Ensuring reliable power for Commercial and Industrial (C&I) sites

ABB Microgrid Business Case

Executive Summary

In many parts of the world regular interruptions to the grid power supply are a way of life, with frequent black- or brown-outs occurring on a weekly or even daily basis. There are many different reasons for a grid to become unreliable, such as energy supply issues, weak infrastructure or extreme weather. Yet, the challenges for Commercial and Industrial (C&I) sites are usually the same: lost production, lower workforce efficiency and potential damage to their process equipment. In many cases power outages on critical manufacturing lines will also damage the work-in-process, further impacting operational costs (Figure 6).

Blackouts are a significant cost burden for even the most developed countries, with a recent Navigant study highlighting 2016 US annual power outage related costs of ~150 BUSD, with 90% of corporations impacted by at least 1 major outage[1]. Unsurprisingly, developing countries are impacted by significantly more outages and associated costs. The World Bank cites numerous regions with revenue impacts above 4% (Figure 3).

To limit these impacts, C&I plant owners often adopt diesel generators to provide back-up power. This enables their site to work in an islanded state during an outage as well as benefiting from relatively low capital costs and the capability of the generator to run without stopping for long periods of time (as long as there is a ready supply of diesel fuel). Unfortunately, generators also suffer from a number of well-known issues: high fuel and maintenance costs, significant environmental impacts (CO2, air quality, noise), and a slow start-up time, typically of ~15 seconds, resulting in the shut-down and resetting of sensitive manufacturing and IT related equipment. Some processing plant operators bridge this power gap by installing an Uninterrupted Power Supply (UPS). While this will provide the highest quality of power, it can come at a significant cost. Beyond their capital, maintenance and replacement costs, UPS systems also consume a lot of energy with a typical efficiency of 96% or less[2].

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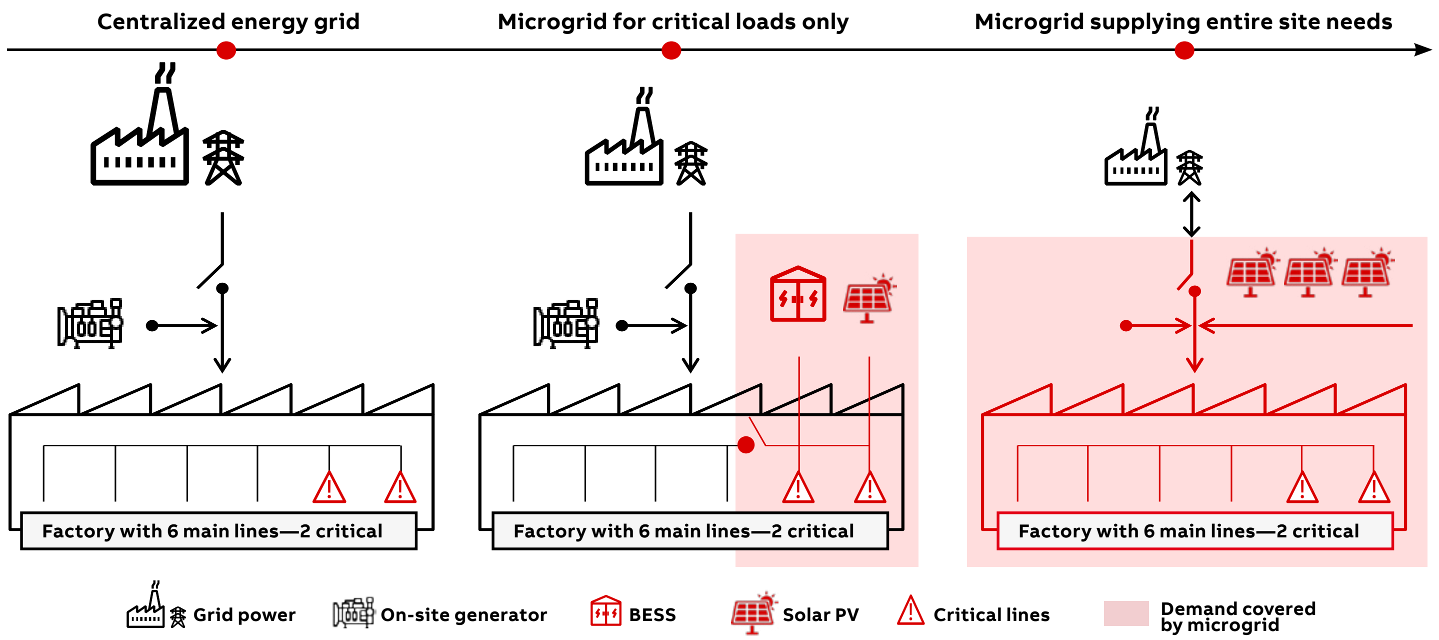

