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Simulation as enabler for Engineering Future Smart Grids

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Abstract

The article presents a study on utilization of simulation to support engineering and governance of smart grids. In particular, it is provided analysis of key factors responsible for efficiency of energy production in smart grids, developed a conceptual model of the target system as well as provided a hypothetical case study in which the proposed solution is expected to be tested.

Keywords: Modelling; Simulation; Smart Grids; Micro Grids;

1. Introduction

Nowadays there is a rapidly growing interest in development and construction of semi-autonomous smart electric grids (Delfino et al., 2018; Janosy, 2015). Indeed, while it is common to perceive a common grid as consolidated and impartible structures, efficiency of energy generation and consumption could be improved by segmentation of the grid in smaller ones with higher level of control capabilities. In fact, due to availability of energy storage systems, efficient and relatively cheap photovoltaic panels, wind turbines as well as some other much less diffused sources of energy, it becomes possible for facilities and households to play role not only of consumer but also of energy producer; sometime a term of "prosumer" is used to define this new type of entities.

In this context it is important to highlight that most of these power sources are strongly dependent on weather; in fact, cloudiness and wind speed define amount of energy output. Of cause, there are also more stable but also very rare types of renewable energy sources, such as small hydro power plants, biomass and even geothermal ones, however, they are typically limited to some very specific use cases and are out of scope of interest of this study. Another important aspect is related to possible misalignment between peaks of energy production and demand. For instance, during the evening the households are typically consume high amount of energy, while solar-based energy sources are mostly inefficient in the same period. Similar consideration is applicable to the wind-based power sources, that have no guarantee to be operational and to cover demands when required. Considering this, the electric grid still requires ways to produce additional power when renewable sources are not sufficient; typically, it could be done by following means:

- Reliance on traditional power plants (gas, coal);
- Introduction of small auxiliary generators (e.g. gas or diesel ones) to cover peaks of demand;

- Energy storage, typically using batteries (e.g. BESS – Battery Energy Storage System);

Considering this, it is evident that modern electric grids are characterized by much higher level of complexity that traditional ones. Obviously, blur out of classes of energy suppliers and consumers introduces numerous difficulties related to planning of energy production and in particular in its optimization. Indeed, presence of numerous independent participants leads to difficulty of prediction of consumption. Hence, intelligent control is required in order to ensure proper and efficient operation of the system.

Nowadays such Smart Grids are rapidly constructed all around the world. Typically, such grids are covering small, respect to traditional power grids, areas, which could be a group of households, university campus, industrial facility or even small islands. Considering this, these grids are often referenced also as Micro Grids, even if their energy production and consumption could be at order of megawatts (Chae et al., 2015).

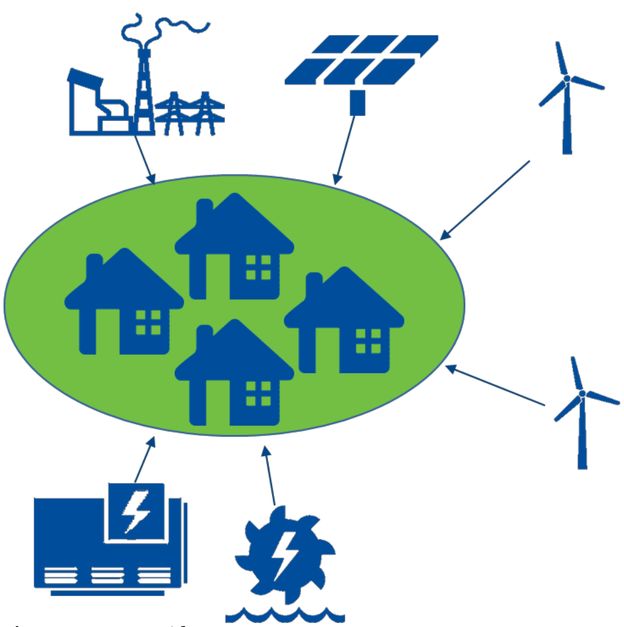


Figure 1. Smart Grid

Hereafter is present a study on utilization of modelling and simulation to support engineering and operation of smart grids.

