Application of the Open Source Energy Management System OpenEMS in Hybrid Power Systems

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Abstract— **In this paper, the open source energy management platform OpenEMS is used to evaluate its usability in off-grid hybrid power systems. Two additional bundles are implemented into the OpenEMS framework which emulate a generator and a generator controller. With help of these bundles, implemented into OpenEMS, a realistic emulation of a Nepalese village mini-grid is simulated and the effect of the integration of photovoltaics and batteries into the system is analyzed. The investigation shows that with the help of OpenEMS a complex hybrid power system can be managed in a simulation environment.**

Keywords-OpenEMS, Energy Management System, Generator, Battery

I. INTRODUCTION

In hybrid power systems, a large variety of different energy sources and loads can be combined and their interaction needs to be managed in a meaningful way. Depending on the objective to be pursued, a different management strategy must be implemented. The objective can for example be the reduction of the overall costs, the maximization of the autarky or to maximize the stability of the energy system. The translation of these objectives into a management strategy is a central task in the development of hybrid power systems. The corresponding algorithms together with the control hardware and the interfaces for the different communication protocols are generally referred to as Energy Management System (EMS). Depending on the architecture of the energy system, the hardware of the EMS can be separated in several edge controllers and a backend controller. An example for such architecture is given in Figure 1.

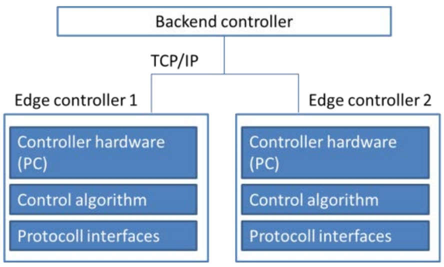

Figure 1: Architecture example of an Energy management System (EMS) with a backend and two edge controllers

A central challenge in the realization of an EMS is the intercommunication between the different EMS controllers, which need to be able to understand the communication protocol that each and every component is using. This is an easy task if the EMS and all the components are fabricated by the same manufacturer or if only one communication protocol is used by all the implemented components. In this case, the compatibility of the components is reduced to a setup procedure that is generally described very well in the manuals of the components.

If components shall be combined that are using different communication protocols and if proprietary algorithms shall be implemented in the central controller unit the setup procedure of the system can become very complex and time consuming. As this is a recurrent problem, it would be favorable if an open source platform would be available that can provide the users with pre-programmed protocol modules that can easily be implemented into the system to allow the communication between the EMS and the other components of the system. Also, the customization of the control algorithms could be done in such an open source platform where all the code is visible for the users. An additional advantage of such an open source EMS platform would be that the platform could be optimized and further developed by a large community of interested stakeholders. Such an open approach would free up resources and allow companies to focus on their core competencies.

The OpenEMS Association was founded launched in November 2018 to maintain, promote and develop an EMS platform that includes all the positive aspects of an open-source approach. Numerous projects were already realized with the help of this platform. However, most of these projects were grid-connected systems and there are only a few examples of off-grid systems realized with the help of OpenEMS.

In this paper we focus on the implementation of an EMS that controls a hybrid power system consisting of several diesel generators, a photovoltaic (PV) system and a central battery storage system. The central question that will be answered in this paper is if the OpenEMS platform allows controlling the generators such that a maximum fuel saving potential due to the integration of PV into the system can be achieved.

II. OpenEMS: An open source Energy Management System platform

The OpenEMS association was founded by 30 companies, organisations and research institutes to establish an open source energy management platform. The main goal of the association is to establish a joint development process of the software to make it more stable and secure and to implement the most important communication protocols that are used by components that can eventually be part of an energy system. Making the platform available to the public will free up capacities at companies and other user groups and thus will give them the possibility to concentrate on their core business.

The software platform is based on well-establisched Java OSGi framework that allows creating a modular software architecture, where components can be added and removed during runtime of the platform. Every element of the energy system is represented in form of a so-called "bundle". The user interface, in contrast, is written in JavaScript.

If one wants to setup a system only containing devices that are already part of the OpenEMS framework the setup can easily be done by simply activating the corresponding bundles. If a component is not yet included in the framework, a new bundle needs to be created for it. This requires some basic programming knowledge. Additionally, the structure of OpenEMS needs to be understood in detail and basics of object-oriented Java programming, basics of the OSGi framework and Bndtools basics need to be acquired.

The basic OpenEMS code, hosted on GitHub, was initially developed by the company Fenecon, which uses the platform to setup and manage their storage systems in the field. Thus the platform has already been tested and debugged in many real systems and several further systems outside of the company Fenecon confirm the good performance of the current platform version. The quality was additionally emphasized by the fact that the platform was awarded third place on the PV magazine's list of "the top ten developments in the field of Energy Storage Highlights" [1].