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01 Incremental expansion of Microgrids will transform energy supplies for many industries

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[1]C&I Microgrids: Grid-Tied and Remote Microgrid Forecasts, Technology and Policy Market Drivers, and Key Players (2017Q2)

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[2]For example Conceptpower DPA UPS product offerings in "online double conversion" mode

Microgrids offer businesses an alternative to mitigate the power disruptions that negatively affect their operations. Furthermore, thanks to rapidly decreasing battery and renewable energy costs, they have the potential to drive down overall energy costs and reduce carbon emissions. To assess the true potential offered by micrgrids, ABB has developed a business case for IndustryCo, a glass factory located in India with recurrent outages. This analysis considers the costs and benefits of implementing a microgrid for IndustryCo's critical loads only, providing an opportunity for further incremental expansion at a later date (Figure 1). These loads relate to the critical glass manufacturing process itself, where even a short power outage stops production, requiring the removal and clean-up of the Work in Progress (WIP) glass products. In this case, the scrap glass products can be recycled back into the process.

This business case considers three implementation scenarios optimized using HOMER Pro[3] microgrid modeling software. IndustryCo's results (Figure 2) show that the highest investment IRR (Internal Rate of Return) of 35% is possible by installing a Battery Energy Storage System (BESS) where the main benefit comes from the reduction in outage-related costs. Alternatively, by combining this with solar photovoltaic (PV) panels, IndustryCo can substitute expensive diesel fuel with cost competitive solar energy thereby delivering the largest reduction in fuel consumption (45%) and LCOE[4] (19%), while maintaining a healthy IRR (26%). This does not include the additional benefits provided by a BESS such as improved power quality and deferred cost of additional generators.

The sensitivity analysis itself offers a good summary of which scenarios result in the most cost effective microgrid solutions, i.e., sites with:

- High operational outage costs (either due to many outages or high costs per outage)
- Low PV installation price
- High grid power price

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02 20 – 30 % energy related savings are possible for C&I facilities with an unreliable grid

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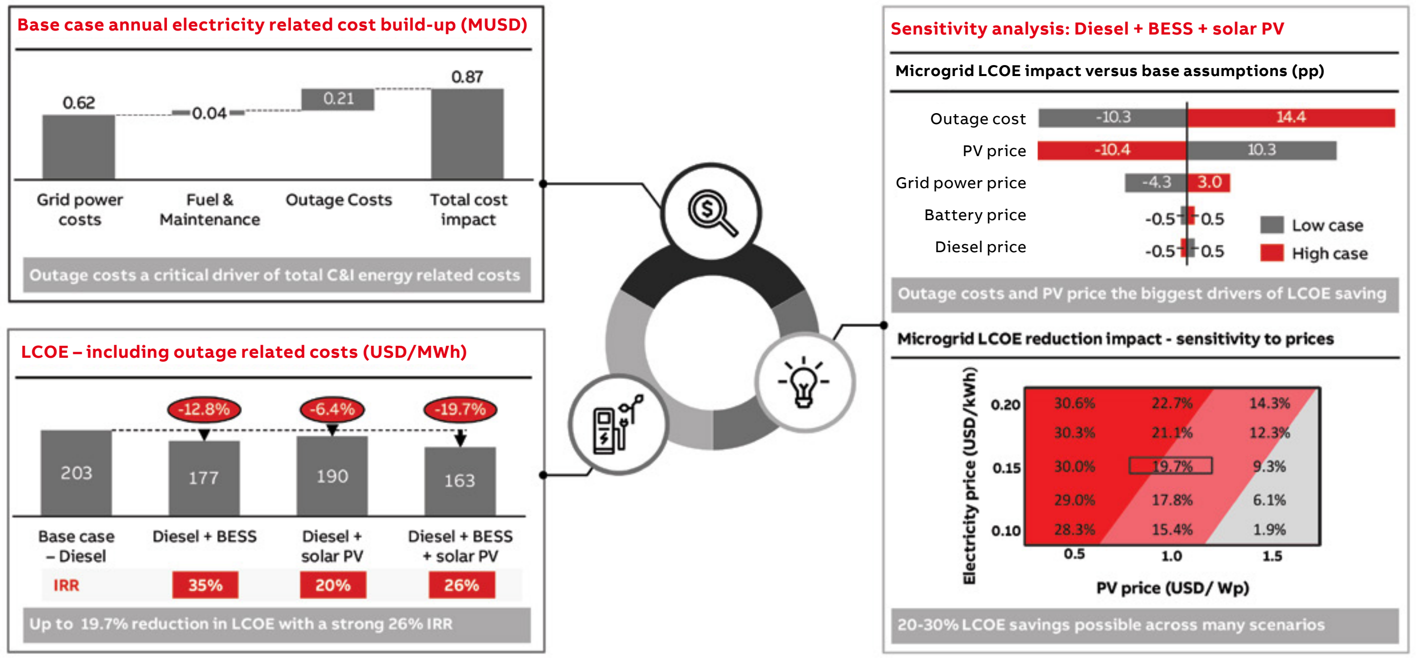

