Impacts of the Implementation of Hybrid Systems with High Renewable Penetration on the Operation of Thermal Units in Isolated Grids

Thorsten Althaus
OneShore Energy GmbH
Berlin, Germany

Philipp Kunze
OneShore Energy GmbH
Berlin, Germany

Christos Tsakiroglou
OneShore Energy GmbH
Berlin, Germany

Mohamed Helmy
OneShore Energy GmbH
Berlin, Germany

***Abstract*— The addition of renewable energies to isolated grids can lead to significant changes in the operation of existing thermal units, which are mostly diesel or HFO generator sets. Also, the amount of PV or wind power that can be integrated into the isolated grids is limited due to operational constraints of the thermal units. Main factors are the increased requirement of spinning reserve to react to fluctuations of renewable generation as well as the generator sets' minimum load. This paper outlines the impact of system hybridisation on the operation of a diesel generator plant considering the integration of renewable energies in scenarios with and without short term storage. Changes of runtime, efficiencies and number of starts and stops will be evaluated in a case study based on data obtained from the Greek island of Kythnos.**

I. Introduction

The output of a PV system can drop up to 80% within a minute due to cloud movement. Thermal units must be able to compensate for this sudden shortage of electricity. For this reason, spinning reserve needs to be provided in addition to the power that is generated. While renewable energy systems (RES) decrease the power demand from diesel generators, they increase the demand for spinning reserve at the same time.

In hybrid systems without storage many diesel generator sets must be kept online to provide spinning reserve, even if they are not needed for actual energy generation. Hence, they are operated at a low power output, which is only acceptable to a certain extent: the minimum loading. Diesel generator sets must be operated above this threshold to avoid decreasing efficiency and damage to the engine. The more thermal capacity is online due to the spinning reserve requirement, the greater the total minimum load becomes, which limits the potential to include energy from RES.

Short term storage (STS) can be used to safely switch off diesel generators during times of high renewable generation. In the event of sudden drops of renewable output, such storage systems can immediately intervene to stabilise the system and provide power for enough time to start additional diesel generator sets if needed. Switching off some units decreases the absolute minimum load during these times, which gives more room for the integration of RES. However, the number of starts and stops of the diesel generator sets increases significantly.

The focus of this paper is to outline the impact of hybridisation on the diesel generator system, particularly looking at generator efficiency, runtime and number of start-ups and stops.

II. Case Study

The analysis in this paper is based on data of the island of Kythnos, which belongs to the Cyclades and is one of the 32 non-interconnected island systems in Greece.

Depending on season the average load on Kythnos amounts to between 700 and 2,000 kW with peak values rising to more than 3,000 kW. Power is supplied by three 1,200 kW Mitsubishi and four 400 kW MWM diesel generator sets. Currently generator dispatch on the island sets priority to the large units, of which typically as least one is being operated. More units are added as required by the load. Especially during the peak summer months all three of the large generators must be operated. Of the small generators typically one or two are added when needed.

In addition to the diesel generator sets a total of 250 kW of PV are in operation across the island. As those units are not integrated with the thermal plant with a hybrid control system, they will be only considered as a negative load for the further analysis and all PV sizes stated hereafter refer to additional capacities.

In two scenarios the integration of further RES is simulated and evaluated regarding its impact on the operation of the diesel generator sets. To ensure comparability between the two cases the PV systems are sized to the maximum capacity that can be integrated with only 5% of curtailment. The two scenarios are described in the following:

A. Scenario 1: PV diesel hybrid

A 450 kW PV system will be integrated with a hybrid controller that (when required) limits RES production to maintain the diesel generator sets above their minimum loading of 30 %. Generators are expected to provide spinning reserve for 80 % of the momentary PV output.

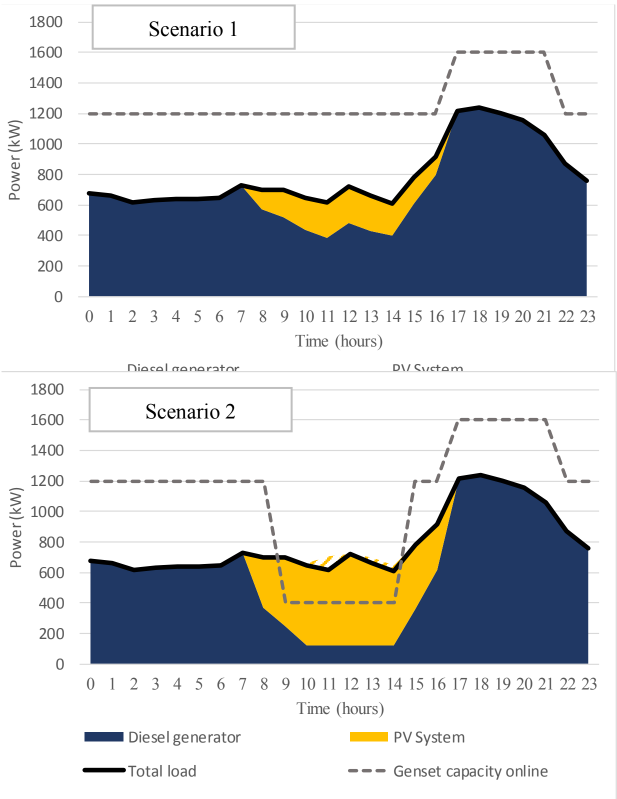

Figure 1. System operation on an example day in scenario 1 (top) and scenario 2 (bottom)

