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Demand response approaches for real-time renewable energy integration
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Real-Time Simulation of Hybrid Energy Solution for Microgeneration in Residential Buildings

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Abstract

The unplanned power outages have occurred for all of us, and we know that from the household inhabitant's standpoint, power outage even for a short period of time is not pleasant. This matter is also true for the residential buildings that are far from the main cities, namely in the countryside or in a small village, and they may have a power outage for a long-term even with a small problem in the power transmission lines. Therefore, an energy solution module is required in order to prevent power outage for household inhabitants. In this paper, an off-grid energy sustainability solution for residential buildings will be represented by considering several small-scale generators. The module consists of several microgeneration units and energy storage systems for maintaining the energy balance. Also, a software-based control unit is used for controlling the production. The main focus is given to survey the performance of the wind turbine utilized in this energy module. The behavior of an induction machine and a permanent magnet machine will be investigated in two levels of simulation and emulation in order to realize the best solution for the wind turbine of presented energy module.

Keywords: hybrid energy solution, power outages, real-time simulation, wind turbine

1. Introduction

The hierarchical structure of the power distribution networks is being updated and move towards the smart grids, and microgrid paradigms [1]. Smart grid concepts provide several flexibilities based on resource management somehow the network operator would be able to control the rate of consumption and generation [2]. On the other hand, the daily increment of electricity demand leads to reduce the method of generation using fossil fuels [3] and optimally utilize sustainable and renewable energy resources, especially Photovoltaic (PV) and wind turbines [4].

The use of the new concepts of the power system, such as Distributed Renewable Energy Resources (DRERs) and Demand Response (DR) programs, by the small and medium players, make the network management more difficult and unstable [5]. This fact could lead to having an unplanned power outage. The power outages have occurred for everyone all around the world, which is very unpleasant for all people, especially household inhabitants. Furthermore, the residential buildings out of the main cities, such as in countryside or in a small village, can suffer from this issue since they may have a power outage for a long-term with a small technical problem in the distribution network. The Energy Storage System (ESS) can be considered as a solution to overcome this problem. However, all ESS has a limit capacity and it can only supply the electricity demand for a short period of time. Also, an ESS with adequate capacity for storing energy is not affordable for the residential buildings in the countryside and small villages. This means an energy solution module is essential to be developed and utilized in those areas in order to prevent the power outages, especially for household inhabitants.

This paper presents an off-grid energy sustainability solution for residential buildings, which employs several small scales generators. This energy module includes several microgeneration units, such as PV panels, a wind turbine, and an emergency generator. Moreover, two ESS are utilized in the module for keeping the energy balance, and a software-based control unit is used for controlling the rate of production. This module so-called HibridGER and a prototype has been implemented by the GPRI research group in Brazil (www.labteca.ecolabore.net). The main focus of this paper is given to study several simulation and emulation models for the wind turbine that can be utilized in the HibridGER. MATLAB/Simulink tools are used for the simulation of the models. Also, a real-time simulator (OP5600), and a 1.2 kW laboratory wind turbine emulator will be employed as Hardware-In-the-Loop (HIL) in order to compare the obtained results from the simulation and emulation.

After this introductory section, the HibridGER module is described in Section 2. Section 3 presents the simulation and emulation wind turbine models implemented by Simulink and OP5600, and their results are demonstrated in Section 4. Finally, Section 5 clarifies the main conclusions of the work.

2. HibridGER Module

As it was mentioned in the previous section, the HibridGER module is related to an off-grid energy solution, which employs several generation resources, including renewable sources, as well as ESS. The renewable sources consist of PV panels with 350 W generation capacity and a wind turbine with a 1000 W generation rate. Furthermore, two 12 V batteries with a total capacity of 85 A/h, are connected to the module. Besides these, a generator with 2000 W capacity supports the module in critical moments. Fig. 1 illustrates an overview of the presented module.