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[3]HOMER is an energy flow modelling tool that also takes the financial evaluation of a proposed hybrid system into acount. HOMER Pro's modelling results are technology agnostic: the optimization is on the net present cost (NPC) of the system. The software is the global standard for rapid assessment of least cost solutions for clean, reliable, distributed power and micrograds (see www.homerenergy.com)

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[4]Levelized Cost of Electricity, including all operating and maintenance costs as well as annualized capital costs

Benefits of storage and renewables for C&I plants connected to a weak grid

Power outages have a material negative impact and remain a major issue in many geographies with significant social and economic impacts. Figure 3 shows an assessment of the impacts on C&I sites in both developed and developing countries.

03 Overview of business recorded power outages, associated costs, and backup generation.

Limitations of traditional back-up generators
To resolve the issue of poor grid power, C&I customers typically use some form of backup power, with diesel generators being most common. In emerging countries, self-generated energy can account for up to 41%[5] of total consumption (Nigeria). While back-up generation does provide added reliability and resiliency, this approach also creates some well understood challenges:

- Generators are not typically online when the grid goes down and cannot always start and ramp up fast enough to ride out sudden transient events and make a seamless transition to an islanded state
- Diesel generators produce significant CO2 emissions and other forms of local air and noise pollution
- Diesel supply can lead to logistical issues and additional storage expense

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	Share of firms experiencing outage (%)	Annual total outage duration - impacted businesses only (hours)	Associated losses (% of annual sales)	Share of firms owning / sharing a generator (%)
Middle East & North Africa	57	1,832	7	41
South Asia	66	1,615	11	45
Sub-Saharan Africa	80	570	8	52
India	55	331	4	47
East Asia & Pacific	46	253	3	33
LatAm & Caribbean	61	66	3	26
High income: OECD	28	15	1	11

Source: Bloomberg/World Bank (2010-2017)

[5] 'The addressable market for off-grid renewables', Bloomberg New Energy Finance, 2017

[6] Islanded mode: ability to provide power independently from the main power grid

How a microgrid that integrates renewables and energy storage can help
A microgrid consists of distributed energy resources and loads that can be operated in a controlled, coordinated way either connected to the main power grid or in islanded mode[6]. They offer an effective solution to manage a range of energy needs in a coordinated way, for example:

- A microgrid controller is able to manage a BESS and/or a UPS to provide a range of power back-up and power quality services (Figure 4)
- A BESS/UPS microgrid is able to provide the required ramping and transient response to respond to sudden grid events, load changes, and sudden changes in renewable power and allows seamless transition from the grid-connected state to islanded state and vice-versa, thereby eliminating outage-related costs
- Combining a BESS/UPS with renewables increases self-consumption of cost competitive renewable energy and can help keep critical loads online for longer durations during outages, and/or delay the need to start a generator
- Implementing a BESS/UPS can defer the costs of purchasing additional generators as the load grows with time
- The microgrid controller can integrate deferrable loads within the plant to shift energy demand to match renewable output or reduce peak demand

04 Options to manage different levels of power quality

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Grid | BESS | UPS | Solar PV | Generator