B. *Scenario 2: PV diesel hybrid with short-term storage*

A 1000 kW PV system will be integrated with a 500 kW STS system providing spinning reserve. During times of high RES generation diesel generator sets can be safely switched off. Again, PV output would be curtailed to maintain diesel generators sets above minimum loading if necessary and it is assumed that 80 % of the momentary PV output need to be covered by spinning reserve from either the diesel generator sets or the STS.

Example operation of the two scenarios is depicted in figure 1. The STS in scenario 2 allows to switch off the large diesel generator and use a small unit instead together with the PV. The running genset capacity is in this case lower than the load of the system. The STS makes sure that strong fluctuations of the PV system would not lead to a blackout.

It should be noted that for the safe operation of hybrid systems with high renewable penetration (in both scenarios of this case study) it is crucial that the genset control system considers status and production of PV system and STS for the calculation of required spinning reserve.

Results of the case study are summarised in Table 1. Implications of the integration of PV and STS will be discussed in the following sections.

TABLE I. CASE STUDY RESULTS (ANNUAL)

Item	Scenario		
	Base case	***Scenario 1***	***Scenario 2***
Genset production	7,943 MWh	7,206 MWh	6,397 MWh
Solar share	0 %	9 %	20 %
Genset average loading	63 %	57 %	64 %
Fuel consumption	2,377k l	2,211k l	1,908k l
Fuel reduction	-	7 %	20 %
Genset runtime (total)	11,481 h	11,423 h	10,127 h
- thereoff (1200 kW)	9,986 h	9,967 h	7,337 h
- thereoff (400 kW)	1,495 h	1,456 h	2,790 h
Number of genset starts	561	559	917

III. LOW LOAD OPERATION

Figure 1 shows how increasing penetration of RES pushes diesel generator sets more and more towards lower operating points during sunshine hours.

A. *Impact on diesel generator set condition*

Continuous operation of the diesel generator sets at low loading can lead to severe issues with the machinery such as [1]:

- Wet stacking: unburnt fuel condensing in the exhaust system
- Sooting: carbon deposits settling on injectors, pistons, valves and turbochargers
- Bore glazing: unburnt fuel and oil derivates surfacing the cylinder liner and hindering lubrication

All these effects reduce performance of the diesel generator set and increase wear and tear, which may lead to frequent replacements of engine parts and hence downtime of the generator set.

For this reason, the determination of the minimum loading is always a big discussion point when it comes to integrating RES with existing diesel generator plants. Typically, this value can vary between 30 and 50 % depending on the generator set and how conservative operators are.

Manufacturers have been investigating this aspect and recommend principles for low load operation. As an example, Finnish manufacturer Wärtsilä specify for one of their engine types that 100 hours of operation below 20 % loading are acceptable if the load is afterwards increased to at least 70 % loading [2]. This measure will blow any soot and fuel residues out of the system and 'undo' the effects of low load operation.

In this paper a minimum load of 30 % is aplied for all diesel generator sets. The change of average loading in the different scenarios is depicted in table 1. Integrating PV without storage leads to a significant decrease of generator set loading during daytime and overall to a 10 % decrease compared to current operation.

With STS this can be avoided as it is possible to switch to a smaller unit, which is then operated at a higher loading. Hence, for scenario 2 average loading remains almost unchanged. Due to the permanent operation above minimum load, none of the issues outlined above need to be expected, especially considering that the load profile leads to an 'automatic' increase of generator set loading towards the evening hours, which will have a cleaning effect on the engine.

B. Impact on diesel generator set efficiency

Little is known about diesel generator efficiency at low loading, as datasheet fuel curves are typically only stated between 50 and 100% output of nominal rating.

At the site of an industrial customer, who operates a well oversized diesel generator set, the lower range of the fuel curve was measured by OneShore using metering devices for fuel and electricity. Figure 2 shows the resulting data points and compares them to the extrapolated values from the datasheet.