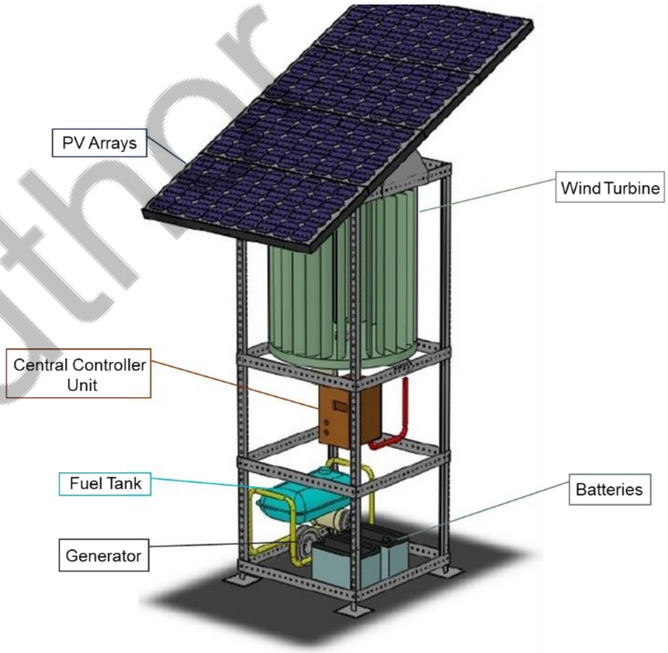

Fig. 46: Architecture of HibridGER Module.

The central control unit of this module is responsible for several functionalities. Several energy meters and relays are embedded in the module that are all connected to a software-based controller (Arduino® - www.arduino.cc) in the central control unit. Energy meters are responsible to monitor the energy generation and the output of the module, and the relay is accountable for connecting or disconnecting the sources of the module.

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The software-based controller intelligently decides about the operation of the sources based on an internal algorithm. The priority of the system is to supply the demand from the renewable sources, and while there is no demand, the batteries would be charged from those sources. If the electricity demand is out of the capacity of renewable sources, the controller connects the batteries in the power circuit to feed the loads. In the last stage, if the renewable sources and batteries were not adequate for supplying the demand, the emergency generator would be connected to the power circuit in order to supply the loads.

3. Wind Turbine Models

This section surveys the functionalities of the wind turbine used in HibridGER by providing two types of machines in order to identify the most efficient solution. Therefore, this section is divided into two subsections, which the first one describes the performance of an induction generator, and the second subsection focuses on a permanent magnet generator.

3.1 Wind Turbine Models

The induction machine considered in this section is related to a laboratory 1.2 kW wind turbine emulator. In this emulator, an inductive three-phase generator has been coupled with a three-phase asynchronous motor with variable speed. In fact, the motor emulates the blades of the wind turbine. Therefore, the operator can simulate the wind speed by controlling the speed of the motor. While the emulator is turned ON, the generator is connected to the power network in order to inject the produced power. Consequently, the emulator should follow the frequency of the grid (normally 50 Hz). If the speed of the generator goes above the frequency of the grid, the generator injects the produced power to the grid. However, if the speed of the generator is not adequate, it would not be able to produce energy.

In order to control and manage this emulator by the real-time simulator (OP5600), the analog input terminal of the speed control unit has been integrated into the analog output board of OP5600. Then, the wind speed data have been converted from km/h to a value in the range of 0 to +10V in order to provide it to the speed control unit. The computations of this conversion have been implemented in Simulink. Also, for monitoring the real-time generation of the emulator, an energy meter has been embedded in the machine, which is connected to the OP5600 through Ethernet interface, with MODBUS TCP/IP protocol. More information about this process is available on [6][7]. Fig. 2 illustrates these configurations.

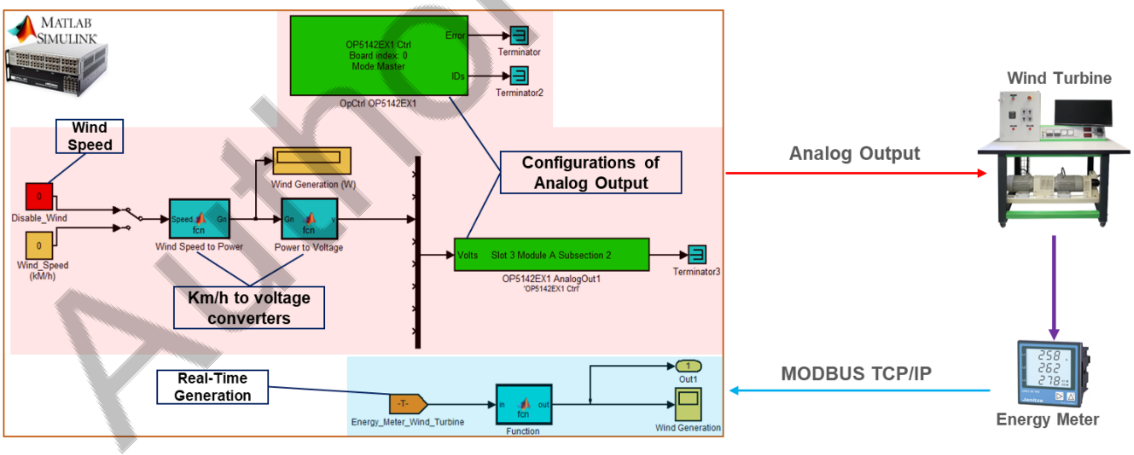

Fig. 2: Real-time simulation architecture for wind turbine emulator.

