



MERUS POWER

Investment feasibility of an off-grid hybrid power system

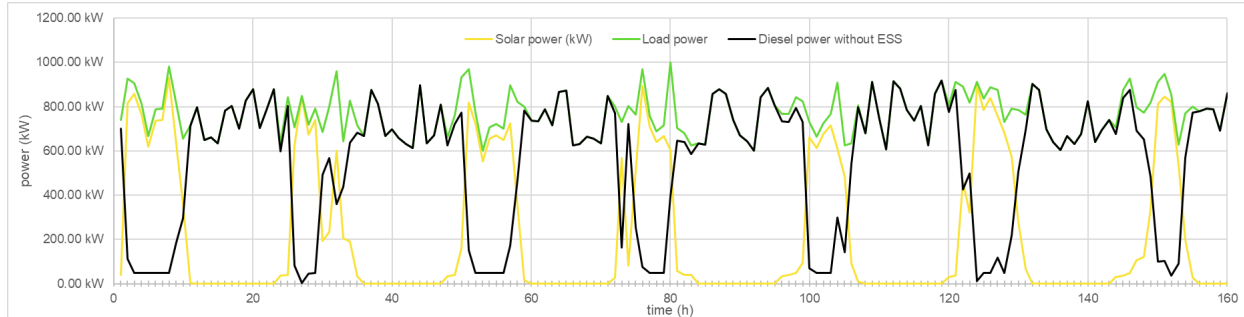


Figure 1 Microgrid powered by diesel generators (DGS) and solar power.

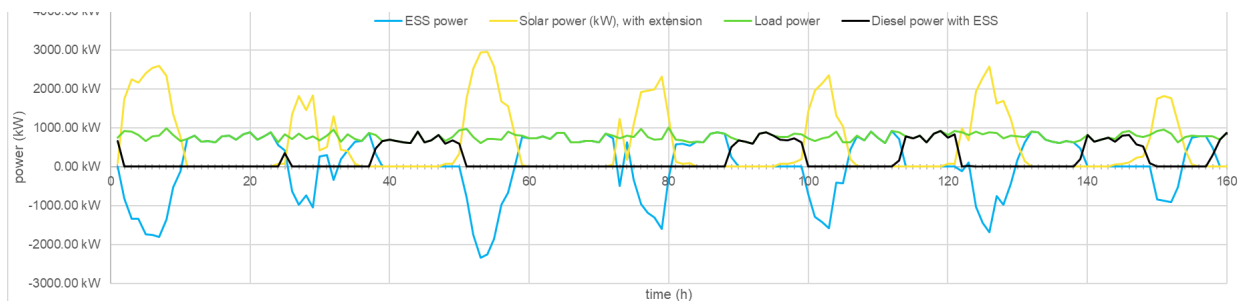


Figure 2 Microgrid powered by diesel generators (DGS), solar power and Merus™ ESS energy storage system.

Abstract – The production in an off-grid microgrid typically consist of renewable energy generation and internal combustion engine powered generators, such as diesel gensets. When a sophisticated battery energy storage system is installed in the microgrid, substantial savings can be obtained from reduced need fuel and maintenance cost of the gensets. This application note includes study results of an off-grid microgrid with and without Merus™ ESS energy storage system. The measurements and studies are from customer’s mining microgrid located in Indonesia. This study shows that with typical fuel cost in a rural microgrid the energy storage system’s payback time is 1 – 4 years.

1. Introduction

Microgrid is a localized electrical system consisting of electrical loads and electricity production units. Normally, a microgrid is connected synchronically to a traditional wide area synchronous grid; however, a microgrid can also operate independently without a grid connection. This is called islanded operation.

Islanded operation can be used during wide area grid’s blackout, or for economic reasons. In some cases, there is no connection to a wide area synchronous grid at all. These kind of off-grid microgrids are typical for many small Pacific islands or rural mining plants located in Africa, for example.

