern gas-fired units are preferably used – especially if there is a good supply of gas. Typically, it is very difficult to combine these on-site gas-based power generation units with renewable energy.

Ripasso energy is a Swedish manufacturer of a solution that combines two alternative power sources to produce base-load electricity: solar and fuel. A high share of renewables can be achieved by using CSP as a renewable base technology. If the weather conditions do not allow for enough heat from the CSP system, additional heat can be provided from a fuel-fired heater. The integrated system allows for generating base-load electricity in a very cost-effective way. One of the main advantages is that many different kinds of fuel can be used: anything from natural gas, LNG, LPG, biogas, industrial off gas to diesel.

The study analyses the Stirling engine based system and its suitability for mining applications. It covers aspects as baseload capabilities, robustness of the system, flexibility regarding fuel types and land and water use.

[1] Conti, John et al., International Energy Outlook 2013 (US Energy Information Administration, 2013); http://www.eia.gov/forecasts/ieo/pdf/0484(2013).pdf (retrieved 02/01/2016).

[2] See database of THEnergy platform for "Renewables and Mining" at http://www.th-energy.net/english/platform-renewable-energy-and-mining/database-solar-wind-power-plants/.

2 Developments of renewable energy and mining

2.1 Mining industry

Many mines are located in extremely remote sites, which is problematic for the energy supply. Grid connection is often either expensive or not feasible at all. Typically, these remote mines are powered with on-site power plants, very often consisting of diesel gensets.

Factoring in related costs such as transport, theft and taxes, diesel is a very expensive source of power. In addition, diesel is dirty, not only with respect to greenhouse gases, but as well regarding local emission of hazardous off-gases.

With the development and cost digression of renewable energy more and more solutions arise that can contribute to reduce the use of conventional energy for powering off-grid mines.

The recent mining down-cycle has slowed down the diffusion of renewable energy solutions at mine sites. Recently, more and more see in renewable energy an opportunity to reduce their operational costs and improve their competitive position.

2.2 Renewable energy industry

Renewable energy has turned in recent years into an increasingly important electricity source. As prices for most renewables are falling constantly, it can be expected that this trend will continue. Another factor supporting this assumption are the decisions at the UN Climate Conference in Paris which took place in December 2015. The Paris climate warming limits can only be achieved through a substantial use of renewable energy.

Renewable energy includes solar, wind, hydro, biomass, biogas, tidal, wave and geothermal energy.

In extremely sunny regions such as African mining countries the sun is often the best energy source. In these areas, wind is not always strong enough and water not abundant enough for economical renewable energy plants.

Photovoltaics is the most widespread type of solar energy. There are already some large grid-connected PV installations that power mines such as in Chile. For off-grid mines, some first installations have been built in which solar reduces diesel consumption. As solar energy is an intermittent resource, PV cannot power a mine on its own. In theory, energy storage in combination with a larger PV plant could fully power mine sites in many locations. However, this is really a theoretical case, because the costs are currently still too high. So it is no surprise that solar plus storage is so far at most used to switch off the diesel engine during daytime on sunny days.

CSP is another solar technology which has been applied in various large scale installations. In general, in CSP plants the solar irradiation from a large area is concentrated through mirrors or lenses to a small area. Concentrated sunlight is converted to heat, which is used to run an engine – normally a steam turbine. Typically, CSP is only economically viable in large scale installations.

RiPasso Energy has developed a system that consists of smaller units in which the heat is then used to power a Stirling engine. The system is a so-called hybrid system, because it combines

two different energy sources. When the sun is not strong enough to provide sufficient power, the heat can also be generated through traditional burners. One of the main advantages of the system is that it can provide baseload energy with a high share from renewable resources – especially if biogas is used. Even without biogas the renewable energy share is typically higher than in so-called PV-diesel hybrid systems.