2. State-of-the-Art

Important example of utilization of simulation in urban areas is Vestige, which is a city simulator created to support strategic decision makers in various activities related to crisis management (Bruzzone et al., 2020a; 2014). Indeed, the solution simulates life cycle of entire population, including utilization of transportation network, daily activities etc., while taking care on modelling of crisis events, e.g. flood, collapse of transport infrastructure, pandemic, in order to evaluate impact of countermeasures on evolution of events. Hence, utilization of Vestige allows to forecast impact of different threats on the city, while providing possibilities to develop better response tactics. While this solution does not cover directly energy demand and production, the core mechanics provides nearly all information required to do so. Another example of simulation in field of urban and industrial areas and crisis management is ALACRES2, even if it is focused mostly on operation procedures in seaports (Bruzzone et al., 2019).

Multiple studies address topic of simulation for analysis of production and operation of specific components of micro grids, such as wind turbines and solar powered solutions (Lamas-Rodríguez, 2020; Tagliafico et al., 2014). At the same time, different experimentations with physical prototypes were done in order to fine-tune existing models of solar-based power generators (Scarpa et al., 2015).

3. Conceptual Model

As stated previously, engineering and optimization of smart grids is a complex task, which could be addressed by means of simulation. In particular, it could be used to cover following needs:

- Prediction of energy demand based on consumers' life cycle and boundary conditions (time, weather, holidays etc.);
- Forecasting of possible production based on time and weather (expected luminosity, wind speed and direction);

In particular, this knowledge would allow to predict both energy demand and production capabilities, hence, to ensure that the grid is able to satisfy needs of the client. For example, it must be possible to identify when

- The renewables are sufficient to cover all needs;
- BESS could be charged taking part of produced energy;
- BESS should be employed to cover insufficiencies;
- Generator must be started and stopped;
- External network must be connected and disconnected;

Of cause, this list addresses only instant values, while in order to function properly, their forecast in at least brief period is essential.

In order to ensure that these goals could be achieved in efficient way, it is necessary to guarantee sufficient data flow from sensors as well as to provide statistical data regarding typical consumption and production of energy (Azofra et al., 2016). At the same time, the system must foresee consumption trends:

indeed, while most of devices improve energy efficiency to consume less, such factor as electric mobility and necessity to recharge vehicles could lead to significant increase in energy consumption, which could be especially critical for the smart grids.

Among other factors, it would be necessary to know current energy generation by controlled sources, estimation on its production by independent generators (e.g. private household photovoltaic modules), forecasts etc.; significant part of this data could be obtained from embedded controllers and IoT (Internet of Things) devices. Vice versa, vast amounts of data produced by new sensors will be used to improve prediction capabilities of the model, hence, to further increase efficiency of the grid. Furthermore, with increased quantity and quality of data, it could be possible to utilize a prediction model based on machine learning algorithms (Bruzzone et al., 2020b).

Apart from optimization of energy production, it is expected to have additional, respect to traditional power grids, benefits related to quality of service. In particular, to have an ability to adjust independently frequency and voltage, reduce frequency of blackouts and interruptions of service.

4. Case Study

As case study it was chosen to utilize a hypothetical scenario, based on a small island community in Mediterranean Sea. In particular, it is presumed presence of approximately 500 households as well as service infrastructures, such as shops, hotels and entertainment facilities. Considering this, it was developed a macro diagram of the grid, as presented in the following figure.

