Full title: A Simulation Model For Expandable Hybrid Power Systems.

Correspondent Author:
Prof. Dr.-Ing. E. Ortjohann, University of Applied Sciences Südwestfalen, Division Soest, Fachbereich 16 – EV u. EW, Lübecker Ring 2, D-59494 Soest.
Tel.: +49 2921 378 432, FAX: +49 2921 378 433, E-mail address: ortjohann@fh-swf.de

Co-Authors:
1) M.Sc. Engineer O. Omari, University of Applied Sciences Südwestfalen, Division Soest, Laboratory of Power Systems and Power Economics.
2) Engineer R. Saiju, University of Applied Sciences Südwestfalen, Division Soest, Laboratory of Power Systems and Power Economics.
3) Dip.-Ing. N. Hamsic, University of Applied Sciences Südwestfalen, Division Soest, Laboratory of Power Systems and Power Economics.
4) Dr. D. Morton, Bolton Institute of Higher Education, Faculty of technology Admin.

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Purpose: The purpose of the work is to investigate a specific architecture of autonomous hybrid power system (HPS). This architecture is based upon the utilization of a DC bus, a DC/AC inverter, and an individual DC/DC converter for each power source. Some advantages and disadvantages of this architecture will be discussed.
Furthermore, the system's inherent flexibility to be easily expanded is going to be explained.

Method: The whole work is based upon simulation. Models are made to simulate the different power sources (PV system, Wind turbine, Diesel generator, …), a storage battery, the electrical loads, and the relevant meteorological conditions, in addition to other items that are needed to represent the autonomous power system satisfactorily.

Approach: MATLAB/SIMULINK is the used software for simulating the whole system. Concentration is mainly given to the power sources and the battery (power generation side). The distribution grid and the loads are represented as a power demand that needs to be satisfied according to a given voltage and frequency. The approach is structured in such a way that a separate sub model is developed for each item of the power generation side, the main DC/AC inverter, the isolated grid (including the loads), and the relevant environmental variables. Each model is then individually investigated. Other sub model(s) are developed for control and management. The performance of the overall model is investigated afterwards under different operating conditions.

Results: Good performances of the individual sub models and of the overall model are achieved. The control/management units show ability to prioritise the functionality of the power supplies in such a way that the cheaper has the higher priority while guaranteeing the reliability of the whole system. A main advantage of the discussed system's architecture exists in providing a decoupling of the state values of the conversion systems from those of the grid through the use of the DC/DC converters.

Conclusions: This architecture may become a good choice for the construction of HPS. It helps in overcoming the limitations on expandability that exists in most centralised supply systems. More investigation is needed, and actually is being done, in this field.
Decoupling the state values of the conversion systems from the state values of the grid allows an easy and individual control of each power conversion system. Moreover, a clear and hierarchical structure of the control/management units can be easily designed.

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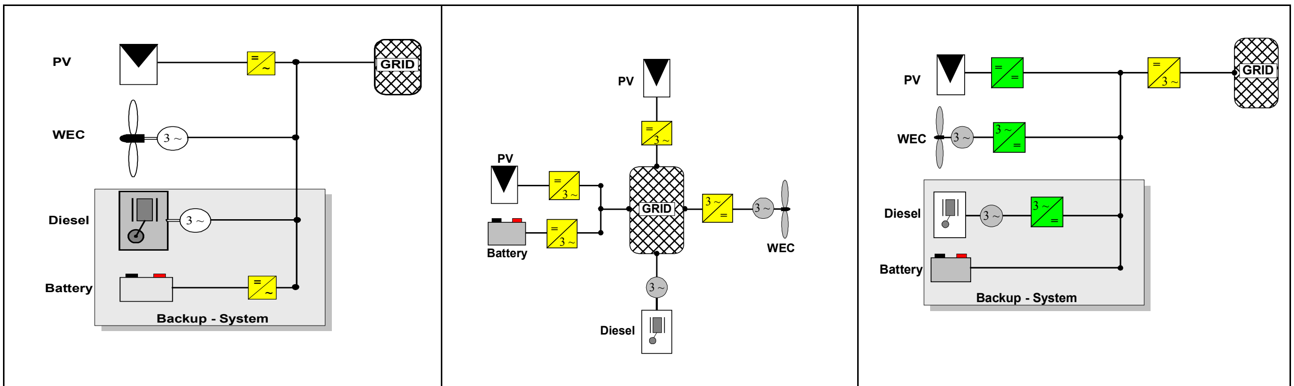
Explanatory Information

The different kinds of electrical power generators that might be used to feed power into a hybrid power system can be connected to the grid in several different ways.