2. Example mining microgrid

The example case examined within this application note is an off-grid mining microgrid located in Indonesia (0° S, 115° E). The power of the microgrid was previously produced by 1.0 MW solar power plant and 7 x 800 kW of diesel genset capacity. After the installation of the ESS system it is possible to extend the solar power plant to 3.0 MW and reduce the amount of online diesel gensets.

1.2. Location and solar irradiance data

Solar irradiance data for this location is used in this study to estimate the solar power generation. The source of the irradiance data is the EU Science HUB Photovoltaic Geographical Information System (PVGIS).

Merus Power Dynamics Oy

www.meruspower.com

Address: Pirkkalaistie 1, 37100 Nokia, Finland

Email: sales@meruspower.com

Phone: +358 20 7354320

Fax: +358 3 2255344

Y-No: 2230775-9

VAT No: FI22307759

The information and trademarks contained in this document and any copyright attached to it is the sole property of Merus Power Dynamics Oy. Any unauthorized reproduction or redistribution of any part or as a whole is strictly prohibited without written permission of Merus Power Dynamics Oy. Merus Power Dynamics Oy reserves the right to alter or discontinue the products and/or specifications referenced herein at any time without notice. Merus is a registered trademark of Merus Power Dynamics Oy. © Copyright Merus Power Dynamics Oy, 2020.

2.2. Solar power

The example microgrid had 1.05 MW of solar power (7x150 kW) before installation of Merus™ ESS. The powers of such microgrid are shown in Figure 1 and Figure 4. In an islanded microgrid the maximum solar power generation capacity cannot exceed the maximum installed genset capacity. Also, during the operation the maximum power output from the solar generation cannot exceed the load demand at any given moment since the generators cannot be used to absorb the excess generation.

If the installed generator capacity is significantly higher than the maximum load consumption, the installed solar generation capacity is typically sized based on the maximum load demand to maximise the solar generation yield per installed panel.



Figure 3 Solar power installation

The solar inverters operate in an MPPT operation mode (Maximum Power Point Tracking), which means that the solar generation is maximal at all times and reduced only during a rare situation when the load power is smaller than the available solar generation. The solar power reduction can be done by switching off solar inverters (with 150 kW steps).



Figure 4 Solar generation capacity is limited by load level. DGS are used for power balance control.

When Merus™ ESS is installed, it is possible to increase the installed solar power capacity. This is shown in Figure 2 and Figure 5.

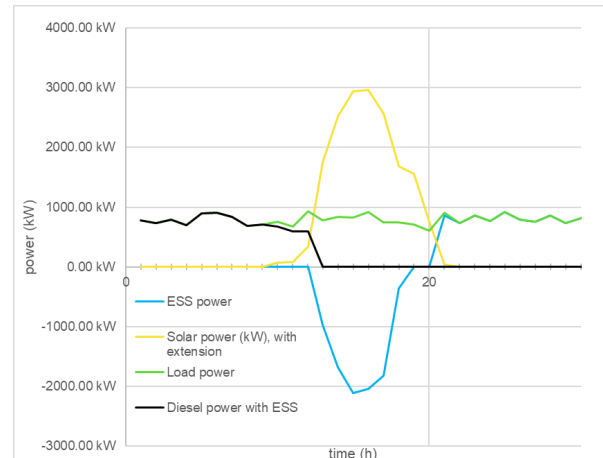


Figure 5 Installed solar capacity can be increased when ESS is installed.

The installed solar power capacity could be extended to 3.0 MW (20x150 kW) when the ESS is installed. Also in this case the inverters operate in the MPPT mode, but now all inverters can always stay running because the excess energy (the difference between solar generation and load demand at any given moment) is stored in the Merus™ ESS.

3.2. Diesel generators

Diesel generators (DGS) are used in the microgrid for three purposes. Firstly, the diesel generators are used to generate electricity to match the consumption while the generated solar power is not sufficient.