3 Ripasso Stirling Hybrid system for robust baseload power generation

3.1 The technical background

The Ripasso Stirling Hybrid system is a hybrid energy solution, as it generates electricity from two different energy sources. Solar irradiation is collected through a concentrated solar power (CSP) component. The system allows for extremely high conversion efficiency. The second energy source is diesel or gas – anything from natural gas, LNG, LPG, biogas, industrial off gas to different kinds of diesel. Combining solar energy with a flexible energy source makes the Ripasso Stirling Hybrid system baseload ready.

The system consists mainly of:

- Parabolic concentrator
  - o Dish structure
  - o Mirrors
  - o Engine support
- Tracking system
  - o Tracker structure
  - o Actuators
  - o Control cabinet
  - o Concrete foundation
- Power Conversion Unit
  - o Heat receiver
  - o Stirling engine
  - o Alternator
  - o Cooler

The parabolic concentrators are made of parabolic glass mirrors. The purpose of the parabolic dish reflector is to collect the solar radiation and to concentrate the energy onto the thermal receiver in the Power Conversion Unit.[3]

The radiation is absorbed in the receiver, and heats the working hydrogen gas of the Power Conversion Unit to a temperature of approximately 720 °C. The heat is converted into mechanical energy by the engine. An alternator, connected to the crankshafts of the engine converts the mechanical energy directly to grid quality three-phase electricity.

To keep the concentrated solar energy focused on the heat receiver, a high precision dual axis tracking system follows the sun throughout the day.[4] The electrical output of the system is

[3] In order to simultaneously achieve a high energy concentration ratio and a uniform thermal distribution of energy over the heat receiver, it is important to have a highly stable dish structure regardless of elevation angle and wind conditions. The concentrator in the Ripasso Stirling Hybrid system has been designed, analyzed and tested carefully to have a very stiff and light weight steel structure that keeps the shape of the parabolic concentrator firm over the entire elevation span and under all wind conditions. Mirrors, consisting of light weight, high precision sandwich elements with a thin glass mirror surface, are mounted on the parabolic concentrator steel structure.

[4] The actual solar position is constantly calculated to fine-tune the position of each concentrator. Ripasso Energy has developed a proprietary monitoring system that determines the actual real time position of the concentrated energy spot. The tracker actuators are then set to regulate the spot position to optimize

proportional to the sun's radiation, and at a DNI (Direct Normal Irradiance) of 960 W/m2 the Ripasso Stirling Hybrid CSP unit will produce a typical output power of 31.5 kW electrical energy. The total solar to grid quality efficiency of the system is well above 30%. The generation data for a Ripasso Stirling Hybrid plant in South Africa's Kalahari Desert even goes well beyond that. 32% of the sun's energy hitting the mirrors is converted to electricity. This means that 32% of the available solar energy is converted to grid quality electrical energy. In addition, the CSP system is designed as a balanced system to minimize parasitic losses.

Power Conversion Unit (PCU)

In the Power Conversion Unit, the CSP and the flexible fuel fired unit are combined. The Stirling cycle is the most efficient thermodynamic cycle to transform heat into mechanical energy.[5] The engine works without internal combustion, and fully depends on an external heat supply. Its high efficiency makes it ideal for transforming heat into mechanical energy.

In the engine, hydrogen gas is constantly being heated and cooled. Due to expansion during heating, and contraction during cooling, the gas sets the piston in motion. The pistons are connected to crankshafts that drive an alternator to produce electrical energy. The efficiency of the Stirling engine increases with a temperature difference between the hot and the cold side, which makes it ideal for solar applications where very high temperatures can be achieved.

The Stirling engine

A Stirling engine is the key component of the Power Conversion unit. Stirling engines can have broad significance and technological advantages for distributed renewable energy applications.[6]

Stirling engines are combusted externally and modern versions of this engine have a closed internal gas cycle.[7] Stirling engines have a high efficiency compared to steam engines.[8] They are also capable of quiet operation and can use almost any heat source. The heat energy source is generated external to the Stirling engine rather than by internal combustion as with the Otto cycle or Diesel cycle engines. As there is no internal pollution due to combustion, the life length of pistons, bearings and sealing is very long.

