A tool for the simulation of large PV-diesel-systems with different dispatch strategies

Silvan Faßbender, Christian Brosig, Evandro Dresch, Eberhard Waffenschmidt
Cologne Institute for Renewable Energy (CIRE), Cologne University of Applied Sciences,
Betzdorfer Str. 2, 50679 Cologne, Germany.
Corresponding author: silvan.fassbender@gmx.de

Abstract — **Hybrid energy systems have the potential to bring modern energy services to the 17% of the global population with no access to electricity. The use of diesel generators to provide power for such applications has been the standard for several decades, but due to decreasing prices of photovoltaics, hybrid systems are becoming more common.**
As a special challenge expanding existing diesel generators with photovoltaics leads to increased dynamic specification and non-favored operation states for the diesel engine. While it is common to limit the photovoltaics or to add a battery storage to reduce non-favorite operation states, this paper presents load shifting and control as a solution for dispatch. 25 different households are simulated including in total 108 different devices and in total 1737 individual electrical consumers. The devices are operated based on ratings of the users to improve the overall subjective satisfaction with the control.

1 Introduction

Photovoltaic (PV) systems are especially suitable for the electrical power supply of remote off-grid regions. However, still today the majority of systems are supplied by diesel generators. More and more those existing diesel grids are extended with renewable energy generators, especially PV [1]. Such a hybridization of diesel systems with renewable energies faces complex challenges, especially if a high penetration of PV is aimed.

As an example, diesel generators are inefficient under certain conditions, e.g. in a power range below 50% of their nominal power or at very high power levels. Low power levels may lead to a reduced lifetime or to higher emissions [2]. In systems with a high share of PV generation this may become problematic, because the diesel generator must at any time be able to compensate for short term fluctuations of the PV generation. In such cases the diesel generator should be operated at an operation point with reduced power to provide enough reserve. To avoid this, usually the PV generation is limited in such a case, especially in systems without battery storage. This is the general principle of the so called “fuel saver” technology.

Here, a tool is presented, which is able to consider and avoid such undesired states of the diesel generator for a simulation. It is able to limit and reduce PV generation and also to include the operation of a battery storage. The tool is also able to consider load control and shifting to optimize the diesel performance. Since this a special feature compared to existing literature, this publication focuses on this option as dispatch strategy for the system. Therefore, this publication presents an algorithm, which switches loads on and off in dependence on the status of the diesel generator with lowest possible impact on the perception of the user.

2 Load Shifting and Control with PV-Diesel Systems - State of the Art

The application of load shifting and load control in PV diesel systems has been investigated in several publications. The work of Sichilalu and Xia [3] investigates the control of heat pumps for warm water provision in grid connected PV-diesel systems with batteries. The heat pump is operated with the energy stored in the battery during high demand times. Therefore, this work principally differs from the algorithms presented here.

A further investigation by Kallel et al. [4] is more similar to the work presented here and describes a system for the load control of off-grid hybrid systems for the electrical power supply of households. In this case the power flow is compensated to minimize the size of the components, the fuel consumption and the emissions and in addition to save the battery lifetime. The algorithm uses the stored data of the consumption behavior of the household’s inhabitants as well as the stored PV power profile and battery state of charge. The diesel generator is used only as additive power source and thus the share of the diesel generator is only 5% of the demand. Contrary, this presented work assumes different frame conditions as the previous cited one, because no batteries are assumed in the system and the load control is used to optimize the operation of the diesel system.

Further publications propose different approaches to predict the user’s behavior, e.g. with Monte Carlos Simulation [4], or an advanced metering infrastructure [5]. Those analyzed systems also include a storage.

As another work, Elamari [6] presents a simple a simple system with only one PV system and one diesel generator. In this case, a frequency controlled electric warm water provision as controllable load is used. This publication shows how to balance the grid frequency with a simple load control algorithm.