Some Architectures of HPSs

Consider a hybrid power system whose power is supplied through a wind turbine, a PV system, a diesel generator, and a battery. Three different possible architectures to connect these systems together and to an isolated grid are shown in Fig. 1 below.



a) Centralized AC-bus architecture | b) Distributed AC-bus architecture | c) Centralized DC-bus architecture

Fig. 1: Three different possible architectures of HPSs

In the first architecture (a), the generators and the battery are all installed in one place and are connected to a main AC bus bar before being connected to the grid [1]. This system is centralized in the sense that the power delivered by all the energy conversion systems and the battery is fed to the grid through a single point. In this case, the power produced by the PV system and the battery is inverted into AC before being connected to the main AC bus.

The energy conversion systems can also be connected to the grid in a decentralized manner as shown in Fig. 1(b)[2]. The power sources in this architecture do not need to be installed close to each other as in (a), and they do not need to be connected to one main bus bar. Otherwise, the sources are distributed in different geographical locations as appropriate and each source is connected to the grid separately. The power produced by each source is conditioned separately to be identical with the form required by the grid. The main disadvantage of this architecture is the difficulty of controlling the system when the diesel generator is in off mode.

The third architecture utilizes a main centralized DC bus bar (c). So, the energy conversion systems that produce AC power, namely the wind energy converter and the diesel generator, firstly deliver their power to rectifiers to be converted into DC before it is being delivered to the main DC bus bar. A main inverter takes the responsibility of feeding the AC grid from this main DC bus [2].

The Suggested Architecture

The following architecture is the one upon which the submitted paper is based. It is an improved version of the centralized DC-bus architecture shown in Fig. 1(c) above. The improvement exists mainly in the addition of a DC/DC converter for each energy conversion system (including the storage battery) before connecting them to the main DC bus (Fig. 2). By this addition of the DC/DC converters, the state values of the energy conversion sources become completely decoupled from each other and from the state values of the grid. The power production of the different sources becomes now freely controllable without affecting the state values of the grid.

Decoupling the state values means that the variations of the renewable resources like the velocity of the wind and the intensity of the solar radiation will not influence the state values of the electrical grid. These values are only controlled by the inverter. On the other hand, changes in the loads, which influence the state values of the grid will not affect the generation side.

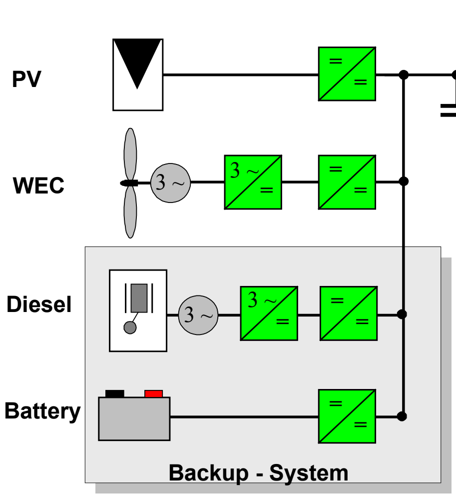


Fig. 2: The suggested architecture

A control/management strategy is developed for this architecture to operate it in the most efficient way. Efficiency here means the most utilization of the renewable energy sources in order to minimise the kWh cost while preserving the reliability of the system.
The control/management unit receives information about the loads from the grid, about the power availability from the meteorological conditions, the battery and the diesel generator, and about the state values of the grid. From these inputs, the control/management unit outputs signals for the different energy conversion systems to inform them about the amount of power required from each of them. On the side of the energy conversion systems, a control unit is developed for each system that receives the signal from the main control/management unit and reacts accordingly.
This control/management strategy is modular in many aspects. The kinds of the energy conversion systems can be freely chosen and their sizes can be freely specified. Depending on the local conditions of the region where the HPS is to be installed, an optimisation algorithm can be used to specify the kinds any sizes of the power sources and the storage devices. To any such system, the developed control/management strategies can be applied without (or with minor) changes.
The power production can be increased to cover any additional loads. This system is expandable since it is possible to add other conversion systems beyond the DC bus without the need to do changes of the control/management strategy. It also can be expanded by using another inverter. In this case it is needed only to change the control strategy of the inverter in combination with the load management system.