Secondly, the diesel generators are needed to provide high enough fault level and enough inertia to the microgrid. High enough fault level is needed to guarantee the short circuit protection functionality while the inertia is needed to achieve frequency stability during transients. Transients can be either a large load connecting on or off or a generator dropping off from the microgrid.

The third application for the diesel generators is the voltage control in the microgrid by producing reactive power. In the example microgrid, Cummins C1100 D5 (1000 kVA/800 kW) diesel generators are used. The fuel consumption of a diesel generator consists of the idle consumption and load consumption. A typical fuel consumption curve for the 800 kW DG is shown in Figure 6.

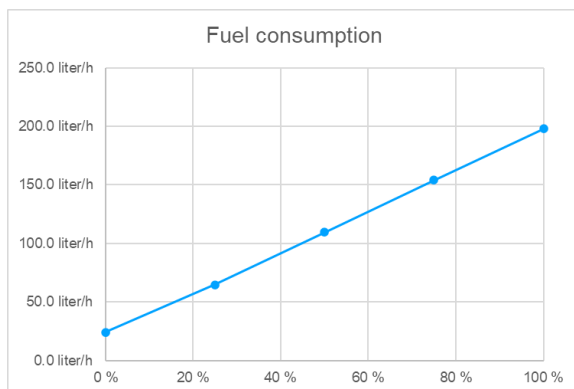


Figure 6 Fuel consumption of used 1000 kVA / 800 kW DGS.

When reactive power is produced with DGSs the efficiency is reduced. Also, the load rate affects DGS's efficiency. This is shown in Figure 7.

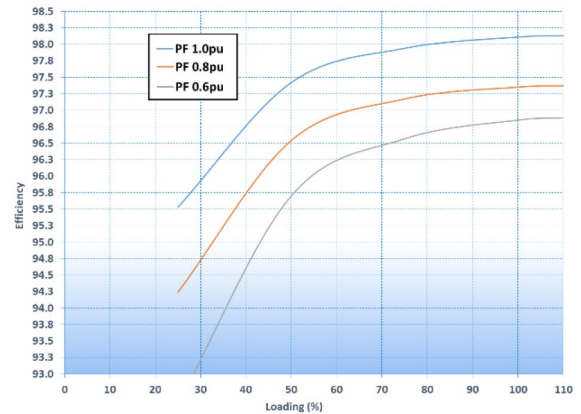


Figure 7 Typical DGS's efficiency curve.

Based on Figure 6 and Figure 7, if the number or running DGSs which is needed to provide the required fault level and inertia is high compared to the consumption level, the fuel costs increase. This is because the efficiency of the DGS is reduced due to low load rates. Also, since the generators are forced to produce reactive power as well the efficiency is decreased further.

If the number of the running DGS can be decreased and the load rate of each generator increased, the fuel consumption will be decreased. In addition, decreasing the number of DGSs running at low load rate causes significant savings in maintenance costs.

4.2. Loads

The main loads of the example mining microgrid are direct online induction motors such as stone crushers, conveyers, fans and air conditioning compressors. Direct online motors (DOL) tend to demand significant amount of reactive power during the start-up and during torque spikes on the motor's shaft. Without proper reactive power compensation these quick changes in the reactive power demand cause sags in the voltage magnitude.

The DOL motor starting and sudden spike in the motor torque demand also cause quick changes in the active power demand, which sets the requirement for the minimum inertia of the system during motor start-ups and torque spikes.



Figure 8 Stone crusher.

In this example microgrid the stone crusher operation sets the requirement for the minimum inertia. Without an energy storage system six out of seven diesel gensets must be online all the time to provide enough inertia and reactive power for the crusher operation. With Merus™ ESS installed the requirement of online diesel genset has reduces to two out of seven. This is because of the dynamic reactive power compensation and voltage support as well as virtual inertia provided by Merus™ ESS.