Protection options	Key elements	Interrupt-ion time	Efficiency (on-grid)	Benefits and drawbacks
Grid only (no backup)		hours	100%	+ Zero additional/capital cost - No backup during outage
Diesel Generator + Grid		~10-30s		+ Low capital cost - 15 sec delay, CO2 & local emissions, noise
BESS + Grid		<150ms	99%	+ No disconnection , BESS services - Voltage sag; Limited backup time
BESS + PV + Grid		(effective for most loads)		+ No disconnection, BESS services, cost & CO2 savings - Voltage sag; Limited duration in low solar condition
BESS + PV + Diesel Generator + Grid				+ No disconnection, BESS services, cost & CO2 savings - Voltage sag
UPS + Grid		No interruption	96%	+ Power quality - Limited duration, low efficiency; no grid services
UPS + Diesel Generator + Grid		(highly sensitive loads)		+ Power quality - Low efficiency; no grid services
UPS + PV + Diesel Generator + Grid				+ Power quality, cost and CO2 savings - Low efficiency, no grid services

A microgrid can flexibly incorporate these and other solutions to meet specific site needs

Four scenarios analyzed
Background of simulated scenarios

05 Overview of the 4 modelled scenarios

The following scenarios consider various options for upgrading a C&I plant with a BESS and / or solar PV generation. In total, four different scenarios are simulated and optimized to provide the lowest LCOE while achieving a minimum 15% IRR. As presented in Figure 5, these include:

Base case – Grid + Diesel
The grid supplies all the required energy, and pre-existing back-up diesel generators only supply energy during an outage

Grid + Diesel + BESS
BESS utilized to reduce grid costs, improve power quality, provide seamless transition to islanded operation, as well as to optimize the efficiency of the generators

Grid + Diesel + solar PV
Solar PV plant without energy storage used to reduce grid costs and fuel costs

Grid + Diesel + BESS + solar PV
BESS combined with solar PV effectively minimizes outage related costs while also benefitting from cost competitive solar energy

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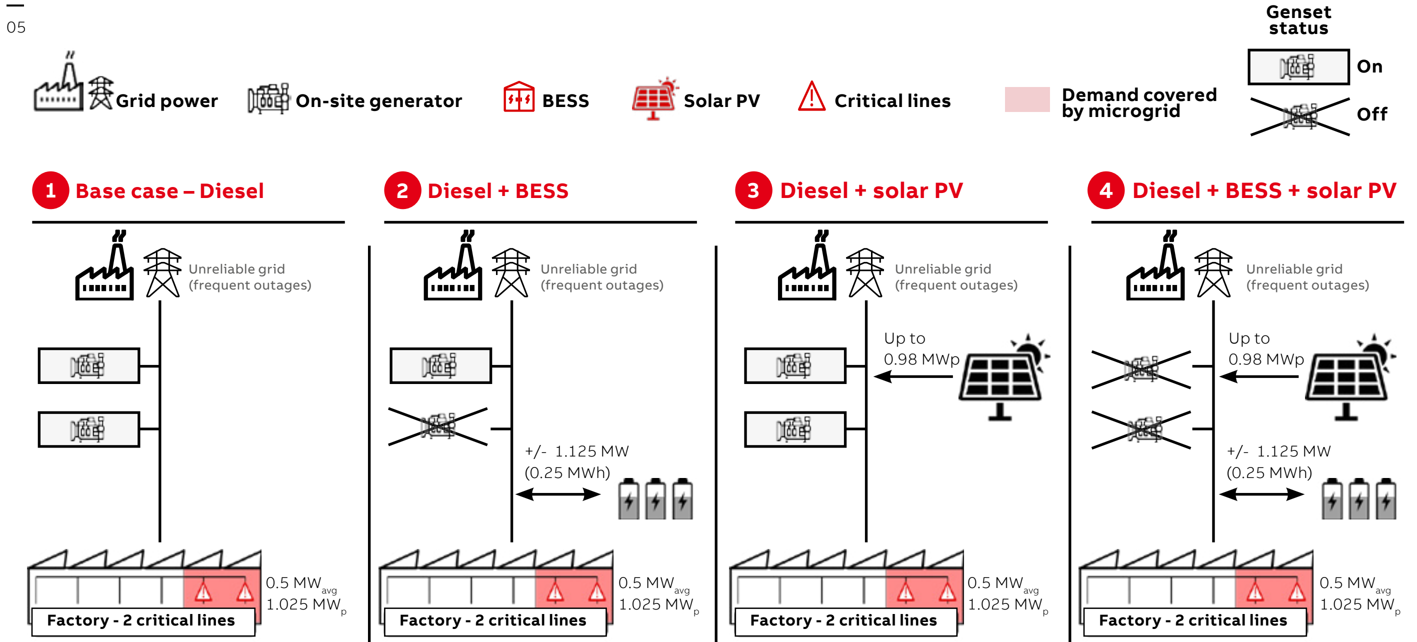

