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GENERIC ENERGY PRODUCTION MODEL FOR SMART GRID EMULATION

This work describes the progress towards creating a model of energy production block to be applied in a smart grid emulator. This block allows reflecting the behavior of many energy production cases and by that enables defining multiple test scenarios for evaluating energy management algorithms. The model is configurable and the behavior is adjustable in run-time.

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Artykuł przedstawia postępy prac w kierunku stworzenia modelu bloku producenta energii, który będzie użyty jako część emulatora inteligentnych sieci energetycznych (smart grid). Blok ten umożliwia odwzorowanie zachowania wielu różnych przypadków produkcji energii i dzięki temu zdefiniowanie wielu scenariuszy testowych w celu ewaluacji algorytmów zarzadzania energia. Model jest konfigurowalny i zmiana zachowania może być dokonywana w czasie jego pracy.

1. MOTIVATION

Currently, the importance of distributed renewable energy resources in the energy grid rapidly grows. Poland, as a member of the European Union, has obligations regarding balancing energy. This work presents the requirements and methods for modeling energy generation devices that may be used in an energy grid model to define a diversity of test scenarios for energy management evaluation. These energy generators include, for instance, inverters with optimized control strategy for both islanded and grid-synchronized operations. However, the supported device set is not limited to inverters and almost any generator class can be modelled. In the low-voltage energy grid emulator these models allow testing how the energy grid behaves under various test conditions. The advantage of the emulator is that it allows defining scenarios usually not allowed in the real grid.

Based on the definition from [1] Smart Grid relies on an intelligent integration of all the actions involving every kind of users, like generators, consumers or prosumers. Main principle of Smart Grid is to ensure sustainable, efficient, economic and secure electricity supply. What distinguishes Smart Grid from regular grid is that the Smart Grid is more flexible, making it possible to connect additional users. Further, Smart Grid allows new users to play a role in optimizing the system by making their own resources available. In addition, the Smart Grid must be resilient to cyberattacks and natural disasters. To meet these conditions advanced control strategies need to be applied.

Micro grid (MG) is a local system that consists of energy sources, like photovoltaic panels, wind turbines or fuel cells connected to the loads within the network. It can be synchronized with the grid or operate as an island. A static switch controls transition between these modes. Grid-synchronization systems require the control parameters of the energy signals to meet the conditions defined by the standards. The most crucial parameter is the phase angle. Grid synchronization usually uses a phase-locked loop (PLL). PLL with adaptive notch filtering and second-order generalized integrator-based PLL are the most common approaches [2, 4]. There are also methods without PLL, like zero-crossing method [3] or Fourier analysis [2]. Island operation occurs when the micro grid is not connected to the main grid and the micro grid control unit is obligated to maintain the proper energy parameters.

Control strategy may change depending on what operation mode is currently active. With the MG connected to the grid, the grid determines voltage and frequency, so the power flow can be regulated by current or voltage as presented in [5]. Other methods include agent-based and distributed control, as presented in [1]. Complex approaches with robust control, like the H-infinite or repetitive control are presented in [3]. In the islanded mode, one of the MG units becomes the master, and is responsible for the power and load distribution. It is usually done with variety of droop control solutions that can be also communication-based, what is widely discussed in [6].

2. PROPOSED APPROACH

Proposed approach of emulator works with 24V AC output voltage with 50Hz frequency. Diagram of possible connections in the MG is presented in Fig. 1.

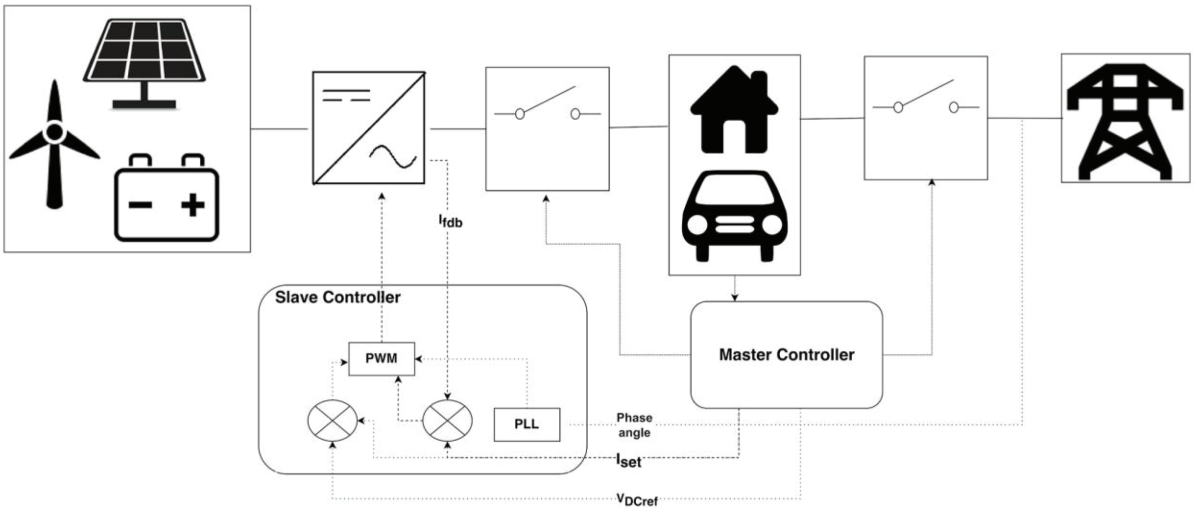

Fig. 1. Diagram of an example Micro Grid
Rys. 1. Schemat blokowy przykładowej Mikrosieci

3.2 Control strategies

There exists a variety of strategies for controlling the micro grid parameters. For now there is no standard document that can set the requirements for control strategies. And because most micro grids differ from each other according to the possibilities of using renewable resources and loads, it may not happen in the near future. That is the reason why a large number of strategies has been implemented.