III. Setup of the simulation environment

To verify if the OpenEMS platform is capable of effectively controlling an off-grid hybrid system, a practical as well as a simulation approach is feasible. As the practical approach would present only the results for one configuration the simulation approach was chosen for this paper.

For the simulation two new bundle elements were added to the OpenEMS platform. One of the bundles is a representation for each generator where the characteristic data of the generator needs to be setup. For every generator one of these bundles needs to be activated. The second newly developed bundle is a central generator control unit that collects the information of the different generators in the system, determines the output power for every generator and sets them to the corresponding value. Every generator can operate in one of the following states:

- State 1: OFF
- State 2: MAXIMAL POWER
- State 3: SPINNING RESERVE MODE
- State 4: DROOP MODE

For the control of the generators different parameters need to be taken into account. Every generator has a minimum load factor (MLF) value that may not be undershot. This value is given by the manufacturers and is often in the range of 40% [2, 3]. If the generator is operated beneath this value it can severely reduce its lifetime. For the overall stability of the system, a spinning reserve (SR) value is often set. This means that one of the generators is not operated at nominal power but ensures availability of a power reserve that can be activated if suddenly high load peaks occur (e.g. if the PV system is suddenly switched off due to an inverter error) [4].

The generator control algorithm as implemented in the controller bundle maximizes the off-time of the generators and thus minimizes the fuel consumption of the generators. The architecture of the system that was simulated for this paper is given in Figure 2.

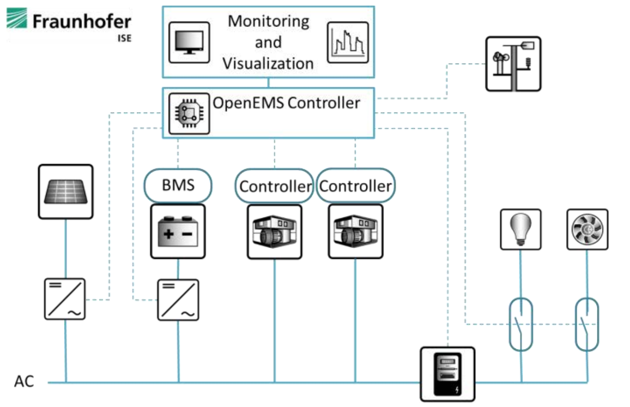

Figure 2: Schematic representation of the system architecture that was chosen for the simulation. BMS stands for battery management system.

The load and radiation data are given as fix values and are given in form of a CSV file that is read into the OpenEMS framework by the already available DataSource bundle.

IV. Testing the simulation setup

A simulation example was conducted using the load and radiation data of a rural village in Nepal. It is a small isolated town on a trekking route in the Annapurna massif. It has about 350 households as well as small shops, hotels and restaurants for tourists. There is no connection to the national electricity grid and there is no possibility for grid expansion. Although power generation in Upper-Ghandruk is done by a small hydropower plant, the village is chosen as an example because of its representative features. Many other villages in the Himalayas and other regions of the world have comparable load profiles. The hourly load profile of the village can be seen in Figure 3.

The base power for the electricity supply consists of two diesel generators with a nominal power of 50 kW each. Different hardware configurations for the generator control hardware are possible. Either both generators are controlled from a central unit, or each generator has an individual controller. An overview on the control methods and the available genset control units is given in Lopes et al. [5].

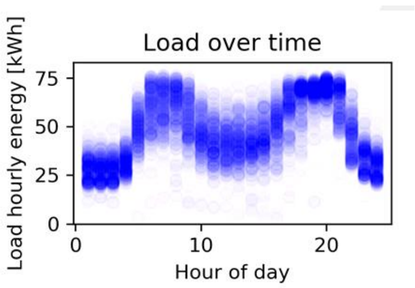

Figure 3: Hourly load profile of a village in Nepal. The darker the color the more often the energy value occurs at a specific hour of the day.

The simulation was performed on an hourly basis and the results were compared to the results obtained with an energy-analysis software tool from Fraunhofer ISE. The results are almost identical. The simulation was carried out for different PV penetration levels (ratio of PV peak power to maximum load power value). The system was also simulated for the case without battery and for three different battery sizes. The fuel saving potential that can be achieved as a function of PV penetration is shown in Figure 4. It turns out that the fuel savings potential at a given level of PV penetration is saturated depending on the size of the battery. Saturation occurs at higher PV penetration values the larger the battery is.

