

AN ENERGY STORAGE INTEGRATION TOOL FOR MICROGRID TECHNO-ECONOMIC ASSESSMENT

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ABSTRACT

This paper presents the Energy Storage Integration Tool (ES-IT) that has been developed by DNV GL, which allows for simulation of the behavior of microgrids with Distributed Energy Resources (DER) and Energy Storage Systems (ESS). ES-IT is a python-based optimization tool that provides practical results for the design of both islanded and grid-connected micro-grids, and for households with ESS. The optimization for system dimensions can be selected for achieving different goals and it allows for more robust and efficient micro-grid architectures to be used. The ES-IT tool enables system developers to design a sustainable microgrid to provide customers in remote areas with cost-effective, sustainable and reliable electric power, focusing on RES and thus minimizing dependency on fossil fuels. In this paper, the tool and its capabilities together with the model inputs and outputs are described. Moreover, a comparative study that has been performed using the ES-IT tool for two case studies is presented. Finally, the two projects, SOPRA (Sustainable Off-grid Powerstation for Rural Applications) and CSGRIP (Cellular Smart Grids Platform), within which the ES-IT tool has been developed, used and validated, are discussed.

INTRODUCTION

Increasing the share of Renewable Energy Sources (RES) while reducing the use of fossil fuels for power generation constitutes a challenging topic. The main reason for that lies on the introduced variability that characterizes RES (solar and wind), due to the dependency on weather conditions. Especially when this needs to be achieved within microgrid applications for remote villages, islands or isolated areas, where weak grid connection constitutes an additional barrier, special care is required to conclude robust and efficient microgrid designs and architectures with the optimal location and size of the various systems used to realize such applications.

The rural electrification issue is not a rare one. Globally, approximately 1.6 billion people do not have electricity and clean water [1]. For many of these people, connection to public utilities is not economically feasible. However, RES constitute cost efficient and abundantly

available sources of energy that can potentially serve as a solution for the rural electrification problem, if used within appropriately designed microgrid architectures. Moreover, ESSs enable the maximization of RES in such applications [2]. Important issues need to be addressed though, such as optimising the lifetime of the system as well as optimal dimensioning of the storage system in combination with RES. Additionally, in order to enable the design of an efficient micro-grid that requires fewer or no diesel generators, it is important to provide insight into the impact of ESS in combination with RES.

To tackle these challenges, the Energy Storage Integration Tool (ES-IT) has been developed by DNV GL as a solution to provide practical results for designing islanded or grid-connected micro-grids or households with ESS. At first, this paper introduces the ES-IT model and its capabilities as well as the inputs and outputs of the model. In the following, a comparative case study for Burundi and the Netherlands is presented, where the ES-IT tool has been used for concluding to the optimal micro-grid architecture according to various optimization goals. The simulation results are presented and discussed. Finally, the two projects within which the ES-IT tool has been developed, used and validated and presented and discussed in more detail.

ES-IT MODEL DESCRIPTION

ES-IT is a python-based optimization tool that provides practical results for the design of both islanded or grid-connected micro-grids and for households with ESS. It constitutes a user-friendly and flexible tool that can aid solution providers by efficiently dimensioning the system components.

This tool contains technical and economic models of ESS, photovoltaics (PV) and wind systems as well as back-up diesel generators. It can assist in designing robust micro-grid architectures, since it provides information regarding the optimum configuration of these systems through specifying the location and number of wind turbines, PV panels and storage system. The optimization for system dimensions can be selected for achieving different goals, such as lowest costs, lowest emissions, maximum self-sufficiency or optimum battery life.

ES-IT Model Inputs

The main inputs of this model are the yearly profiles for the consumption of the connected users as well as yearly generation profiles for the connected renewable energy sources (derived from weather profiles). Other important input information constitutes the CAPEX cost figures of the ESS, the PV and the wind system, and the diesel generator. Certain key characteristics of the ESS system, such as the C-rate (ratio between power and capacity), efficiency as well as cycle and calendar lifetime also need to be provided. The PV and wind systems' lifetime and efficiency and the diesel generator's fuel costs, efficiency curve, start-up and stop time also constitute important model inputs. If certain information is not available, the model allows for default values to be extrapolated.