As can be seen in Fig. 2, the OP5600 would be able to control and monitor the emulator in real-time. In other words, OP5600 can send the desired wind speed data to the emulator and receives a real-time amount of generation. By this way, the performance of the induction generator could be surveyed, as it will be demonstrated in the next section.

3.2 Permanent Magnet Machine

The permanent magnet machine is another target of this paper in order to investigate its performance while it is used as a wind turbine. Since there was no available laboratory equipment for this machine, it is decided to develop a MATLAB/Simulink model, as Fig. 3 shows.

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In this model, the permanent magnet machine is configured with a three-phase connection while the stator phase resistance is set as 0.0018 ohms and stator phase inductance is set to 8.5e-3. Also, the voltage rate is configured as 400V line to line, and the torque of the machine is controlled externally from the other blocks. The model is shown in Fig. 3 is embedded in OP5600 and the results and its performance will be shown in the next section.

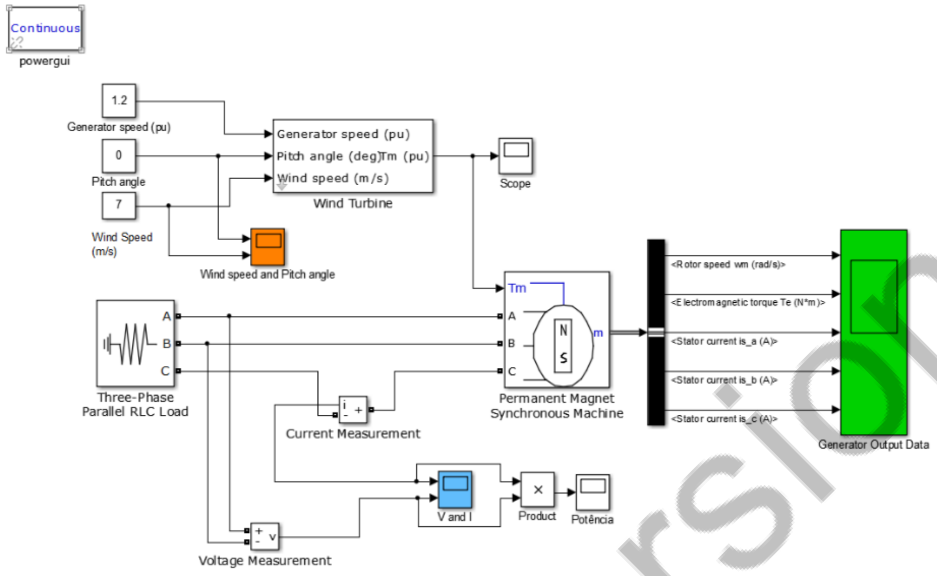

Fig. 3: Simulink model of a permanent magnet wind turbine.

4. Results

This section demonstrates the results obtained from the simulation and emulation models described in the previous section. At first, the results of wind turbine emulator controlled by OP5600 are proposed, and then the permanent magnet behaviors are discussed. Fig. 4 shows an experiment implemented by the 1.2 kW wind turbine emulator.

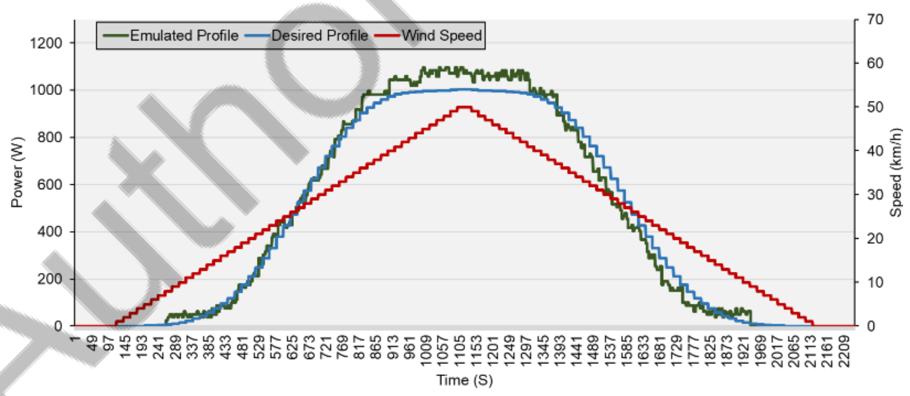

Fig. 4: Comparison of real and simulated wind generation profiles by wind turbine emulator.