Here, a similar approach is presented, which, however, uses load profiles for ordinary households to take decisions concerning switching on or off of loads. The aim is to keep the diesel generator in a most efficient and long-lasting operation point while switching only that equipment, which has a low subjective importance to the users.

3 SIMULATION

The presented algorithm for the load control is developed with MATLAB in order to be able to integrate it into a simulation environment for PV-diesel systems, which is in development. Similar to reference [4] loads of households are used. The tool LoadProfileGenerator by Noah Pflugradt [7] is used to generate high resolution load profiles. 25 different households are simulated including in total 108 different devices and in total 1737 individual electrical consumers. Measurement data of a 4.51 kWpk system [8] is used for the PV profile, scaled to the individual cases. Data sheets of the diesel generator [9] are the source for data on fuel consumption. Data about the consumer behaviour and the priority of the individual device types are taken from [8] and [10]. In this publication the priority for the users is attributed to different devices based on a survey. The priority varies between 1 and 5, where 5 has a high priority for the users and 1 the lowest. As a Figure of Merit a sufficiency coefficient *Sk* is introduced [8]. *Sk* is a value, which indicates how satisfied the users are with the solution provided by the control. It ranges between 0 and 1, where 1 corresponds to full satisfaction (every device can be used as desired) and 0 means no device at all can be used. It can also be considered as a qualitative grade of autarky.

The aim of this simulation is to develop an algorithm, which is able to switch on and off loads taking into account the operation point of the diesel generator and the subjective priority for the users. In general, any profile data could be used for this algorithm. However, the data used in this work is used to demonstrate and verify the function of the algorithm. One month in summer and one month in winter are investigated with a time resolution of 15 min. The algorithm checks the operation point of the diesel generator at each simulation step. If it is operated in a less suitable range (below 50% or above 90% of the nominal power), the actual load profile of all households is checked and devices are switched on or off randomly but taking into account the user's priority.

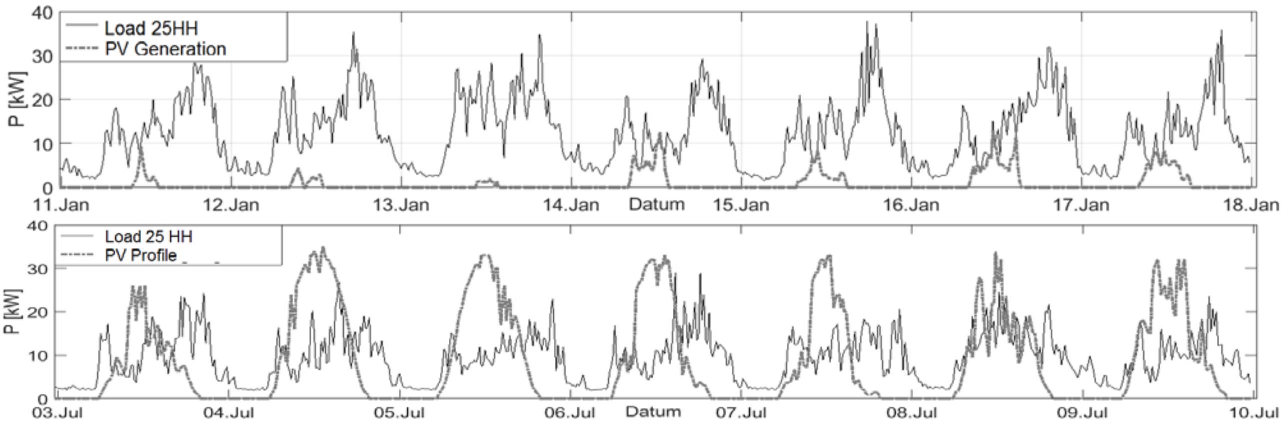

Figure 1: PV and load profiles considered for two weeks in a winter (top) and summer month (bottom)

4 RESULTS AND DISCUSSION

The graphs in Figure 1 show the PV and load profiles of the 25 households considered for two weeks of a winter and summer month. The reference system consists of a 20 kW diesel power plant (Prime power) [10] and a 45.1 kWp PV-plant.