Because the Stirling engine is compatible with alternative and renewable energy sources it could become increasingly significant in light of concerns such as depletion of oil supplies and climate change.

Stirling engines use alternate heating and cooling of an enclosed gas to move pistons. In the simplest version, the Stirling engine is a sealed system with an expansion cylinder and a compression cylinder, filled with a working gas. The pistons of these cylinders are connected to one crankshaft. If now the working gas in the expansion cylinder is heated it will expand due to

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the working conditions for the Power Conversion Unit of the energy distribution over the thermal receiver surface. Using this Ripasso Energy proprietary closed loop tracking system enables the use of low precision and inexpensive sensors and control actuators and still achieves state of the art accuracy.

[5] Stine, William B., Richard B. Diver, (1994), The Dish/Stirling Solar Electric Generating System, Sandia National Laboratories.

[6] He, M., Sanders, S. (2016), Design of a 2.5kW Low Temperature Stirling Engine for Distributed Solar Thermal Generation, Online Working Paper American Institute of Aeronautics and Astronautics, (Date: 01.02.2016).

[7] Snyman, H., Harms, T.M. and Strauss, J.M. (2008), Design analysis methods for Stirling engines, Journal of Energy in Southern Africa, Vol 19 No 3.

[8] Backhaus, S., Swift, G. (2003). "Acoustic Stirling Heat Engine: More Efficient than Other No Moving-Parts Heat Engines". Los Alamos National Laboratory.

increasing temperature, and the piston will be pushed down by the pressure and induce power. Part of the power is used to push the hot working gas from the expansion cylinder into the compression cylinder. Once completely in the compression cylinder, the piston will return due to inertia of the crankshaft, and the working gas is compressed at low temperature. The gas is then pushed back into the working cylinder. Overall the expansion of the hot gas in the expansion cylinder delivers more energy than is needed for the compression of the cold gas in the compression cylinder. This energy can be used to run an electric alternator directly connected to the crankshaft of the engine.[9]

Hybridization Components

To enable 24/7 operation of the Ripasso CSP technology, a hybridization capability is added to the PCU. This capability enables the Stirling engine to be heated up by burning fuel. The capability can be adapted to multiple fuels such as natural gas, biogas, CNG, LPG, LNG, furnace gas and diesel.

Cooling system

The Stirling cycle efficiency depends on the temperature difference between the hot and the cold side. That is why it is important to have an efficient cooling system. The Ripasso Stirling Hybrid system uses a standard cooler, optimized for the application, mounted on the tracker structure. Dissipated heat is removed from the Stirling engine working gas through the gas cooler and transferred to the cooling system in closed water based system.[10]

Efficiency of fuel conversion

The Stirling cycle is the most efficient thermodynamic cycle to transform heat into mechanical energy.[11] It is no surprise that the Ripasso Stirling Hybrid is highly efficient with a fuel conversion ratio of 35%.

3.2 Baseload optimization through integration of intermittent solar and flexible fuel solutions

One of the main disadvantages of most renewable energy types is their intermittency. Typically, the output is determined by external factors such as solar irradiation, wind speed or water flow. In industrial applications, the electricity consumption in industrial applications is driven by production output related factors. Especially in mining we see very often 24/7 operations which require a dispatchable electricity supply.

Ripasso Energy has developed a solution that fully integrates two energy sources and allows for a highly efficient use of energy. In traditional hybrid system, two fully functional independent systems are set up and then balanced according to the load of the electricity consumers.

In the Ripasso Stirling Hybrid solution, however, key components of the system are used for both energy sources. The heat source is either solar radiation or fuel combustion. With the exception of the fuel and air injection systems, all other components of the PCU are utilized in both cases.

[9] For an introduction of the Stirling principle see e.g. Senft, J.R. (1993), Ringbom Stirling engines. New York: Oxford University Press.