1 Base case – Diesel
- 2 generator system (0.6 MW each), both required during power outage
- Generators kept off while grid-connected to save on fuel costs
- Facility undergoes outage every time the grid goes down

2 Diesel + BESS
- BESS provides seamless transition to island state
- BESS provides required ramping and reduces need for generators
- BESS can delay or eliminate the need to start up a generator during short term outages

3 Diesel + solar PV
- Requires generator spinning reserve equivalent to 75% of the maximum solar PV output to account for shading

4 Diesel + BESS + solar PV
- All the benefits of Diesel + BESS case, as well as Diesel + Solar PV case
- BESS provides required ramping for solar and thus during daylight hours all generators can be shut down

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Plant activities and operations have a big impact on outage costs

Power outage impacts

- Shutting off or malfunction of the machinery
- Damage to equipment and products
- Decrease in productivity

Modelled outage costs for C&I plant

Hidden costs can add up for a manufacturer experiencing 260 outage events in a year

	Cost line item	Cost per event	Cost per year
Disrupted production line	Idle workers	$350	$91'000
	Lost product	$350	$91'000
	Lost efficiency	$100	$26'000
Annual total cost		$800	$208'000

06 Outage related costs are typically hidden alongside other operating costs

The business case is built around IndustryCo, a glass factory in India, however it would apply equally to any industrial operation of a similar size and with similar grid issues. While the whole factory has an average load of 15 MW with 24/7 operation, we have modeled the critical load only with a peak load of 1 MW and average of 0.5 MW with hourly (but no seasonal) variations. The plant is modeled with 260 outages per year, with each outage lasting an average of 1 hour. This outage frequency and duration is representative of businesses in other developing regions of the world such as Middle East, Africa and Asia according to the World Bank Enterprise Survey[7]. Cost assumptions related to an outage (Figure 6) includes $350 for idle workers, $350 for value of lost product, and $100 for lost efficiency, totaling $800 per outage, or $208,000 per year. Power quality provided by a BESS is effective in resolving IndustryCo's outage related costs.

The minimum operating reserve of the power system is set to vary as a function of load and PV output. The two generators supporting the critical loads are a standard model benchmarked on a leading manufacturer. Each generator has a capacity of 0.6 MW and operates on diesel fuel. The minimum load ratio for the generator is 30% with no minimum run-time.

This case study only considers new investment costs for the hybrid system as the generators are already installed on-site. For comparing each scenario we use a grid price of $0.15/kWh, an all-in diesel fuel price of 1.0 USD/L, which is inclusive of transport, taxes etc., and a total CAPEX for the installed solar PV system, including inverter, of 1.0 USD/Wp[8]. In the simulation, the assumption for the solar irradiation is 5.6 kWh/m2/day. To account for cloud cover 75% of the PV's power output must be collectively covered in the operating reserve by the grid, diesel generators, or BESS. The BESS uses Li-ion batteries and the roundtrip efficiency is assumed to be 90%.

To assess LCOE and annualized costs, a 15% nominal discount rate is applied and a project lifetime is assumed to be 10 years, after which the solar PV modules, BESS and inverters 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 demand, reserve requirements) with 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.

Base case –Grid + Diesel
The base case refers to IndustryCo continuing to rely on the grid for all its energy needs, and only running the existing diesel generators as backup. During an outage, depending on the load and spinning reserve requirements, one or two diesel generators with a 0.6 MW nominal rating each may be required to serve the load.

If both generators are online, they would operate in proportional load sharing which means each generator has the same capacity factor. The sum of spinning reserve[9] carried by the first generator may allow the second generator to trip or the load to instantly increase without the need for load shedding. This operation leads to additional O&M costs from the second generator runtime as well as lower fuel efficiency due to a lower capacity factor.