Figure 2 shows the Operation point of the diesel generator with or without load control for the considered weeks of the previous figure. In a winter month (Figure 2, top), the diesel generator without load control is overloaded due to various load peaks. Therefore, several consumer must frequently be switched off, in particular in the evening. The generated diesel power does not significantly change, because the supplied of PV-power is low. Especially at night, the diesel generator have to run at low operation points. In consequence, power consumer have to be switched on to guarantee a minimum partial load of 50%. Ideally, these *dump loads* are heating elements that convert electrical power into heat or hot water. Nevertheless, in this case the consumer behavior of household residents must be adapted to optimize the operation point of the diesel generator.

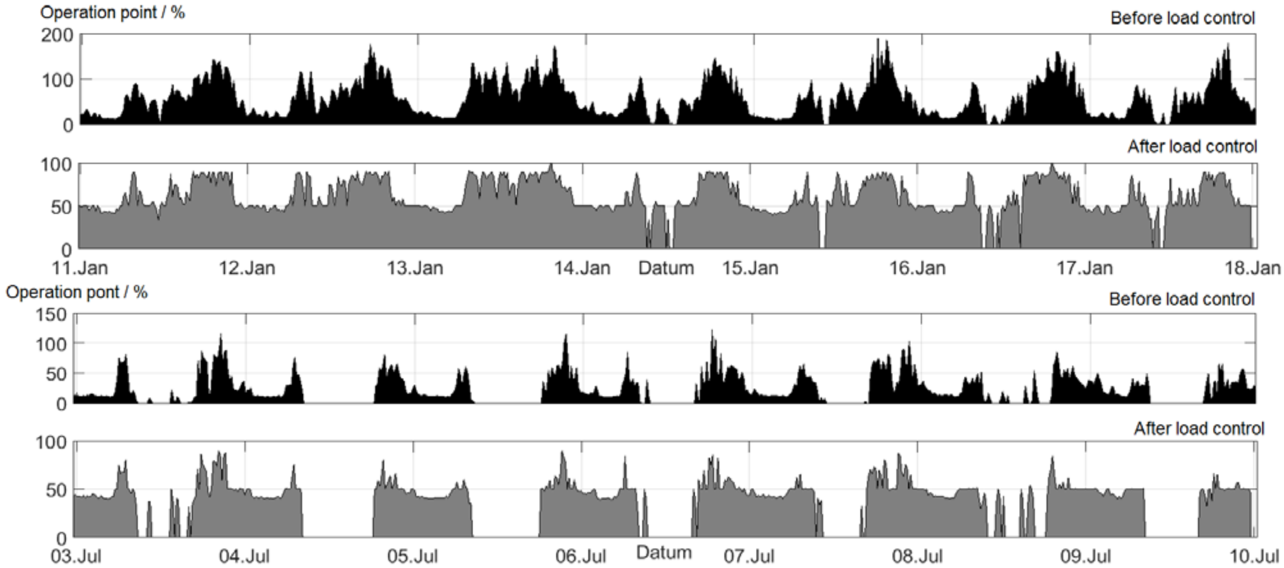

Figure 2: Operation point of diesel generator – with and without load control. Top: winter month, bottom: summer month

In a summer month (Figure 2, bottom) the loads during daytime are almost completely covered by solar power and the diesel generator can often be shut down. However, the PV-power often has to be limited. Furthermore, at night the operation point of the diesel generator is still too low. The generator operation can be optimized by means of a load control, but again various dump loads have to be switched on. Alternatively, this problem could be solved by installing two diesel generators – one would cover the base load and the other would cover only load peaks.