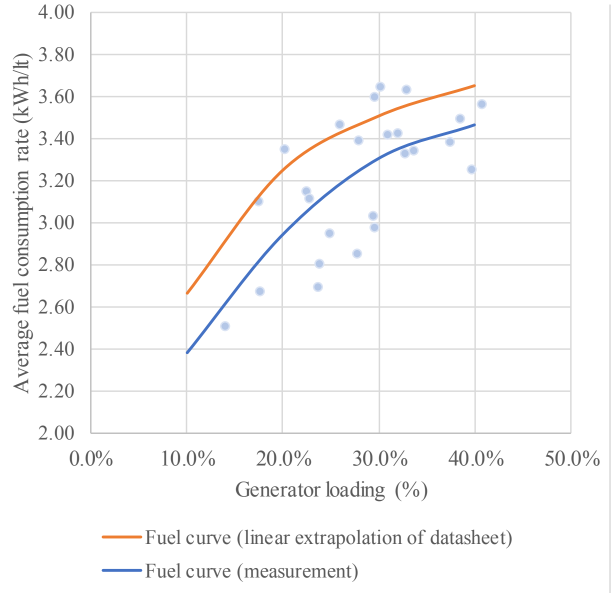

Figure 2. Specific production of a 400 kW diesel generator set operated at low loading

The curves are similar in shape, but measurement values on average 5 to 10% lower than the extrapolated reference values from the datasheet. Especially during very low loading the curves spread. The deviation can be explained by age and wear and tear of the diesel generator set, as well as derating due to environmental conditions.

The diesel generator sets on Kythnos are already advanced in years, so the fuel curve of their datasheets was adapted similarly to this exemplary case above for calculating the fuel consumption. Achievable fuel savings for each scenario per year are illustrated in table 1.

Fuel savings in litres are notably lower than electricity savings (solar share) in scenario 1. This can be directly related to the reduction of average generator loading and reduced efficiency in this range.

IV. Runtime Reduction

Manufacturers of diesel generators provide recommendations for preventive maintenance such as general inspections, cleaning, lubrication, servicing of air, fuel and cooling system, as well as exchange of parts. Maintenance tasks are to be carried out according to the running hours of the diesel generator set, typically every 250 to 500 hours.

If hybridisation of the diesel generator plant allows reducing running hours of the individual units, operating cost are expected to be reduced. This will particularly apply to consumables required for maintenance, small spare parts, oil and grease and any other variable cost. Fixed cost for operators' salaries, building rental, etc. will remain.

Total running hours of the gensets per year are outlined in table 1. In a hybrid system without storage no significant reduction can be expected, as due to the high spinning reserve requirement operation is almost the same as in the base case without PV.

In scenario 2 total running hours can be reduced by 12 % as gensets can frequently be switched off during times of high PV production. It is notable that running hours of the large diesel generator sets decrease by more than 30 % whereas running hours of the small diesel generator sets increase and almost double. Hence, there is a shift from power generation from the large diesel generator sets to the small units. This can be explained, as during the seasons with lower loads often a single small generator set is sufficient to supply the load together with PV and STS instead of having to run a large engine.

V. Generator Starts and Stops

Reducing and shifting running hours as described above leads to more frequent starts and stops of the generator sets. A frequent start and stop, which today is already common in cars, is unusual for diesel generator sets and increases stress on battery, bearings and starter.

The number of starts and stops in the case study are depicted in table 1. As for the running hours there is no change looking at scenario 1, as they are both at 1.6 starts per day. In scenario 2 the number of generator set starts and stops increases significantly to 2.5 starts per day, which is not a critical value.

Starts and stops for maintenance breaks and rotation of the engines to balance running hours are not considered in above numbers.

VI. Conclusion

In this paper several aspects of the operation of diesel generator sets were discussed. In a case study the effect of hybridisation on these parameters was evaluated for two scenarios.

It was shown that low load behaviour of the diesel generator is a critical factor. The aspect of increased wear and tear can typically by avoided: On the one hand based on enforcing a minimum load with a hybrid controller, on the other hand due to increasing loads towards evening hours that allow operation at higher loadings to clean the system.

However, low load efficiency has a strong influence on achievable fuel savings, especially in scenarios without storage. Due to a lack of data in the datasheets as well as required derating of diesel generators in the field it is recommended to carry out measurement campaigns to make an accurate forecast of fuel savings. When planning green-field systems a high efficiency over a wide range of loads should be one of the key selection criteria for the diesel generator sets.

Simulation results showed that the integration of PV and STS leads to significant changes in operation of systems with differently sized diesel generator sets. In such case in parallel to a reduction of total running hours a shift of operation from larger to smaller engines can be watched. How this translates into actual cost savings needs to be elaborated with the operating personnel on site.

For future works the operation of the STS will be evaluated in more detail using higher resolution data to refine and verify operation of the diesel generator sets in the second scenario.

[1] J.M. Hamilton, M. Negnevitsky, X. Wang, A. Tavakoli and M. Mueller-Stoffels, “Utilization and Optimization of Diesel Generation for Maximum Renewable Energy Integration”, in Smart Energy Grid Design for Island Countries, DOI 10.1007/978-3-319-50197-0_2, Springer International Publishing AG 2017

[2] “Wärtsilä 32 product guide”, Wärtsilä Finland OY, 2016