In grid-following techniques for control, the strategies are based on different reference frame. The natural frame system is hard to control in case of three-phase system due to need of possessing controller for every phase. Further, some methods are presented for both stationary and synchronous rotating frames that are reached by Clark or Park transformation. These methods can be also used in a single-phase system, but with use of approaches that will generate missing vector. For that purpose one method requires implementing imaginary circuit another approach is to use capacitor current from LC filter or finally delayed signal of current to generate missing vector.

Power control in grid-forming type can be divided into communication and non-communication based. Communication-less control indeed are less expensive and do not require huge amount of peripheral devices, but in complex micro grid with multiple generator unit or when synchronization with grid is possible this solution seems not to be proper. This group of methods mostly contain any variation of droop strategies like power-frequency droop, power-voltage droop or voltage-current droop. Communication-based control is a great tool for power sharing between grid and inverters, or for parallel work of multiple inverters. Although additional communication system adds extra costs to the design and can cause problems in expansions of the grid. Most of well-known methods are based on centralized control that uses one control unit that declares current and voltage references to all power converters. Another approach is master/slave control. This concept sets as a master one of the inverter units and the logic included in that unit set the phase and amplitude angle, while the slave units are synchronizing to these master parameters.

When it comes to controlling the inner loops that are useful for controlling the power quality and for tracking the output of an energy-producing unit, a variety of methods can be adopted. A unique and widely used one is the proportional–integral–derivative (PID) controller. Another approach is the Deadbeat controller. Its main advantage is fast dynamic response that can eliminate errors within a finite number of cycles. The drawbacks of this controller are high sensitivity to feedback signal variations due to high gain and the required accurate filter model. H-infinity controller along with repetitive controller are examples of robust control. It has great adaptation for worst-case scenarios and therefore; it finds an application in slower loops for fault detections. Some additional approaches using machine-learning theory like neutral networks or fuzzy logic can be implemented, but they are out of scope of this work.

4.2 Hierarchical control

For a hierarchical control, a system can be split into four (4) levels: inner loops, primary, secondary and tertiary control. This architecture supports both centralized and decentralized strategies. The purpose of implementing hierarchical control is to ensure active power balance maintained between power demand and power production no matter what kind of disturbances or emergencies happen.

Most of the control loops like voltage regulation, PLL, maximum power point tracking (MPPT) and current loops are included in the inner loop control, although some architectures do not distinguish inner loop and primary control and keep them together. This is the fastest loop with bandwidth of several dozens of kHz.

The obligation of the primary control is the inner control of Smart Grid system. When energy is produced with synchronous machines, then this control regulates the inertia of the system. However, when system is solely based on power electronics devices, then this level can focus only on output impedance. In primary control, all faults should be detected as fast as possible. More, this level should also allow plug and play capability of different loads as well as sources. Ability to recovery after grid faults, which is called self-healing, is one of the fundamental features of Smart Grid. This control creates all the responses within couple of seconds.

The secondary control is connected strictly with parameters inside the given MG like voltage variations or frequency. This level is also responsible for the connection to the grid. This is low-frequency control scheme. Following the voltage or frequency deviations, first the primary control is regulating the parameters of the grid within some steady-state error. After that, the secondary control come into play and restores the voltage into the required level wherein minimize steady-state error. This happens even in a period of seconds. By gathering necessary information from other SG units, this level can ensure appropriate control in islanded mode according to grid-forming strategy. When operating in grid-connected mode, the secondary control works as a bridge to the grid.

Finally, the tertiary control is responsible for flow at the point of common coupling of the power between the main grid and micro grid. This part is also valuable for the economical point of view and can deliver most efficient scenarios for the energy management. When the MG is disconnected from load, then this control level is disabled.

5.2 Grid Synchronization mode

The most widely used and most researched method to ensure synchronizing with the grid is the implementation of the phase-locked loop (PLL). This solution is based on feedback loop signal that is compared with the reference signal, (which is the grid voltage) and then error signal is produced. The error signal is minimized by the internal components that are using oscillators for keeping phase of the grid synchronized. Signal that is locked is proportional to the performance of this system. The structure consists of three blocks: phase detector, loop filter and voltage controlled oscillator. Such structures by definition have trouble with filtering out the doubled grid frequency, so modified PLL solutions are used that involve an adaptive notch filter or a second-order generalized integrator.

6.2 Micro grid protection

In case of unintentional islanding, i.e. resulting from power outage in the grid, the rules in most countries say that, the inverter must be disconnected within up to two (2) seconds. There are many methods for detecting islanding. They can be grouped into remote and local. Remote methods usually require advanced infrastructure and are quite expensive. As for local methods, they can be divided into two subcategories: passive and active. Passive methods are based on the monitoring of online network parameters (frequency, phase, amplitude, harmonics), while the active methods work by injecting small interference into the system and observing its response (Perturb and Observe).

7. FURTHER STEPS

This work shows the basic issues that are important while designing the elements of Smart Grid, focusing on micro grids. Multiple approaches associated with control schemes have been covered as well as architecture of supervisory control. Additionally, grid synchronization method using PLL was introduced and principle of protection methods. That knowledge will be applied in the emulator unit to be used for testing different energy-related scenarios. The results and solutions achieved using in the emulator can be adapted onto the 230V system or even 3-phase system.

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