Figure 3 shows the needed number of switched-off devices considered in a winter and summer month and depending on the PV-plant size. Any device can be switched off for a minimum time step of 15 minutes. In the simulation, the load profile of the next time step is evaluated before switching on again. Therefore, it is possible a device of a low usage priority is switched off for hours.

The number of shutdowns only weakly correlate with the PV-plant size, in particular in the winter month. In addition, a PV-plant greater than 45 kWp would not be profitable, because the power is limited to a larger extent. The savings of the diesel consumption only decrease lowly in terms of a greater PV-plant size. Without PV-plant the monthly diesel consumptions is equal to 2300 liters. With a PV-plant of 90 kWp the diesel consumption is about 1900 liters. In the case of load control by switching loads on at night, the diesel consumption increase by 50%. In the summer month the total amount of needed switched-off devices almost decrease by a third compared to the winter month due to higher PV power supply and a lower power demand. With a 90 kWp PV-plant, again, the diesel consumption results in 1900 liters. Without PV-plant the diesel consumption is equal to 2400 liters.

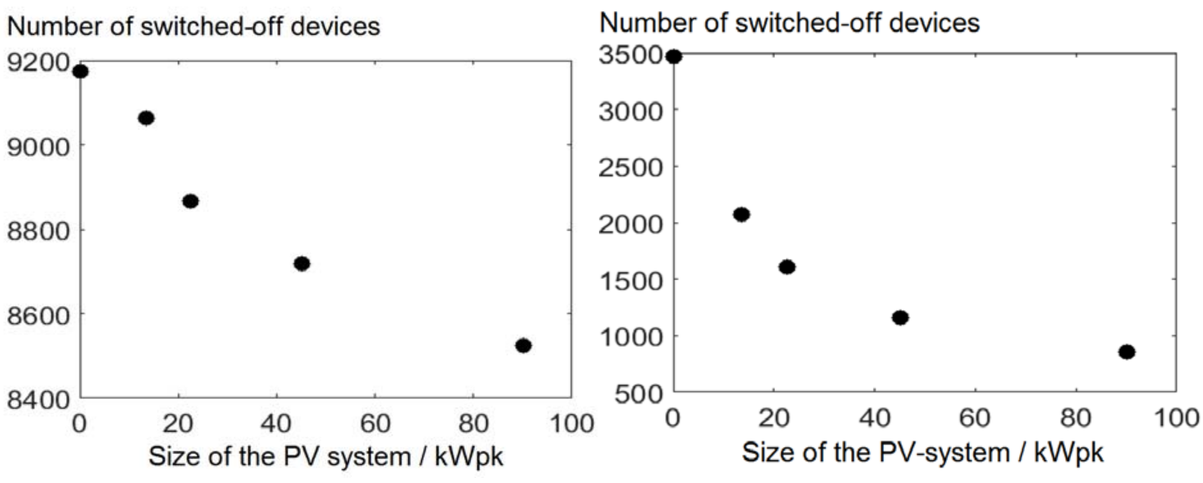

Figure 3: Number of shutdowns of consumers in winter (left) and summer (right) depending on the PV-plant size. Every shutdown lasts for a minimum of 15 minutes.

The number of needed power-on actions to optimize the operation point of diesel generator in a winter and summer month is equally very high. This operation mode turns out to be unrealistic. In consequence, the power supply for 25 households by a PV-Diesel system can only be implemented by more complex operations. Either a battery is needed or the number of generators must be increased. Thus, the potential of a load control to avoid an overload of the diesel generator is much higher.