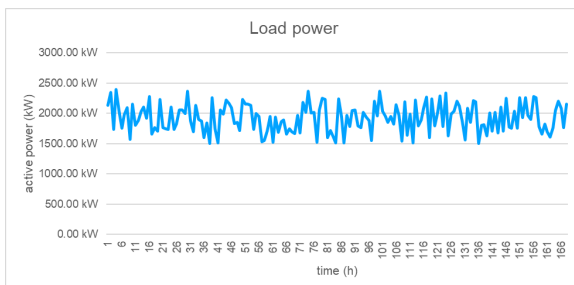


Figure 9 Load power profile.

For the energy balance and power generation studies, a power profile of the loads of the microgrid is needed. The load profile used within this application note is based on the measured load powers from the example microgrid. The load profile is shown in the Figure 9.

3. Merus™ ESS in a microgrid

There are numerous applications for Merus™ ESS in an off-grid microgrid. These applications are explained in the following.



Figure 10 Containerized Merus™ ESS solution.

1.2. Peak shaving

The Merus™ ESS can be used for renewable generation peak shaving. This means that during the hours of high production from the renewables the energy is stored into the battery. This allows that the momentary generation from the renewables can be higher than the momentary power consumption of the off-grid microgrid during those hours of high production. Also, in the case where a power plant is connected to the transmission grid, the peak shaving with Merus™ ESS enable higher installed renewable capacity than the contracted connection point power limit. In this example case, the installed ESS enables solar plant extension from 1.0 MW to 3.0 MW.

2.2. Reactive power generation and voltage control

Reactive power is used to control the voltage magnitude in the microgrid. In conventional microgrids diesel generators are used to provide reactive power and voltage control using AVR (Automatic Voltage Control) feature of the generator. However, reactive power generation decreases the genset's efficiency. This effect is shown in Figure 7. The PCS (Power Conversion System) of Merus™ ESS can be used for automatic reactive power generation and voltage control. This removes the need of reactive power generation with the gensets and thus, improves the efficiency of the generators.

3.2. Fault current provision

Even though the diesel gensets are not needed for the active power generation, there is a requirement for the minimum amount of online gensets. This requirement is based on the minimum fault current supply criterion to guarantee the protection coordination inside the microgrid. Merus™ ESS can be used to provide fault current to guarantee the required fault level; therefore, the number of the idling online diesel gensets can be reduced.

4.2. Virtual inertia

Another reason why there is a limit for the minimum number of online diesel gensets in an off-grid microgrid is the minimum inertia requirement in the system. The amount of inertia in an AC system is essential for the grid's frequency stability. Changes in the frequency are caused by load and production imbalance. The lower the inertia of the grid, the higher the frequency change during load and production imbalance. This can be understood by examining the power system swing equation:

$$\frac{2H}{f_s} \frac{\partial f}{\partial t} = P_{\text{prod.}}^{\text{pu}}(t) - P_{\text{cons.}}^{\text{pu}}(t) = \Delta P^{\text{pu}}(t) \quad \text{Eq. 1}$$

$$H = \frac{W_k}{S_n} \quad \text{Eq. 2}$$

$$W_k = \frac{1}{2} J \omega^2 \quad \text{Eq. 3}$$

where H represents the inertia of the network in per unit, f_s is the synchronous frequency of the grid, $\partial f / \partial t$ is the rate of change of frequency $P_{\text{prod.}}^{\text{pu}}$ and $P_{\text{cons.}}^{\text{pu}}$ per unit powers of electricity production and consumption, respectively, W_k the kinetic energy of the system, S_n the nominal power, J the total moment of inertia connected to the microgrid and ω the angular frequency.

Inertia is caused by rotating machines, such as generators, connected to electrical AC system. Typically, renewable generation is connected to the AC system through inverters, and those inverters do not provide any inertia to the grid.

