Intelligent, Data-driven, and Grid-stabilizing Energy Management Platform

Developing a Pilot for Industrial Application

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***Abstract* — The trend of renewable energy sources increasingly replacing large and centralized conventional power plants is changing the security level of energy supply and is specially leading to strong fluctuations of day-ahead and spot wholesale electricity prices. This poses enormous challenges, in particular, for energy-intensive, industrial companies. Against this backdrop, we propose an intelligent, data-driven, and grid-stabilizing energy management platform (IDGE Platform) for industrial customers integrating modules for own-generation, external procurement, and flexible consumption. In this work, we focus on the optimization of own-generation modules, i.e. diesel generators, batteries, photovoltaic systems, and wind turbines. Our optimization algorithm aims for maintaining and securing grid stability and cost-efficient energy management in terms of an economic optimization for all connected assets. To validate and continuously improve the behavior of the IDGE Platform in a real-world application scenario, we set up a demonstrator, which consists of genset, battery storage units, photovoltaic systems, and dynamic loads. The system enables both operations in off-grid and grid-parallel mode.**

Keywords – energy management platform; own-generation; optimization

I. INTRODUCTION

The increasing abandonment of nuclear and coal-fired power plants as well as the expansion of photovoltaic and wind power plants are current trends in power generation worldwide. In particular, the growing share of renewable energy sources is increasingly endangering the security of energy supply and leads to strong fluctuations of electricity prices [1]. This poses enormous challenges especially for industrial companies, as rising and strongly fluctuating energy costs have a negative impact on their production costs [2]. Therefore, intelligent energy management solutions are needed which integrate self-generation, energy storage, external power purchase, and flexible consumption [3, 4].

Against this backdrop, we are currently developing an intelligent, data-driven, and grid-stabilizing energy management platform (IDGE Platform) for utility-scale customers. For energy production, the IDGE Platform is able to integrate conventional, e.g., diesel or gas gensets, and renewable energy generation, e.g. photovoltaic systems PV and wind turbines WT, in combination with energy storage BESS, e.g., lithiumIon batteries. Moreover, the platform connects flexible consumers and offers an optional interface to power and energy markets. In order to optimize the generation from an economical perspective and maintain a balance with consumption, we developed and implemented an optimization algorithm which aims to increase power quality, i.e. grid stability, and to reduce the generation costs. Our work is part of a publicly funded project[1]. The interdisciplinary project team consists of experts from research, i.e., Project Group Business & Information Systems Engineering of the Fraunhofer FIT, and practice, i.e., MAN Energy Solutions and software developer XITASO.

The remainder of this paper is structured as follows. In Section 2, we illustrate the general layout and functional requirements of our IDGE Platform. In Section 3, we present the optimization algorithm for connected onsite-generation as the core of our work. Essential components are an optimization for grid stability and an economic optimization. We then outline how we validate our results in Section 4. Finally, we conclude by summarizing our results and give an outlook on future efforts for further platform development.

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II. IDGE PLATFORM

A. *Layout of the IDGE Platform*

The overall aim of the IDGE Platform is the integration of onsite-generation, external power and energy procurement, and flexible consumption (Figure 1) to enable intelligent energy supply and consumption.

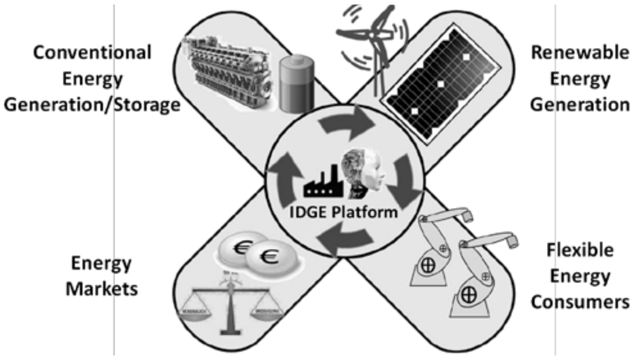

Figure 1: Basic Structure of the IDGE Platform

The energy supply is to be controlled via standardized interfaces to energy markets, own onsite generation plants, and energy storage facilities. The energy consumption is controlled via interfaces to machines, production infrastructure, energy storage facilities and external consumers. Speed and flexibility of generation as well as flexibility of consumption is offered on control power markets. The core of the IDGE Platform is a linear optimization algorithm that uses all integrated functionalities to automate and enable intelligent, data-driven, and grid-stabilizing energy supply management in real time. In this work, we focus on the optimization of self-generation.