At a grid price of $0.15/kWh, and diesel fuel price of 1.0 USD/L, the base case has annual grid power costs of 0.62 MUSD, and fuel and maintenance costs of 0.04 MUSD, resulting in an average annual operating cost 0.66 MUSD. However, if we include the outage related annual costs into the equation, this leads to total electricity related expense of 0.87 MUSD with an associated LCOE of 203 USD/MWh. The following scenarios are benchmarked to this base case.

Grid + Diesel + BESS (Highest IRR)
A BESS (e.g., ABB PowerStore™)[10] is able to provide seamless transition to the islanded state, improve overall power quality, reduce grid costs by smoothing load demand peaks, and help delay or avoid the start of a generator.

Total investment costs for a BESS solution meeting the modelled size requirements of 1.125 MW/0.25 MWh are estimated to be 0.55 MUSD. The simulation economics are such that the BESS is mainly used for the transition to the islanded state, and to smooth any sudden changes in load, leading to a small reduction in generator usage. Results show annual grid power costs of 0.62 MUSD, and fuel costs of 0.04 MUSD which, together with maintenance and minimal outage-related costs, results in an average operating cost of 0.67 MUSD with payback period of 2.7 years and IRR of 35%. The LCOE is reduced from 203 to 177 USD/MW, mainly due to a reduction in outage-related costs.

Grid + Diesel + solar PV
This scenario pursues an alternative path to hybridization initiated by a PV-only upgrade without energy storage. Here we replace grid purchases and diesel fuel by cost-competitive solar PV.

Installing this 0.98 MWp PV system requires a CAPEX of 0.98 MUSD. Results show annual grid power costs of 0.42 MUSD, and fuel costs of 0.03 MUSD which, together with maintenance and outage-related costs, results in an average operating cost of 0.65 MUSD. As a result, the LCOE is reduced from 203 to 190 USD/MWh with grid cost savings, and fuel savings are the primary value-drivers for this scenario. The payback time is 4.5 years and the IRR is 20%, somewhat lower than the diesel + BESS scenario that had an IRR of 35%. This is clearly a sub-optimal solution as both the LCOE and the IRR are higher than the Grid + Diesel + BESS options.

Grid + Diesel + BESS + solar PV (Maximum Savings)
In this scenario, the two technologies, BESS and Solar PV, are combined. An investment of 1.5 MUSD is required to add a solar PV system of 0.98 MW and a BESS of 1.125 MW/0.25 MWh.

Results show an annual grid power cost of 0.40 MUSD, plus fuel costs of 0.02 MUSD which, together with minimal outage and maintenance costs, results in an average operating cost of 0.43 MUSD. Savings come from the 0.20 MUSD reduction in outage-related costs, 0.02 MUSD of fuel cost, and 0.22 MUSD of grid cost reduction annually. This solution offers maximum value stacking from the storage component as it almost eliminates outage costs, reduces grid power costs, reduces diesel fuel costs, substitutes diesel generators as operating reserve and smooths demand peaks.

The investment returns an IRR of 26% with a payback period of 3.6 years and an LCOE of 163 USD/MWh, and is easily the best option from an LCOE perspective.

Recap
The transformation to a solar PV + BESS microgrid can be achieved through incremental hybridization investments that lower investment risk and enable an effective response to changing market conditions such as increased grid energy prices, increased diesel fuel price or decreased solar PV price. Adding a BESS alone addresses the immediate concern of outage-related costs and provides the highest IRR. Alternatively investing in a solar PV + BESS solution leads to the lowest average cost of energy. The summary of all scenario results are presented in Figure 7.

