Reducing Energy Costs and Environmental Impacts of Off-Grid Mines

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***Abstract*— Power systems in mining and other industries are seeing a major structural transformation as renewables and energy storage costs continue to decline and global pressure to mitigate carbon dioxide remains strong. For off-grid mining renewable and storage technologies present an ideal opportunity not only to improve the mine's environmental footprint, but also to reduce energy costs while improving power quality. This paper shows the off-grid business case for a mining site relying on diesel generators for electricity. Four scenarios of different battery energy storage systems (BESS) and solar PV configurations have been simulated and related econometric metrics are discussed. The microgrid solution with BESS and solar PV has the lowest fuel consumption and Levelized Cost of Energy (LCOE) among other scenarios. The battery is providing the required spinning reserve that yields to turning off diesel units. The sensitivity analysis shows that the main drivers for LCOE reduction are diesel price and installed PV prices**

Keywords-component; mining industry, diesel generator, microgrids, battery energy storage systems, spinning reserve.

I. INTRODUCTION

To date, diesel generation has a good track record in providing a reliable and proven power to off-grid mines. This traditional approach, however, also creates some well understood challenges:

- Power from diesel generators are high cost compared to energy supplied by a network
- Changes in diesel prices are difficult to predict and expensive to hedge long-term
- Additional carbon taxes on fossil fuels are likely to increase future diesel price
- Diesel deliveries can lead to logistical issues and additional storage expense
- Electrification of mines and mobile plant increases demand over time

For off-grid mines operating in remote locations, the cost of electricity can reach 300 USD/MWh and consume up to 15% of mining revenues. Lowering energy costs will not only increase viability of mining operations today but also help future proof them against rising fuel costs.

Renewables and energy storage systems have already proven themselves as an effective solution for generating high quality electricity [1]. Following the successful completion of numerous such projects, the focus is now on developing unsubsidized, profitable business cases that effectively reduce fuel dependency. Here a modular approach allows the hybridization process to be started with a smaller investment in either renewable energy or storage that can later by extended, for example, as framework conditions such as diesel fuel prices change.

The typical stakeholders in the path to hybridization include: the mining company itself, the project developer (internal or external), the financing company (debt versus equity), the EPC (Engineering, Procurement, and Construction), the technology suppliers and the O&M provider. Various business models among these players are possible, however an essential element across all models is the involvement of technology suppliers at an early stage of the design. Additionally, stakeholder management and commercial integration remains key in delivering a successful hybridization project.

To test the viability of storage plus renewables for brown field mining sites, we consider four scenarios that are optimized using HOMER Pro microgrid modeling software. The benefits compared include:

• Fuel saving (and associated reduction in CO2 emissions & maintenance costs)

• Reduced Levelized Cost of Electricity (LCOE) with an attractive Internal Rate of Return on investments (IRR)

• Improved power quality

Four Scenarios are analyzed to evaluate the microgrid solution for the mining industry. The business case is described in section II, then the results and sensitivity analysis are discussed in section III, and conclusion is stated in section IV.

II. BUSSINESS CASE STUDY

The following scenarios consider various options for upgrading an off-grid mining operation with an energy storage system and / or a solar PV power plant. In total, four different scenarios are simulated and optimized to provide the lowest LCOE while achieving a minimum 10% IRR. The simulated scenarios include:

• Base case – Diesel: Pre-existing diesel generators continue to supply power and operating reserve

• Diesel + BESS: BESS utilized to remove need for operating reserve as well as optimize the efficiency of the generators

• Diesel + solar PV: Solar PV plant without energy storage used to deliver fuel savings

• Diesel + BESS + solar PV: BESS now combined with solar PV to deliver improved diesel generator operating efficiency as well as increased solar PV integration

For all 4 scenarios, we assume a mine with a 24/7 average load of 5 MW with hourly (but no seasonal) variation. The peak load can reach a maximum of 6.3 MW. In addition to the load requirements, the minimum operating reserve of the power system is 1.2 MW - an entire generator's capacity. The generators are all a standard model benchmarked on a leading manufacturer. Each generator has a capacity of 1.2 MW and operates on diesel fuel. The minimum load ratio for the generator is 30% and the minimum run-time is 2 hours.

This case study only considers new investment costs for the hybrid system as the generators are already installed on-site. For comparing each scenario an all-in fuel price of 1 USD/L is used, which is inclusive of transport, taxes etc. The total CAPEX of the installed solar PV system, including inverter, is 2 USD/Wp. In the simulation, the assumption for the solar irradiation is 5 kWh/m. To account for cloud cover 75% of the PV's power output must be covered in the operating reserve by the diesel generators or the BESS. The BESS uses Li-ion batteries and the roundtrip efficiency is assumed to be 90%. The assumptions are rather conservative in that they reflect, for example, higher construction costs at remote locations.