[10] It is a closed system, filled with water and inhibitor at commissioning. There is no water consumption during operation. The fan is speed controlled to keep the parasitic losses to a minimum.

[11] Stine, William B., Richard B. Diver, (1994), The Dish/Stirling Solar Electric Generating System, Sandia National Laboratories.

3.3 Robustness of the system

The Ripasso Stirling Hybrid system is extremely robust and can provide baseload power in a very reliable way. A unit consists of an autonomous 33 kW system that operates independently from other units. In case a single unit fails, the other modular units will still provide full power.12

The Stirling engine has many advantages regarding maintenance and reliability. The technology is proven with years of performance in the navy. The design of the Ripasso solution originates from Kockums, Sweden, who have developed and manufactured Stirling engines for submarines for a long time. A lot of effort has been spent to get a robust design with an extremely durable sealing system, further developed by Ripasso Energy. Combustion takes place outside the engine itself. Since there is no internal pollution due to combustion, the life length of pistons, bearings and sealing is very long.

Robustness also prevails regarding the selection of components in the Ripasso Stirling Hybrid system. The electrical control system of the tracking system is designed for a high safety level with built in redundancy, and the system includes an internal battery backup system that enables movement without grid connection. Performance degradation is negligible and the lifetime expectation of the system is 25 years or more. Additional advantages are very long service intervals and low O&M costs.

3.4 Flexibility regarding fuel types

One of the main advantages of Stirling engines is that they can use heat from various sources. The advantage becomes obvious in the Ripasso Stirling Hybrid solution where CSP and fuel is used for providing the heat.

The advantage goes even one step further because many different kinds of fuel can be used in the system. For example:

- natural gas
- CNG
- LNG[13]
- LPG[14]
- biogas
- industrial off gas
- coal methane gas
- or even diesel

No single fuel would be superior for all locations and objectives. For mine sites in developing countries and at remote locations, the supply side is of particular importance. Flexibility regarding the selection of fuel during the lifetime of the power plant might also have direct consequences on the availability of electricity. The ability to change the input fuel short-term

[12] On a malfunction or a grid loss the tracking system will automatically take the Ripasso Power Converter out of the concentrated solar spot. The system is connected via a TCP/IP network to a control center at site level, where the system is monitored and controlled on a higher level i.e. each unit can be set in operation, stopped, forced to wind safe position etc. The control center also includes a solar radiation measurement system and weather station. The software supplied by Ripasso Energy also enables the system to be remotely controlled.

[13] Liquefied natural gas

[14] Liquefied petroleum gas

might avoid production losses if a shortage of a particular kind of fuel exists during certain periods.

The usage of biogas allows a Stirling Hybrid system to run 100% on renewable energy and to have an optimal CO2 footprint. This could actually become an important factor in the near future if additional CO2 taxes or CO2 certificate schemes are introduced or the price in the already-existing ones increases. The Stirling Hybrid system provides the flexibility for mining companies to be prepared for such measures.

The usage of industrial off-gases is another interesting aspect which merits a closer look. In combined mining & metal processes industrial off-gases are often burned and their energy content is not used. This has two downsides:

(1) Energy that could be used for power generation is lost and other resources have to be used to provide the power
(2) The off-gases already have a negative impact regarding CO2 emissions – even if they are not used for power generation.

Feeding off-gases into a Stirling Hybrid solution does not increase the CO2 footprint of the plant and generates additional cost savings.

3.5 Efficient land-use and water

The Ripasso Stirling Hybrid solution has advantages regarding land and water use that can be interesting as well for mining companies.