We chose a modular platform structure for enabling an easy integration of additional modules regardless of the respective application context. To ensure grid-stability and cost-efficient energy supply, the platform evaluates sensor data of connected modules. Based on this data input, the optimization algorithm calculates the optimum share of available energy modules to meet the current demand. Thereby, the platform reduces complexity for human users and provides decision support and recommendations for the control of the power plant in real time. The user interacts with the IDGE Platform via special user interfaces, which allows for setting a context-specific target functions and requirements.

Plant operators can monitor and control the following key parameters for power quality:

- Frequency
- Active Power generation and demand
- Voltage
- Reactive Power generation and demand
- Power-Factory generation

Plant operators can monitor the following key parameters for economic optimization:

- Current generation costs
- Marginal generation costs
- Fuel Price
- Wholesale power and energy prices

B. *Functional Requirements*

Figure 2: Functional Requirements

Based on market requirements, certain use-cases for hybrid and microgrid applications have been identified: Fuel saving, peak shaving, spinning reserve, ancillary services, power arbitrage, enhanced dynamics.

Looking at the use-cases and customer requirements MAN identified six archetypes, describing a path of de-carbonization by enhancing RES-penetration for off-grid and grid-parallel operations. Those archetypes will lead the way to an up to 100%-RES world.

- Archetype 1: Microgrid with conventional generation and strong grid-connection
- Archetype 2: Conventional-Hybrid-Plant with strong-grid-connection
- Archetype 3: Microgrid with conventional backup-power and weak-grid-connection
- Archetype 4: Microgrid with conventional generation and weak-grid-connection
- Archetype 5: Microgrid with conventional and RES-generation without grid-connection
- Archetype 6: Microgrid pure RES-generation and storage without grid-connection

Depending on the specific application and configuration, the IDGE-plattform can operate in the following modes:

1. Supply to Grid
2. Supply from Grid
3. Island (Generator)
4. Island (No Generator)
5. Black Start
6. Unintentional Grid Outage (Generator)
7. Unintentional Grid Outage (No Generator)
8. Intentional Grid Outage (Generator)
9. Intentional Grid Outage (No Generator)

III. OPTIMIZATION ALGORITHM

The aim of the optimization is to ensure the operator's interest from a business point of view to reduce costs and maximize revenues. The basic prerequisite, however, is a stable operation (in terms of frequency and voltage stability) of the microgrid.

In the following, an integrated optimization will be presented which both (1) ensures grid-stable operation of the microgrid minimizes the costs of power generation and (2) minimizes the costs of power generation. For this purpose, two separate optimization models were developed. The interaction of both enables intelligent control of the overall system:

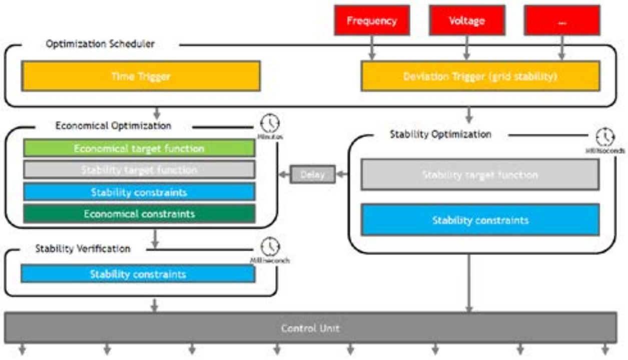

Figure 3: Interplay of Layer 1 and 2

A. *Grid stability – Layer 1*

As a prerequisite for economic optimization, a grid-stable optimization model was developed, which reacts to short-term changes in the state of the grid, which are triggered by any deviation from the dead band set points for frequency and voltage. No economic factors are included in the grid-stable optimization. The primary objective is to restore grid stability as quickly as possible. In order to enable calculation in near real time, only grid-stable restrictions are considered and supplemented by a target function for grid stability. In addition, the model is limited to a linear optimization model in order to keep the runtime low and to meet the requirement of a near real-time calculation. Once the calculation has been completed and the recommended course of action has been passed on, the economic optimization is initiated. If both optimizations are completed at the same time, the grid-stable optimization is always prioritized. Figure 4 summarizes this procedure. In the further course of the document, the economical and grid optimization are considered as one integrated model, unless explicitly stated.

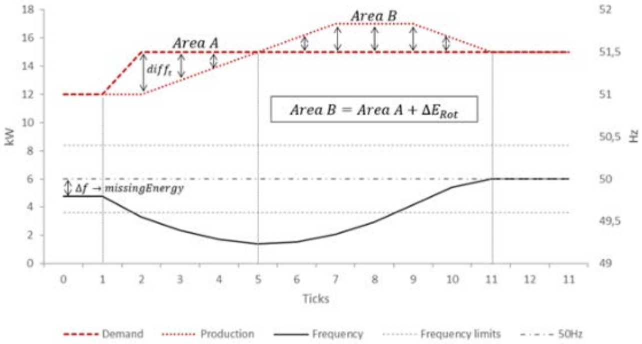

Figure 4: Model reaction

B. *Economic optimization – Layer 2 (FIT)*

The economic optimization consists of a target function that takes into account different cost factors of energy generation. The target function should always be minimized, which means that an economically optimal solution is also the most cost-effective. Thus, layer 2 mainly consists of the calculation formulas for all cost factors. It is optional to apply economic restrictions as well, e.g. to limit the costs of individual system components. Cost factors are the battery charging, the genset fuel and resource consumption and maintenance, and energy shortage. Photovoltaics and wind power will be added at a later stage of the project.

Layer 2 compares grid-stable solutions from an economic perspective. Each solution implicitly provides values for the power of the engine, how much energy the battery is charging or discharging, and how many loads have to be dropped. These values are used as input for layer 2 as they represent the main cost drivers. However, the calculations of the battery and engine costs are more complex and can be divided into several areas.

An engine generates costs by consuming resources, due to wear and tear, and due to emissions. Fuel consumption is the most expensive component, but we also consider lubricating oil, urea, starting resources such as starting air, and other auxiliary materials. Wear and tear costs relate to individual parts of the engine and the current power that periodically either need to be replaced or serviced. Some components must be serviced or replaced after a certain number of starts or after a certain number of operating hours. In practice, wear and tear costs only occur if a part has to be serviced or replaced. In the model, however, we have to compare different engine loads within limited periods of time and, hence, have to compare wear and tear costs per time unit. Therefore, each engine start and each operating hour causes proportionate costs for maintenance and replacement. For example: A part must be replaced after 1000 starts and costs 2000€. Hence, this specific engine part adds 2€ per start to the wear and tear costs. At last, the emission costs are directly related to the fuel consumed and the individual costs per consumed emission unit.

Although the battery has high initial costs, it only consumes small and negligible costs during operation. Thus, using the battery costs a proportionate amount of the replacement costs. There are two possible reasons to replace the battery. The battery can reach its maximum lifetime or its maximum number of cycles, i.e. of complete discharging. In other words, if we discharge the battery, the remaining number of cycles decreases, and replacement draws closer. However, we always take the ratio between the remaining lifetime and the remaining cycles into account. If a battery were to reach its maximum calendric lifetime one way or another before reaching the maximum number of cycles, further cycles do not generate any additional costs.