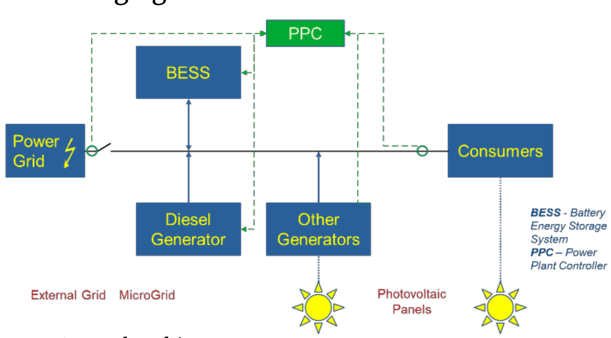


Figure 2. General Architecture

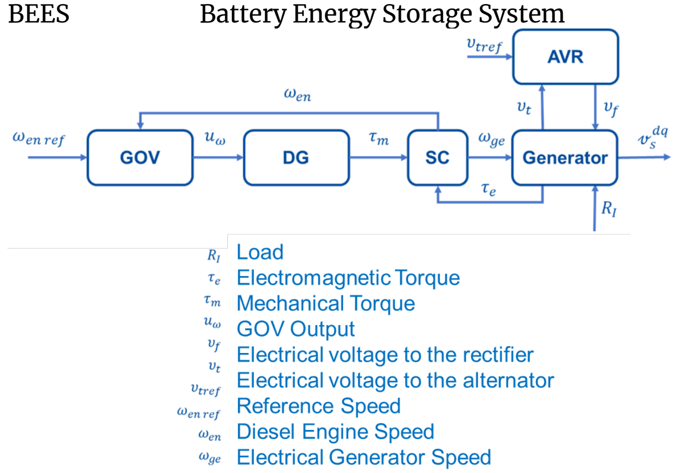
As illustrated, a Power Plant Controller (PPC) is expected to address power supply task by managing available generators as well as connection to the main grid, while taking into account forecasted energy production and consumption.

In this scenario, the simulation addresses life cycle of the community including common daily activities. Hence, the model is capable to provide information on electric power demand in any time. At the same time, weather information from past observations is used to recreate a typical situation observer in the area of interest. Finally, based on this data the model handles power production by switching on and off available power generators, providing possibility to analyse its behaviour in different initial (installed generators) and boundary (weather, time) conditions.

Apart from macro model, in order to increase precision of simulation as well as to be able to provide more useful indications to the decision makers, it is necessary to simulate also single components of smart grids.

For example, considering constraints in utilization of groups of diesel generators, such as the start-up time, it would be essential to have a proper model of it. In particular, it should take into account operation of the motor, generator, voltage regulator and speed governor (Reiners et al., 2019). Indeed, for instance, the main modules to be simulated respect the Diesel Group could be summarized as following

DG	Diesel Engine and Injection System
SC	Shaffle Coupling
Generator	Asynchronous Generator
AVR	Automatic Voltage Regular
GOV	Governor
BEES	Battery Energy Storage System



Similar models need to be created for all the different elements of the grid by adopting a modular approach that could guarantee to integrate them within the same simulation framework. From this point of view it could be interesting to adopt interoperability approach and utilize standards to keep the overall architecture open to growth by creating a federation able to include progressively other elements, machines, power generation facilities as well as users within the grid. In this way it could turn possible to adopt digital twin approach and each time a new real component or elements is added to the grip could be coupled with a model to be included in the simulation. The disadvantage of this approach is related to limited popularity of interoperability standards among power generation community and the necessity o work into adapting available models, therefore this approach could be interesting for the future to create a much more flexible capability in simulating power grids.

5. Conclusions

Utilization of smart grids is rapidly growing. Indeed, availability of efficient and relatively inexpensive energy generators and storage systems allowed their employment in various cases, starting from pilot plants in universities and up to full-scale grids covering entire communities. However, considering difficulties in engineering and management of these systems it could be convenient to employ simulation. Indeed, possibility to reproduce behaviour of an urban area and relative power generation and consumption could allow to find best design of such system as well as to ensure that it operates in efficient way. For demonstration, the authors propose hypothetical case study on which it is applied a model which takes into account identified critical factors.

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