Especially for open pit mines, the solar power solution might take some flexibility regarding the extension of the mine in the future. This issue can be minimized by improving the land use of a solar power plant. If the solar power plant is highly efficient, less land is used to generate the same output power. In a South Africa based power plant delivered by Ripasso Energy, a world leading efficiency of 32% has been demonstrated since November 2012. The land use is minimized with the Stirling Hybrid solution to approximately 2.5 hectares/MW. This figure is in the same range as the best values for optimized PV-diesel installations.[15]

Many mine sites are located in regions with limited water resources. It is important to mention that the Stirling Hybrid solution uses a cooling system based on a closed water system that exchanges dissipated power with the ambient air, filled with water and inhibitor at commissioning. There is no water consumption during operation. This is another advantage of the Stirling engine in comparison to steam turbines. The main demand for water within steam turbine based applications is for condensing steam. Depending on the cooling system, water consumption can be relatively high. This can cause additional problems at remote mine sites.

The only water that is used during the operation of a Stirling Hybrid System is water for cleaning the mirrors. Especially in dusty surroundings this is needed to avoid loss of performance due to soiling. The cleaning is done using water with standard high pressure equipment that reduces the water consumption to a minimum. The Ripasso design allows for easy access to the mirrors during cleaning.

[15] Ong, Sean et al. (2013), Land-Use Requirements for Solar Power Plants in the United States.

4 Summary and outlook

The study shows that energy is an important topic for mining companies. Especially at remote sites or in unreliable grids onsite energy generation presents a large benefit for mines. Renewable energy has developed various solutions in the last years that fit very well to special requirements of mines. Renewable energy can contribute to lower electricity costs for many mine sites and improve the carbon footprint. Ripasso Energy has developed a fully integrated modular solution that makes solar energy base load ready.

The Ripasso solution is innovative, as it combines solar with various possible fuels, mainly gases, to provide baseload power even during periods when there is no solar irradiation. The solar and fuel components are complementary by providing the heat for the same Stirling engine.

The combustion is external to the Stirling engine, which has many advantages regarding maintenance and operations of the power plant. The modular design allows for scalability in 33 kW steps and ensures a robust power generation, as the different power modules operate completely independently. The modularity of the Stirling Hybrid solution reduces the probability of production losses due to power outages to an absolute minimum.

In remote locations, the supply of conventional energy is often very critical and costly. An additional advantages of the system is that it can combine solar power with many different secondary fuel types such as natural gas, LNG, LPG, biogas, industrial off gas, coal methane gas or diesel. The Stirling Hybrid energy system can change from one fuel type to the other with relatively little effort and is thus prepared for different future energy options.

Finally, the study identifies advantages regarding the use of land and water. Both can be very critical for mining operations at remote locations.

The Ripasso Stirling Hybrid solution fits very well to the requirement of mining companies whenever reliable baseload power is required. The Stirling solution is proven in naval applications. The first contracts for commercial projects are signed for a power plant in Namibia which is to be commissioned in 2016.

For evaluating the commercial strength of the solution it is important to indicate that Ripasso Power belongs to Ahlström Capital, a family investment company that continues the heritage of Ahlström corporation established in 1851. More than 27 000 employees are employed in portfolio companies globally.

The Ripasso Stirling Hybrid solution can increase the competitiveness of mining companies, especially for baseload applications in regions with high solar irradiation where the Ripasso Stirling Hybrid technology typically has an advantage in comparison to other renewable energy sources. It is also in these regions where the business case for solar is generally best.

About Ripasso Energy

Ripasso's products are highly efficient, renewable and reliable solutions for electricity generation, delivered to utility companies and power systems suppliers in Southern Africa. Ripasso Stirling Hybrid is based on well proven technology further optimized with high quality, simplicity & robustness in order to provide cost efficient solutions with low maintenance for harsh environments.

About Dr. Thomas Hillig Energy Consulting ("THEnergy")

THEnergy assists companies in dealing with energy-related challenges. Renewable energy companies are offered strategy, marketing and sales consulting services. For industrial companies THEnergy develops energy concepts and shows how they can become more sustainable. It combines experience from conventional and renewable energy with industry knowledge in consulting. In addition to business consulting, THEnergy advises investors regarding renewable energy investments in changing markets. It is also active in marketing intelligence and as an information provider in select fields, such as renewables and mining, through the platform th-energy.net/mining or renewables on islands through the new platform th-energy.net/islands.

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