The calculation method for the battery costs demonstrates that it is not the goal to determine all cost factors exactly according to reality. Instead, it is necessary to create a meaningful economic comparative measurement through approximations, which can be applied to grid-stable solutions against each other.

Economic optimization is conducted at regular time intervals on the basis of the current status of the overall system. By combining the target functions of grid stability and economic optimization with the various restrictions, the model can generate an economically optimal recommendation for action which implicitly fulfils the criteria of grid stability. The recommended action describes the optimal operation of the individual components for a period of several minutes (e.g. 15 minutes). It is also possible to alter the time window. The multitude of components, input parameters and dependencies leads to high complexity, which is reflected in a high calculation time of several minutes. Since the state of the microgrid can change during the calculation, the result of the economic optimization is checked again after the calculation for compliance with the restrictions of the grid stability. If the calculated solution still turns out to be grid stable, the (business) action recommendation can be implemented. If, however, the solution violates restrictions on grid stability in the meantime, the calculated recommendation for action must be rejected and the optimization initiated again.

IV. EVALUATION

A. *Software Tool*

1) Technical platform layout

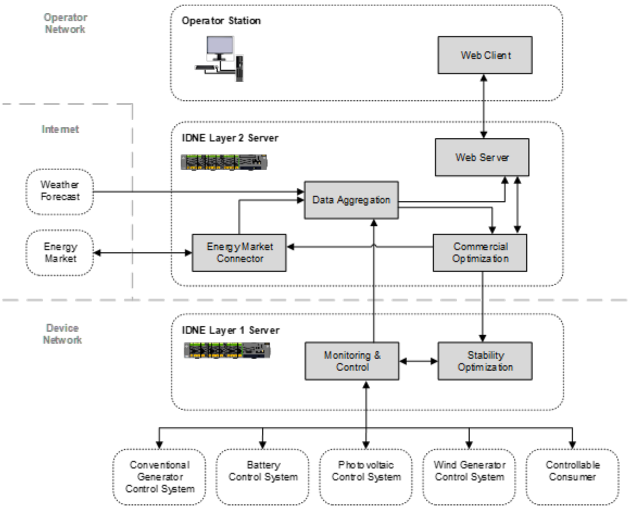

Figure 5: Technical platform layout

The system architecture copes with the two part optimization algorithms and their different aims (stable vs economical solution) by setting up the platform on a two-layer server architecture as shown in Figure 5. Each layer runs on its own hardware, thus resources for grid stability optimizations are not occupied by some expensive calculation finding economical optimal solutions. Besides, Layer 1 serves as a connector to various power management and consumer systems.

At the lowest level, existing power management systems manage the low-level details of the controlling specific power devices. Typically, these systems have reaction times in the lowmillisecond range, but are limited to controlling a single logical device. Where possible, these systems are connected to IDGE platform using standardized protocols mainly based on IEC 61850 and secondary on common industrial communication protocols.

2) IDGE Layer 1

The IDGE Layer 1 is responsible for maintaining the stability of the microgrid as a whole. The Layer 1 server monitors the state of all connected power devices and issues control commands according to the current control strategy. In case of a sudden parameter change that threatens grid stability, such as a surge in power usage, it is the responsibility of this layer to compute and execute commands that re-establish stability before any safety protections are triggered. There are two main components in Layer 1:

- Monitoring and control: This component communicates with the connected control systems. It periodically reads sensor data and sends the current control commands to those devices.
- Stability optimization: A fast-running optimization algorithm that computes a stable grid configuration in real time.

To ensure low response times, IDGE Layer 1 is deployed to a dedicated Linux server that is specifically configured to minimize interruption by background tasks. Furthermore, the IEC 61850 protocol (GOOSE) provides the possibility of real-time functionalities.

Once stable grid operation is established, Layer 2 computes a economically optimized control strategy that coincides with the constraints that ensure grid stability.