The results shown in Fig. 4 are related to a test that has been performed by OP5600 and 1.2 kW wind turbine emulator. In this test, the wind speed has been increased from 0 to 50 km/h and vice versa. The blue line in Fig. 4 is the desired power rate and the green line is the output generation of wind turbine emulator. Moreover, Fig. 5 illustrates the results of another test implemented by the wind turbine emulator. In this second test, the wind speed data has been acquired from [8], which is the actual wind speed data provided to the emulator. As can be seen in Fig. 5, the set points are the favorable values that have been requested from the wind turbine to be emulated. Consequently, the emulator produces power and transmits the actual measurements of active power generation (green line in Fig. 5) to the OP5600. By this way, the system is able to emulate the wind generation profile based on the electrical grid conditions, such as voltage variations. Regarding the permanent magnet machine, Fig. 6 illustrates the obtained results from the Simulink model.

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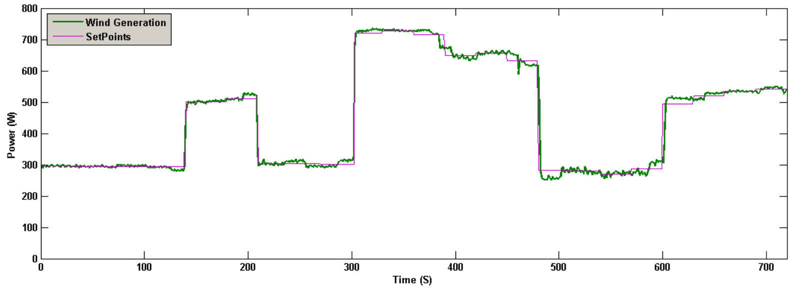

Fig. 5: Real-time results of wind turbine emulator.

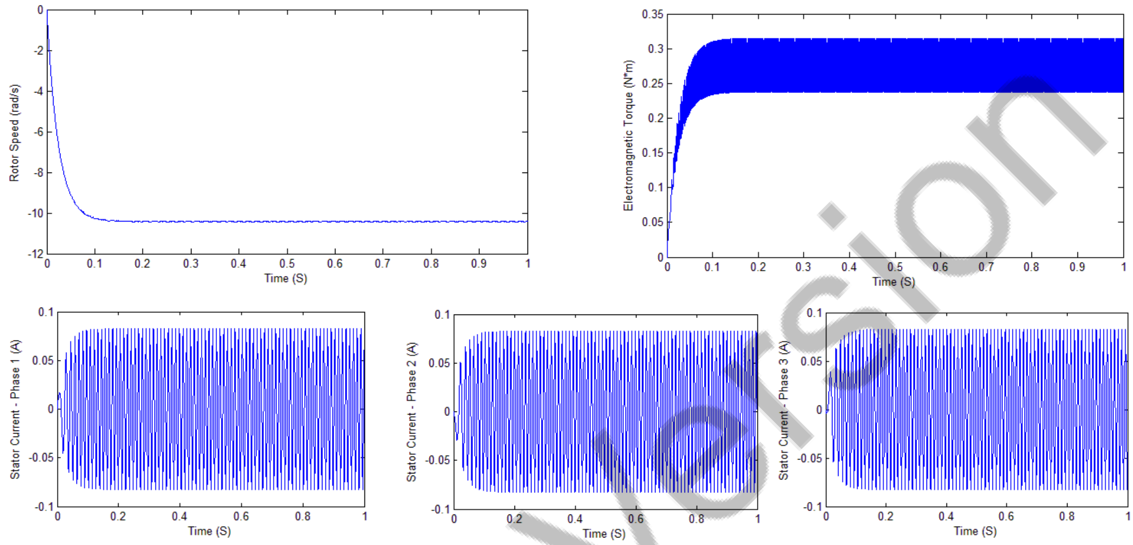

Fig. 6: The results of simulation for the permanent magnet generator.

The results shown in Fig. 6 are gained while the wind speed is set to 7 m/s, generator speed is 1.2 p.u, and 30 degrees in the pitch angle.

5. Conclusions

This paper proposed an off-grid energy solution for residential buildings in order to overcome the power outages. This energy module consists of renewable energy sources, energy storage systems, and an emergency generator. Two models, including an induction machine and a permanent magnet machine, were presented for the wind turbine employed in this energy module. All the models have been simulated and emulated by laboratory equipment and a real-time simulator, and the obtained results are presented. The outcomes of the paper show that the induction machine is more acceptable and suitable to be used as a wind turbine in the proposed hybrid energy solution.

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