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07 Simulated results across 4 scenarios

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Scenario		Additional investment			Operation costs							Economic benefit	
		BESS (MW/MWh)	PV (MWp)	Initial inv.(MUSD)	Avg. gen. use (hours/gen/yr)	Fuel use (L/yr)	Grid power cost (MUSD/yr)	Fuel cost (MUSD/yr)	Outage related costs (MUSD/y)	Total cost1 (MUSD/yr)	LCOE (USD/MWh)	IRR (%)	Payback (yr)
1 Base Case – Diesel only	**Output**				236	44,500	0.62	0.044	0.21	0.87	203		
2 Diesel + BESS	**Output**	1.125 0.25		0.55	165	43,600	0.62	0.043	0.01	0.67	177	35	2.7
	Change (in %)				-71 -30	-900 -2.0	0 0	-0.001 -2.0	-0.20 -95	-0.20 -23	-26 -13		
3 Diesel + solar PV	**Output**		0.98	0.98	207	28,500	0.42	0.028	0.21	0.65	190	20	4.5
	Change (in %)				-29 -12	-16,000 -36	-0.2 -32	-0.016 -36	0 0	-0.22 -25	-13 -6		
4 Diesel + BESS + solar PV	**Output**	1.125 0.25	0.98	1.53	199	24,500	0.40	0.024	0.01	0.45	163	26	3.6
	Change (in %)				-37 -16	-20,000 -45	-0.22 -35	-0.020 -45	-0.20 -95	-0.42 -48	-40 -20		

NOTE: Numbers may be affected due to rounding
[1]Excludes annualized investment costs

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[8]Solar PV installations costs vary significantly based on country with India having one of the lowest installed costs

[9]Spinning reserve is the extra generating capacity that is online and available by simply increasing the power output of generators

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[10]PowerStore™ is a containerized plug-and-play microgrid solution, available in various ratings with a standardized specification for installations including industry, utilities and village electrification. Its "Virtual Generator" can form the grid, and integrate up to 100% of renewable energy

Evaluation of assumptions

To better understand the drivers of LCOE savings, the full hybridization scenario, diesel + solar PV + BESS, has been analyzed for a range of input factors. This sensitivity analysis includes outage-related costs, grid energy price, diesel fuel price, installed solar PV price, and battery price (excl. converter).

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08 Tornado chart of LCOE savings impact by driver

As presented in Figure 8, outage-related costs are found to have the highest impact on LCOE savings. By increasing the outage related costs from 208 to 416 $k/year, an increase in savings of 14.4 percentage points is possible on top of the standard 19.7% savings. From an installation cost perspective, a decrease in PV installed price from 1.0 to 0.5 USD/ Wp leads to an increase in savings of 10.3 percentage points versus the base case + microgrid scenario.

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High case
Low case

Sensitivity driver	Low case	Base case	High case	Microgrid LCOE impact (pp) vs Base case MG LCOE savings = 19.7%
Outage Cost (k$/year)	104	**208**	416	-10.3 / 14.4
Installed PV price (USD/Wp)	0.5	**1**	1.5	-10.4 / 10.3
Grid energy price (USD/kWh)	0.1	**0.15**	0.2	-4.3 / 3.0
Diesel price (USD/L)	0.5	**1.0**	1.5	-0.5 / 0.5
Installed battery price excl. converter ($/kWh)	300	**400**	500	-0.5 / 0.5

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09 C&I (weak grid) facility microgrid case study

To further assess the impact of grid and solar PV prices, Figure 9 shows the recommended microgrid system configuration and LCOE saving as grid and PV prices vary. As grid power prices increase, or PV prices decrease, the size of the optimized solar PV and BESS becomes larger. Under some scenarios, when energy from the grid 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 its price decreases, or the price of energy from the grid increases.