3) IDGE Layer 2

IDGE platform operations that are not time critical for grid stability are grouped into IDGE Layer 2. This includes the following main components:

- Data aggregation: Sensor data from connected power devices, weather forecast and energy market data is stored and aggregated, both to be sent to the web server for visualization, and as an input for the economic optimization.
- Economic optimization: This component finds an economically optimized stable grid configuration. This optimization can be computed on previously defined time slices or every time there is a significant change to the input parameters or power device capabilities.
- Energy market connector: This component connects to the energy markets and executes trades according to a strategy computed by the economic optimization module.
- Grid operator access: Connection to grid operator for control of active and reactive power as well as failure behavior.

B. Demonstrator

In order to validate and further develop the software and underlying algorithms, a small microgrid is set up at MAN's premises.

This demonstrator comprises the following hardware components:

- Gas Genset (395 kWe), Cos (phi) 0,2 - 0,8
- Li-Ion Battery Storage, 112 kWh, 2C
- PV-Plant (40kWP)
- PV-Inverter: STP 20.000 TL-30 (20 KVA)
- Battery-Konverter: WS Tech BAT280 (Grid-Forming and islanding capability)
- Off-Grid Application as first step, but Grid-Connection to the local MAN Medium Voltage grid.

The above configuration was selected in order to demonstrate and test all scenarios and use-cases described in Section 2. Details are illustrated in the Single Line Diagram, Figure 6.

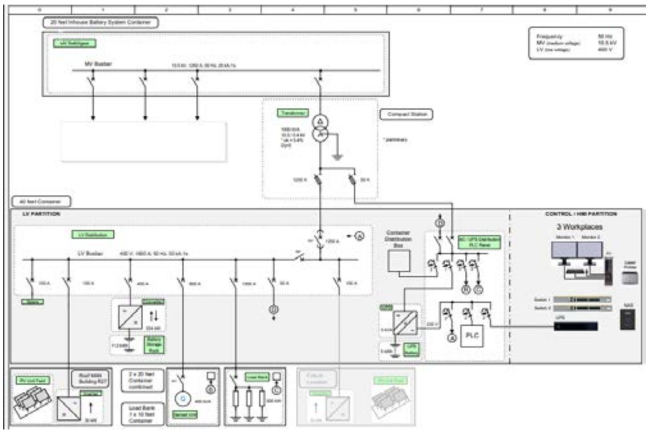

Figure 6: SLD of Demonstrator

This demonstrator can operate both in off-grid and on-grid mode. Hence all relevant scenarios described above can be evaluated.

V. CONCLUSION

Based on current evaluations we identified the following points as most critical for a microgrid control system:

1. Stability-control and economical optimization cannot run in one joint model, due to performance issues.
2. Hardware for Layer 1 and Layer 2 should be separated, to avoid performance delays.
3. In order to ensure grid stability the control needs to be local, a "cloud"-approach is not useful due to the fact, that many remote areas have weak or no permanent connection.
4. Redundant check of Layer 2 is necessary to avoid a closed-loop-optimization without checking the stability requirements.
5. Physical correlations can be simplified in most cases, without significant loss of accuracy.

[1] BNetzA. (2017). BBPlG - Monitoring - Stand der Vorhaben aus dem Bundesbedarfsplangesetz (BBPlG) nach dem ersten Quartal 2017. URL: https://www.netzausbau.de/SharedDocs/Downloads/DE/Vorhaben/BBPlG/BBPlG-Bericht.pdf?__blob=publicationFile

[2] LfSta. (2016). Bruttostromerzeugung in Bayern insgesamt nach Energieträgern. URL: https://www.statistik.bayern.de/medien/statistik/bauenwohnen/stromerzeugung_und_-verbrauch_20161125.xls

[3] Fleten et al. (2010). Gas-fired power plants: Investment timing, operating flexibility and CO 2 capture. Energy Economics 32.4 (2010): 805-816.

[4] Lipp, J. P. (2015). Flexible Stromerzeugung mit Mikro-KWK-Anlagen. URL: https://mediatum.ub.tum.de/doc/1192271/file.pdf.