Merus™ ESS includes a virtual inertia operation mode. This means that Merus™ ESS mimics the operation of a spinning generation and provides inertia to the grid. This sophisticated method enables further reduction of the online idling diesel gensets while maintaining the frequency stability in the microgrid.

5.2. Black start

Black start means the capability of an AC system to generate voltage from zero and ramp up the system without connection to existing electricity grid. The black start functionality of Merus™ ESS can be used to ramp up the off-grid microgrid voltage while other generation units can be connected to this voltage.

4. Studied cases

The operation of the microgrid was studied in three cases. In the first case the microgrid consists of diesel generator sets alone. Second case also includes some solar power. In the last case a 3 MW / 10 MWh ESS is included. In this case, also the solar power extension to 3 MW is included.

1.2. Case 1: Only DGSS

For reference, the fuel consumption was studied for a microgrid in which the production consists solely of DGSSs. Also, the reactive power generation and voltage control is done with DGSSs.

2.2. Case 2: DGSSs and solar power installation

Second study case considers solar power with the DGSSs. The installed solar capacity is 1.0 MW. The solar inverters cannot be used for reactive power generation or voltage control, so it is done with the DGSSs.

3.2. Case 3: DGSSs, ESS and extended solar power installation

The last case is the most sophisticated where a 3 MW / 10 MWh ESS is used for peak shaving of the solar

power production, voltage control and virtual inertia and fault current provision. The installed solar power capacity can be increased. The total installed solar capacity is 3 MW.

5. Investment payback time

The payback time was calculated for Merus™ ESS and solar extension investments. Case 2 is used as a reference. Study results are shown in Table 1.

Table 1 Total fuel consumption and DGS operation hours for one year of operation.

	Total fuel consumption
Case 1	2 791 544 liters
Case 2	2 327 330 liters
Case 3	763 241 liters

	DGS operation hours
Case 1	52 560.0 hours
Case 2	52 560.0 hours
Case 3	17 520.0 hours

The most important components for the investment payback time calculations in this case are the investment costs of Merus™ ESS and the solar plant extension, fuel savings, fuel price and DGS maintenance savings.

Because the fuel price is strongly market and location dependent, it was left as a variable for investment payback time calculations. The maintenance savings were calculated based on the reduced DGS operation hours shown in Table 1. The unit price \$ 40/kW/year for the maintenance costs was used.

The investment payback time calculations are shown in Table 2. It can be noted that the fuel price significantly affects the investment's feasibility. It should be noted that not only the purchase price of the fuel is relevant. In rural microgrids the fuel transportation and storage costs and guarding the fuel play a significant role in the total fuel price.

Table 2 Investment feasibility calculations.

Investment costs

3 MW / 10 MWh ESS + MGC	\$ 4 500 000
2 MW solar power extension	\$ 1 100 000

Maintenance savings per year

\$ 129 648

Fuel savings per year

Fuel price	0.75 \$/liter	\$ 1 304 796
	1.00 \$/liter	\$ 1 696 512
	1.25 \$/liter	\$ 2 088 229
	1.50 \$/liter	\$ 2 479 945
	2.00 \$/liter	\$ 3 263 377
	3.00 \$/liter	\$ 4 830 241
	4.00 \$/liter	\$ 6 397 106

Investment payback time

Fuel price	0.75 \$/liter	3.9 years
	1.00 \$/liter	3.1 years
	1.25 \$/liter	2.5 years
	1.50 \$/liter	2.1 years
	2.00 \$/liter	1.7 years
	3.00 \$/liter	1.1 years
	4.00 \$/liter	0.9 years

6. Conclusions

Renewable generation integration requires a sophisticated energy storage system and microgrid management in off-grid microgrids.

Merus™ ESS and Microgrid controller enable a significant reduction on diesel fuel consumption. The ESS also lowers the generator maintenance cost per year.

Investment payback time strongly depends on the fuel price but is around 1 – 4 years for typical rural off-grid microgrids.