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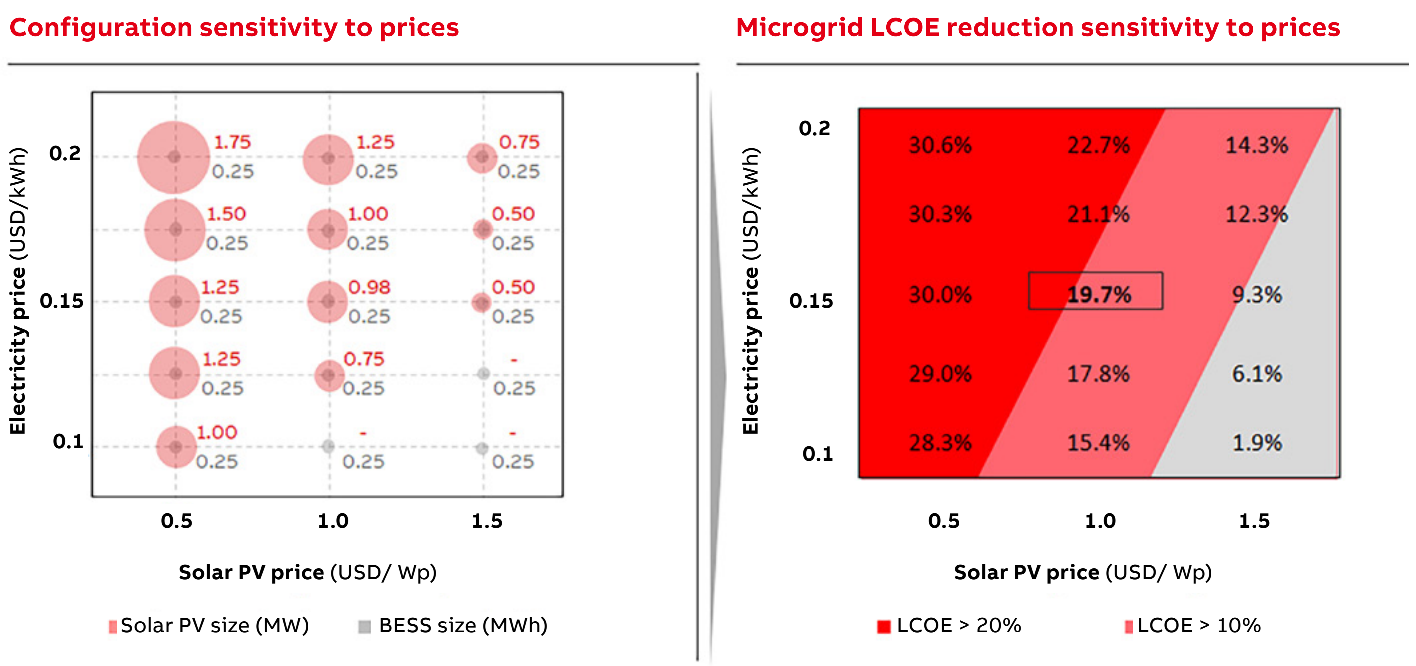

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[11] For further information, please see http://new.abb.com/microgrids

Conclusions and ABB's microgrid capabilities

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10 ABB Microgrid solutions

Relying on a weak grid and diesel generators can leave a C&I plant vulnerable to outage-related costs, lost revenue and lost business potential. It also fails to capitalize on the economic and operating benefits that BESS and solar PV offers today. In some cases, C&I plant owners may prefer the incremental hybridization route as it allows more gradual changes to their operating system and strategy. Given the immediate concern of outage-related costs and lost business potential, it may make sense to consider a BESS as the first step without additional renewable energy capacity. Ideally, the use of a flexible BESS, such as ABB's PowerStore™ would allow the storage capacity to be increased if renewable energy systems are later added. For the example shown, there is the additional opportunity to, over time, absorb the entire factory demand of 15 MW into the microgrid with additional PV and BESS capacity added as required.

ABB has expertise and experience in designing optimized microgrid solutions with a proven track record of well over 40 global installations across a range of applications serving remote communities, islands, utilities and industrial customers. We are a leading provider of microgrid products and solutions that offer a complete end to end approach from initial consultancy through to remote monitoring. Our flagship microgrid solutions for C&I plants are based on two platforms that offer the flexibility and scalability to support power demands from 20 kW up to several megawatts.

PowerStore™ - Energy storage and renewable integration
PowerStore™ is a standardized, containerized BESS solution for power requirements above 60 kW which can be easily transported to any customer site. PowerStore™ can reliably integrate any generation source into the microgrid energy mix thanks to its built-in distributed control system Microgrid Plus.

MGS100 – An integrated system for reliable, sustainable power
For small facilities in the 20 – 60 kW range, the MGS100 integrates all of the components required for a sustainable microgrid in a single device.
The system delivers reliable power from three power inputs: solar PV panels, Li-On or lead-acid batteries, and energy from biofuel/diesel generators or an existing grid connection.

Thanks to our remote portal, ABB offers 24/7 customer support for further optimization of C&I microgrid operations. Furthermore, ABB's microgrid platforms are supported by UPS solutions, a broad range of string and central PV inverters, low and medium voltage switchgear, protection relays, transformers and Electrical Balance of Plant (EBoP).

Whatever your plant's electricity needs, ABB can assist you to design and implement the best strategy for your power supply and technology upgrades, saving you money while ensuring delivery of reliable and high quality power.

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