ES-IT Model Outputs

After the execution of the simulation, the displayed results, that constitute the main output of the model, are the system dimensions for the selected optimization goal. In addition, the yearly profiles of all system variables can be shown graphically, e.g. the battery power and energy content, or the diesel power. The optimization for system dimensions can be selected for achieving different goals, such as lowest costs, lowest emissions, maximum self-sufficiency or optimum battery life. The system dimensions can be provided for systems with or without backup diesel generator (the latter meaning 100% RES integration). Furthermore, a sensitivity analysis is included, allowing for expert assessment of the model results. This means that the expert user can select a solution that is sub-optimal according to the model, but may be more suitable because of other conditions (e.g. geographical) that are not in the model. The calculation time is dependent on the settings and is in the range of a few seconds. An overview of the ES-IT model along with the inputs and possible system dimensioning optimization are shown in Figure 1.

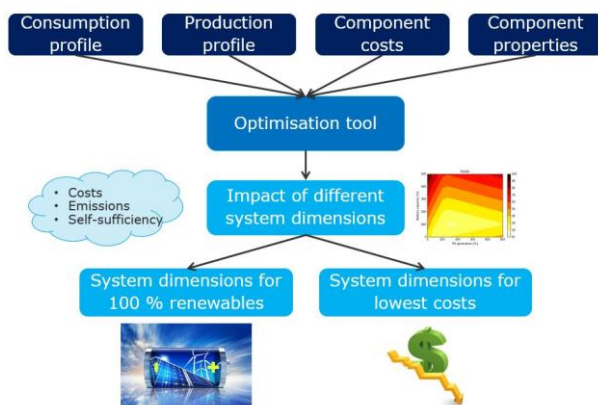


Figure 1: Energy Storage Integration Tool (ES-IT) block diagram.

CASE STUDY AND SIMULATION RESULTS

In this section, a comparative study that has been performed through the use of the ES-IT tool is presented.

The study is performed for two locations, Burundi and the Netherlands (based on 2 study cases in the SOPRA project, see below), for which the ES-IT tool was used to assess the optimal micro-grid architectures (with ESS, PV and diesel only, no grid connection) according to different optimization goals.

The inputs provided to the model in each case together with the corresponding simulation results for the optimization goals of interest are presented and discussed in the following paragraphs.

Input profiles

The input profiles that have been used for the comparative study between Burundi and the Netherlands are presented in this section.

For the household consumption profiles of Burundi, the total energy consumption of a village of 670 households (including hospitals, schools, military facilities, etc.) is scaled to one household. For the Netherlands' household consumption, the total energy consumption of 60 households is scaled to one household. The corresponding daily household consumption profiles for the two locations are depicted in Figure 2.

It is pointed out that the average daily household consumption for Burundi is 0.4 kWh while the average daily household consumption for the Netherlands is 9.6 kWh.

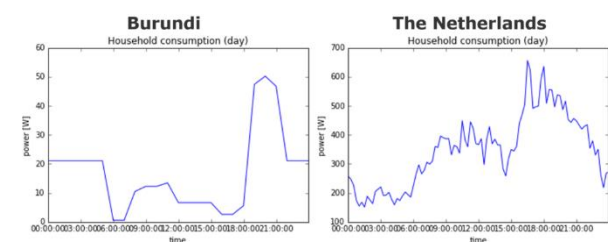


Figure 2: Daily household consumption for Burundi and the Netherlands.

For this case study, only PV production profiles have been used. The annual PV production profiles for Burundi and the Netherlands are depicted in Figure 3.

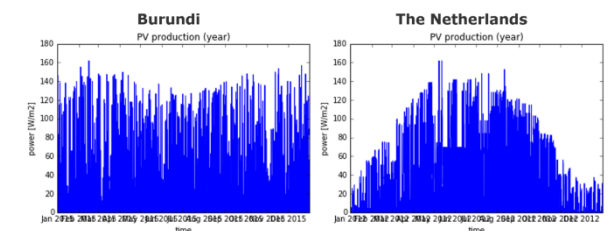


Figure 3: Annual PV production for Burundi and the Netherlands.

Considering 1 kWp installation size, the PV production for Burundi is 1538 kWh/year and for the Netherlands 950 kWh/year.

Simulation Results

Simulations have been performed using the ES-IT tool and the results are presented in Figure 4 and Figure 5.

Focus was placed on maximizing self-sufficiency and minimizing costs, thus analytical results are presented for these two optimization goals (yearly power profiles are not shown in this analysis).