To assess LCOE and annualized costs, a 10% nominal discount rate is applied and a project lifetime is assumed to be 10 years, after which the solar PV modules, BESS and inverter are assumed to have a salvage value worth a third of the original purchase price. The HOMER Pro simulation tool combines the operating requirements (e.g., electrical and thermal demand, reserve requirements), to the physical assets (existing + additional) and key financial inputs (including investment, maintenance and replacement costs). Based on this, the HOMER Pro runs generation dispatch analysis for a range of scenarios, and determines the most economic system to meet the operating requirements.

The scenarios are simulated in Homer Pro and results are shown in Table I. The sensitivity analysis for different drivers are shown in Table II and Table III.

III. Results and Discussion

The base case refers to the mine continuing to run the existing diesel generators as before. Six diesel generators with a 1.2 MW nominal rating are required to serve the load with one additional generator always online as an operating reserve in case any one of the six generators unexpectedly fails. All generators operate in proportional load sharing which means each generator has the same capacity factor. The sum of spinning reserve7 carried by all generators allows one generator to trip or the load to instantly increase without the need for load shedding. This operation leads to additional O&M costs from additional generator runtime as well as lower fuel efficiency due to a lower capacity factor. At a diesel price of 1 USD/L, the base case has annual fuel costs of 11.6 MUSD and maintenance costs of 1.7 MUSD which results in an average annual operating cost of USD 13.3 MUSD and a LCOE of 304 USD/MWh. The following scenarios are benchmarked to the base case.

A BESS (e.g., ABB PowerStore) is able to replace the diesel generator that serves the 1.2 MW operating reserve requirement as well as smooth certain demand peaks with battery storage (an additional 0.9 MW) thereby delaying or avoiding the start of a generator. Total investment costs for a BESS solution meeting the modelled size requirements of 2.1 MWh/1.7 MW are estimated to be 1.5 MUSD. The simulation output shows a fuel reduction of 0.16 ML and an annual cost savings of 0.4 MUSD leading to a payback period of 2.7 years and IRR of 37%. The LCOE is reduced from 304 to 295 USD/MW, mainly due to a reduction of generator maintenance costs.

TABLE I. Simulation results for four scenarios

	Base case-Diesel + Grid	Grid + Diesel + BESS	Grid + Diesel + PV	Grid + Diesel + BESS + PV
Fuel Consumption (kL)	11.6	11.4	9.8	8.4
Investment ($M)	-	1.5	9.0	19.5
IRR (%)	-	36	16	16
LCOE ($/MWh)	304	296	289	273
Payback (years)	-	2.7	5.2	5.2

TABLE II. Sensitivity analysis for key driver of LCOE savings

Driver	Low Case	Base Case	High Case	Low Case LCOE impact (%)	High Case LCOE impact (%)
Diesel price (USD/L)	0.5	1	1.5	-6.5	6.5
Installed PV price ($/Wp)	1.5	2.0	2.5	4.0	-3.5
Solar irradiation (kWh/m2/day)	4	5	6	-3.7	2.7
Installed battery price excl. converter ($/kWh)	300	400	500	0.4	-0.5

TABLE III. Microgrid LCOE reduction sensitivity to Diesel and PV prices

Diesel price ($/l) \ Solar PV price ($/Wp)	1.5	2.0	2.5
1.5	27%	20%	15%
1.25	21%	15%	11%
1.0	17%	11%	7%
0.75	11%	7%	4%
0.5	5%	4%	4%

TABLE IV. Microgrid fuel reduction sensitivity to Diesel and PV prices

Diesel price ($/l) \ Solar PV price ($/Wp)	1.5	2.0	2.5
1.5	43%	41%	29%
1.25	41%	29%	27%
1.0	30%	28%	23%
0.75	28%	23%	6%
0.5	19%	1%	1%

This diesel plus solar scenario pursues an alternative path to hybridization initiated by a PV-only upgrade without energy storage. Here we replace diesel fuel by cost competitive solar PV. In this configuration, the integrated solar PV system is limited by the minimum loading of the diesel generators in combination with their step load capabilities. As the ideal solar PV generation capacity exceeds the step capability of the generators, the PV capacity is limited to 4.5 MW. Installing this PV system requires a CAPEX of 9.0 MUSD. As a result, the LCOE is reduced from 304 to 289 USD/MWh with fuel savings the primary value-driver for this system at 10 times the level of the diesel + BESS scenario. The payback time is 5.2 years and the IRR is 16%, somewhat lower than the diesel + BESS scenario that had an IRR of 36%.