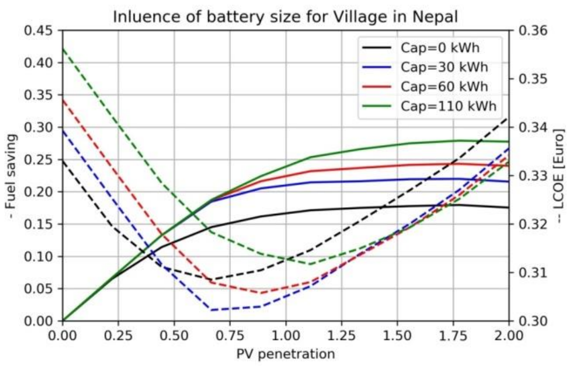

Figure 4: Fuel saving potential and LCOE over the PV penetration for the example of a Nepalese village.

However, to decide which PV penetration level to choose, an additional parameter is often considered, namely the Levelized Cost Of Electricity (LCOE).

The calculation of this indicator requires several assumptions about interests, investments, and operational expenses. A central cost element is the fuel costs of the generators. The cost is calculated as the product of the consumption in liters and the specific fuel price.

In Figure 5 the specific consumption curves of a 365 kW generator is exemplarily shown. Three measurement points are sufficient to find a linear fit from that the specific consumption in terms of energy can be calculated. It is assumed that the specific consumption is linearly depending on the size of the diesel generator such that a projection on smaller engines is possible.

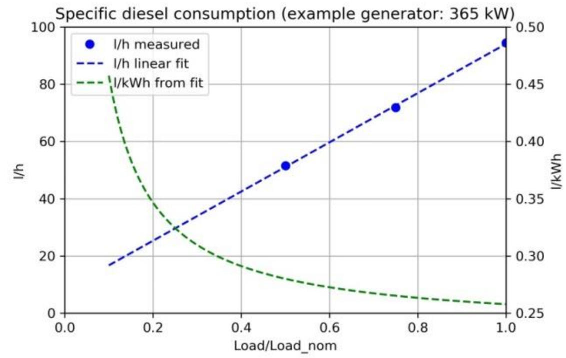

Figure 5: Specific diesel consumption

The specific fuel price is estimated at 1.18 euro per liter. This price includes the cost of transporting the diesel to the system under investigation. It should be noted that fuel prices fluctuate widely and that these economic calculations take neither inflation rates nor possible price increases into account. Other simplifications that have been adopted are:

- No credit costs assumed
- No operation costs except from the fuel costs
- No maintenance costs implemented
- No variation of generator lifetime due to varying run-times

The specific costs for the initial investments and the specific fuel price are given in Table 1.

Table 1: Assumed specific costs for the determination of the LCOE

	Costs	Source
Photovoltaic system	1550 Euro/ kWp	[6]
Battery system	800 Euro/ kWh	
Generator System	580 Euro/ kW	[6]
Diesel fuel price	1.18 Euro/ liter	

The initial investment A_0 consists of the costs for the PV system, the generators and the battery.

If the annual costs A_a and the annual energy yield E_a are assumed to be constant, the LCOE can be determined by the following equation [7].

$$\mathrm{LCOE} = \frac{A_0 + A_a \cdot \sum_{i=1}^{n} \frac{1}{(1+p)^i}}{E_a \cdot \sum_{i=1}^{n} \frac{1}{(1+p)^i}}$$

As proposed in other studies [6] the discount rate p for the case study was set to 9% .

The results in Figure 4 show that the LCOE can be further reduced if a battery is included in the system that is well proportioned. With such a battery more PV can be included into the system and thus the emissions can further be reduced. Including larger batteries the LCOE increases but as a higher PV penetration level is feasible the overall emissions can further be reduced.

V. Results and outlook

The simulation approach described above demonstrates that it is possible to use the OpenEMS framework for the management of all the components in a diesel-based hybrid system. The results for the example case of a Nepalese rural village are identical to those received from another simulation tool developed at the Fraunhofer ISE.

The implementation of new bundles in the framework was straightforward and no major restrictions of the framework were identified. However, it must be mentioned that for newcomers to Java-OSGi programming a steep learning curve must be mastered.

Even though the developed bundles worked well further steps need to be done. Other management strategies need to be implemented into the generator controller bundle. This could for example be an algorithm that maximizes the stability of the hybrid system and another one that is capable of controlling the system as part of a week electricity grid. The controller can also be extended to include other sectors such as heating or cooling processes. Furthermore load and yield predictions can be included into the controller to further optimize the performance of the system [8].

Even though the simulation approach reveals the potential of the framework it is necessary to test the framework in a hardware setup.

Acknowledgment

Above all, Stefan Feilmeier (Fenecon) deserves to be acknowledged for the creation of the OpenEMS framework. Without him this investigation would not have been possible. He also strongly supported us by creating the new bundles for this paper.

VI. References

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