For all output graphs, the PV generation percentage axis represents the percentage of annual generated electricity in comparison with the annual electricity consumption, while the battery capacity percentage axis represents the battery capacity scaled to the average daily electricity consumption. Moreover, PV generation at 100% corresponds to zero-on-the-meter, i.e. production and consumption are equal over a whole year, but not at any moment in time. Battery capacity at 100% corresponds to battery capacity equal to the energy consumed on an average day.

Optimization results for minimized costs

In Figure 4, the optimization results for minimizing the costs are presented for Burundi and the Netherlands.

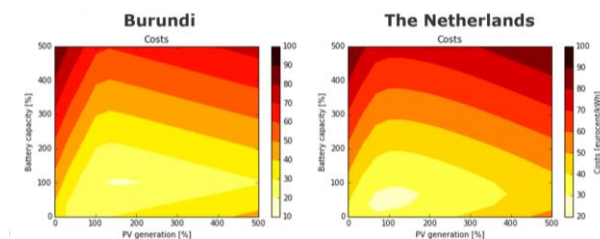


Figure 4: Optimisation results for achieving minimum costs, for Burundi and the Netherlands.

As expected, in both locations (compared to diesel only) energy costs are reduced if a combination of storage and PV systems is used. A combination of at least 100% of PV power and up to 100% of battery capacity leads to the most cost-effective solution. It is noted that the optimum energy cost for The Netherlands will be below 30 eurocents and the optimum for Burundi will be below 20 eurocents. For comparison: the electricity costs with diesel generation only are equal to 0.35 €/kWh in this model.

More analytical information for this comparative study is provided in Table 1.

Table 1: Analytical information from the simulation results for minimizing the costs, for the comparative study between Burundi and the Netherlands.

Parameter	Burundi	The Netherlands
Battery capacity	100 %	67%
Battery capacity per household	0.4 kWh	6.4 kWh
PV generation	166 %	100 %
PV system rating per household	0.2 kWp	3.7 kWp
Electricity costs	0.19 €/kWh	0.28 €/kWh
Emissions reduced	88 %	60 %
Self-sufficiency	90 %	60 %
Annual battery cycles	325	200
Curtaiment	35 %	35 %

Optimization results for maximization of self-sufficiency

In Figure 5, the optimization results for maximising the

self-sufficiency are presented for Burundi and the Netherlands.

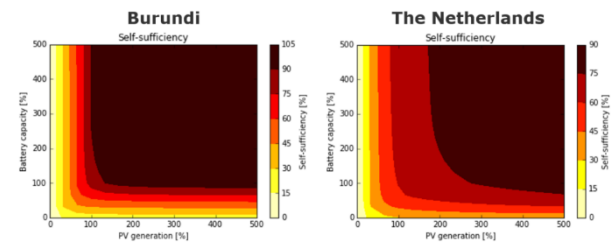


Figure 5: Optimisation results for achieving maximum self-sufficiency, for Burundi and the Netherlands.

In general, 100% self-sufficiency needs a large PV system and a large battery, both need to be larger than 100%. For Burundi, this is technically feasible, with similar costs as with the diesel generator (that is twice the cost of the lowest cost option, see the previous case). However, for the Netherlands 100% self-sufficiency is not feasible and it results in very high costs.

More analytical information for this comparative study is provided in Table 2.

Table 2: Analytical information from the simulation results for maximizing self-sufficiency, for the comparative study between Burundi and the Netherlands.

Parameter	Burundi	The Netherlands
Battery capacity	225 %	1600%
Battery capacity per household	0.9 kWh	153.3 kWh
PV generation	325 %	2000 %
PV system rating per household	0.3 kWp	73.6 kWp
Electricity costs	0.37 €/kWh	2.95 €/kWh
Annual battery cycles	158	18
Curtaiment	70 %	95 %

RELEVANT PROJECTS AND ES-IT MODEL

Examples of projects in which the ES-IT model has been used constitute the Sustainable Off-grid Powerstation for Rural Applications (SOPRA) project and the Cellular Smart Grids Platform (CSGRIP) project.

The SOPRA project constitutes a development project that was started by a group of Dutch industries and knowledge institutes. It focuses on developing a modular platform for renewable power supply in rural areas. The CSGRIP project, which succeeded the SOPRA project, constitutes a collaborative project supported by the Dutch government. This project develops a smart microgrid with power-frequency control and local demand-supply balancing by using ESS. The local power frequency is the control signal for coupling multiple microgrids, thereby reducing the need for a communication network.