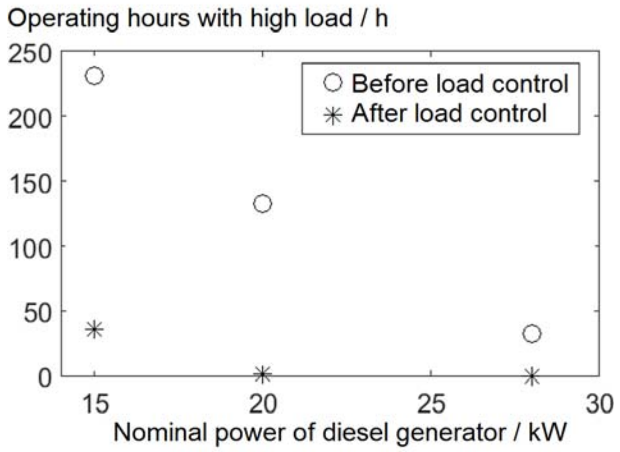

Figure 4: Operating hours with high load depending on the diesel generator size.

The number of operating hours with high load depending on the diesel generator size can be reduced significantly by an intelligent load control. In the latter case, the switched-off devices doesn't strongly affect the household resident's behavior, because devices of high usage priority don't have to be switched off as often. In the winter month, depending on the PV-plant size, devices with a usage priority lower than 1 (about 20 per time step in which devices has to be shut down) are shut down between 259 and 280 times. In this case, the number of powered-on devices depending on the time step rages between 400 and 500. 10 devices of the highest priority must be switched off for 532 time steps in which devices have to be switched off. In the summer month, the number of needed shutdowns is decreased by 80%. Thus, the sufficiency coefficient is in both cases for the 25 households high. This is because residents don't have to abstain from important power consumer for a long time.

5 Perspective

A simple PV-Diesel system without battery is unsuitable for the supply for dynamic household loads, also with load control, because the number of operating hours at low operation points is too high. For this application, a diesel generator with a common-rail-injection system would be necessary, which also works below a partial load of 50%. A generator overload can be avoided by a load control. Further, industrial load profiles should be considered.

This project is funded by the Federal Minitry for Economic Affairs and Energy (BMWi) with the sign PTJ-100196271.

References

[1] R. Kempener, O. Lavagne, D. Saygin, J. Skeer, S. Vinci, and D. Gielen, "Off-Grid Renewable Energy Systems: Status and Methodological Issues," Abu Dhabi, 2015.

[2] E. D. Tufte, "Impacts of Low Load Operation of Modern Four-Stroke Diesel Engines in Generator Configuration," Norwegian University of Science and Technology, 2014.

[3] S. M. Sichilalu and X. Xia, "Optimal Power Control of Grid Tied PV-battery-diesel System Powering Heat Pump Water Heaters," *Energy Procedia*, vol. 75, pp. 1514–1521, 2015.

[4] R. Kallel, G. Boukettaya, and L. Krichen, "Demand side management of household appliances in stand-alone hybrid photovoltaic system," *Renew. Energy*, vol. 81, pp. 123–135, 2015.

[5] L. Zhu, Z. Yan, W.-J. Lee, X. Yang, Y. Fu, and W. Cao, "Direct Load Control in Microgrids to Enhance the Performance of Integrated Resources Planning," *IEEE Trans. Ind. Appl.*, vol. 9994, no. c, pp. 1–1, 2015.

[6] K. Elamari and L. a C. Lopes, "Frequency based control of electric water heaters in small PV-diesel hybrid mini-grids," *2012 25th IEEE Can. Conf. Electr. Comput. Eng. Vis. a Greener Futur. CCECE 2012*, pp. 0–3, 2012.

[7] N. Pflugradt, "LoadProfileGenerator LoProGen." [Online]. Available: www.loadprofilegenerator.de. [Accessed: 26-Nov-2015].

[8] C. Brosig, "Energie-Autarkie von Haushalten durch Suffizienz-Maßnahmen," Fachhochschule Köln, 2015.

[9] K. P. Systems, "Data Sheet Model 20REOZK." pp. 4–7.

[10] Christian Brosig, Eberhard Waffenschmidt, "Energy autarky of households by sufficiency measures", 10th International Renewable Energy Storage Conference (IRES 2016), Düsseldorf, 15.-17.3.2016