In diesel plus solar plus battery scenario, the two technologies are combined. An investment of 19.4 MUSD is required to add a solar PV system of 8.1 MWAC and a BESS of 4.4 MWh/4.0 MW. The solar PV plus BESS system reduces annualized costs from 13.3 MUSD down to 12.0 MUSD, a saving of 1.3 MUSD annually, primarily due to 3.2 ML of fuel reduction. The solution offers maximum value stacking from the storage component as it substitutes the diesel generator as operating reserve, smoothing demand peaks, and also allowing maximum solar PV integration. The investment returns an IRR of 16% with a payback period of 5.2 years and is easily the best option from the perspective of lowering LCOE. In this case, an advanced BESS has the additional benefit of effectively managing the fluctuations caused by renewable energies, e.g., cloud cover, while continuing to deliver high quality power.

The transformation to a solar PV + BESS microgrid can be achieved through incremental hybridization investments thereby lowering investment risk and effectively responding to changing market conditions such as increased delivered fuel price or decreased solar PV price. Depending on the business objectives, it is possible to either maximize investment IRR by adding only a BESS, or alternatively reduce diesel consumption and associated carbon emissions and delivery risks by investing in a solar PV + BESS solution.

To better understand the drivers of LCOE savings, the full hybridization scenario, diesel + solar PV + BESS, is analyzed for a range of input factors. This sensitivity analysis includes diesel fuel price, installed solar PV price, battery price (excl. converter) as well as solar irradiation. As presented in Table II, diesel costs are found to have the highest impact on LCOE savings with an increase in fuel price from 1.0 to 1.5 USD/L leading to an increase in savings of 6.5 percentage points versus the base case.

Table III shows the impact of solar PV price and diesel price on LCOE savings. In case of high solar PV price and low diesel price, the LCOE saving is the minimum as of 4%. On the other hand, if the PV price is cheap and diesel price is high, then the LCOE saving has its highest value of 27%. Table IV shows the impact of solar PV price and diesel price on fuel reduction. In case of high solar PV price and low diesel price, the fuel reduction is the minimum as of 1%. On the other hand, if the PV price is cheap and diesel price is high, then the fuel saving has its highest value of 43%.

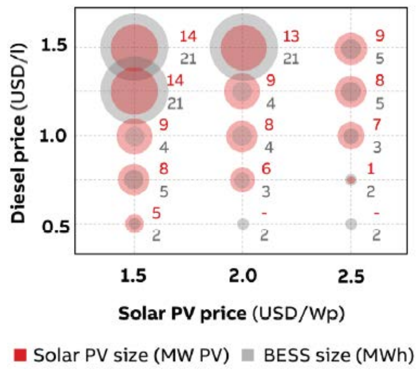

Figure 1. Microgrid configuration sensitivity to prices.

To further assess the impact of diesel and solar PV prices, Figure 1 shows the recommended microgrid system configuration, resulting fuel saving and LCOE saving as diesel and PV prices vary. Under the majority of the conditions evaluated, a mine would achieve an IRR of above 10% for the upgraded systems adding both BESS and solar PV. As diesel prices increase, or PV prices decrease, the size of the optimized solar PV and BESS becomes larger. Under some scenarios, when diesel is very cheap and PV is very expensive, it no longer makes sense to install PV purely from an economic perspective. Under these conditions, it may be best to first install a BESS and add solar PV as their price decreases, or the price of diesel increases.

IV. CONCLUSION

Powering remote mines with diesel generators provides a proven and reliable energy source, but leaves the mine operator vulnerable to diesel price fluctuations, fuel supply risk as well as uncertainty around future carbon taxes. It also fails to capitalize on the economic and operating benefits that BESS and solar PV offers today and potential cost savings from carbon taxes in the future.

In some cases, mine operators may prefer the incremental hybridization route as it allows more gradual changes to the operating system and strategy. This analysis shows that it makes sense to consider BESS in the first step without additional renewable energy capacity as this offers the highest IRR. Ideally, the use of a flexible BESS, such as the ABB PowerStore would allow the storage capacity to be increased if renewable energy systems are later added.

In terms of renewable options, wind has also proven itself to be effective in the mining sector, particularly in those areas with high wind resource and low solar resource. Due to historically lower costs, high scalability and relative ease to gain approvals in remote locations, wind has accounted for 59% of installed renewables in mining to date. Where mine lives are shorter than 10 years new business models13 allowing for relocatable solar PV to be installed could be considered. Once you have found the right renewable choice for your location, combining with a BESS can provide additional cost-savings that mining operators can benefit from today.

.REFERENCES

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