A further description of the SOPRA and CSGRIP projects is provided in the following paragraphs.

The SOPRA Project

The Sustainable Off-grid Powerstation for Rural Applications (SOPRA) project is a development project

that aims at developing a modular platform for rural power supply. This platform is based on the Multi-source Hybrid Inverter (MHI) that has been developed in the Netherlands, combined with an electricity storage system. The MHI enables the design of a modular rural power supply system with any number of power sources of different kinds, e.g. solar PV, wind, diesel generator, thus constituting the SOPRA system a more sustainable alternative for an existing diesel generator plant.

In the project three demonstration sites with different combinations of power sources are set-up to prove the feasibility of the SOPRA system. One of the demonstration sites is located at the HAN University in the Netherlands. The demo site is meant to demonstrate the use of energy storage to maintain distribution power quality in a grid with a large share of distributed renewable energy sources.

In the off-grid system components of renewable energy such as a wind turbine and photovoltaics are integrated as well as other additional components like storage systems, a diesel generator and the MHI. Also dynamic loads can be applied to the whole system, which is monitored by a Power & Energy management unit. A switchable grid connection is included for energy feed-in in case the system is not operational in off-grid mode. Special algorithms for supplying or storing energy, as well as dimensional design considerations are part of the demonstration.

The ES-IT model was used within the SOPRA project in order to conclude to the optimal configuration of the SOPRA system, that includes the location and number of wind turbines, PV panels and storage system. The SOPRA system was designed according the optimal system dimensions provided by the ES-IT tool, allowing for validation of the tool through a realistic application, thus adding significant value to it. The set-up of the SOPRA system is depicted in Figure 6.

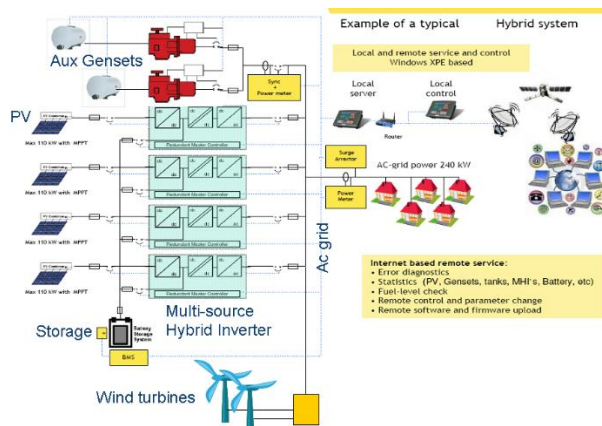


Figure 6: Set-up of the SOPRA-system with solar PV power, wind power, optional diesel generator back-up, electricity storage, and multi-source hybrid inverter for integration, control and optimization of generation and storage.

The CSGRIP Project

CSGRIP (Cellular Smart Grids Platform) is a collaborative project supported by the Dutch

government. The CSGriP project aims at developing a smart grid concept to electrify remote areas with no or weak grid connection by maximally integrating RES.

The concept of the CSGriP is based on its predecessor – the SOPRA project, whose primary objective was to develop a viable stand-alone system to supply power to remote areas in a secure and reliable manner. The goal of CSGriP is to take SOPRA a step further and build a stronger, robust and reliable grid by using power-frequency control of interconnected SOPRA cells [3]. The project develops a smart microgrid with power-frequency control and local demand-supply balancing by using ESS. The local power frequency is the control signal for coupling multiple microgrids (i.e. cells), thereby reducing the need for a communication network.

CONCLUSIONS

In this paper, the Energy Storage Integration Tool (ES-IT) and its capabilities have been analytically described, together with the inputs and output results. A comparative study between Burundi and the Netherlands is also presented together with the simulation results drawn from the ES-IT tool, that in essence provide the optimal system dimensions for the optimization goals of interest. Finally, the SOPRA and CSGRIP projects, within which the ES-IT model has been developed, used and validated, are described in detail. Through the abovementioned studies and realistic applications in which ES-IT tool has been used, it is proven that this tool enables system developers to design an optimised sustainable microgrid. In this way, they can provide customers in remote areas with cost-effective, sustainable and reliable electric power, focusing on RES and thus minimising dependency on fossil fuels. More specifically, ES-IT aids solution providers by efficiently dimensioning the system components. Besides remote villages, military compounds, refugee camps and disaster response field hospitals could also benefit from having a rationally designed micro-grid.

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