System Simulation model

A complete model simulating the above architecture of the HPS is done on MATLAB/SIMULINK. A lot of sub models are put together to constitute the main model as shown in Fig. 3 below. Each energy conversion system is included in one sub model. There are also sub models for the storage
The model in the Fig. 3 simulates the discussed architecture of the HPS very accurately. Some of the results achieved from this model are shown in Fig. 4 below. What can be noticed in the figure is the power balance of the HPS. In the first sub graph the grid load is shown. The following sub graphs show the power production of each energy conversion system. Notice that in the first 100 seconds, the load is lower than the renewable power and the battery is charging. When the battery becomes fully charged, a bit before 100 second, the battery power drops to zero and the power production from the renewable sources decreases accordingly to keep the power balance of the system. After that, the load started to increase and the renewable power production followed until the renewable energy conversion systems were producing their maximum power. The additional load then was fed from the battery. After 200 seconds, the resources of the renewable systems were decreasing and the battery substituted the power shortage. Before 600 seconds, the online

controller sensed that the SOC of the battery was about to reach the minimum level, and then it started the diesel generator and loaded it gradually.

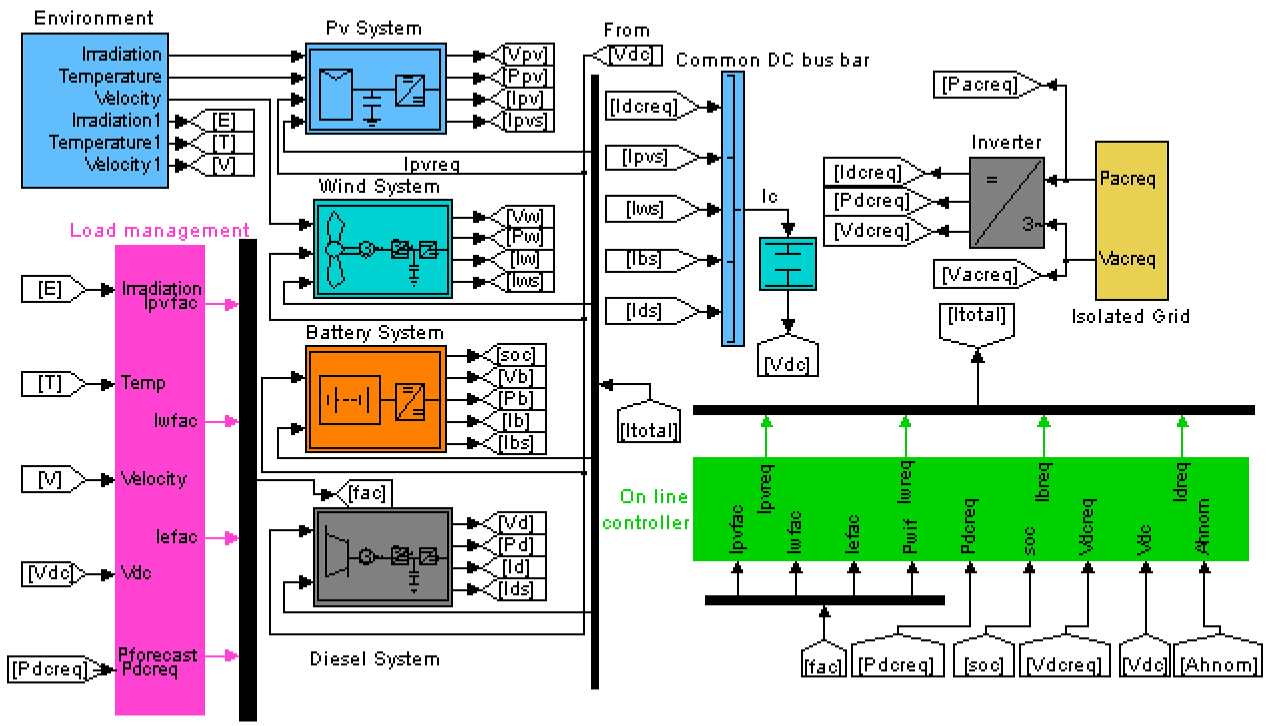


Fig. 3: A simulation model of the HPS

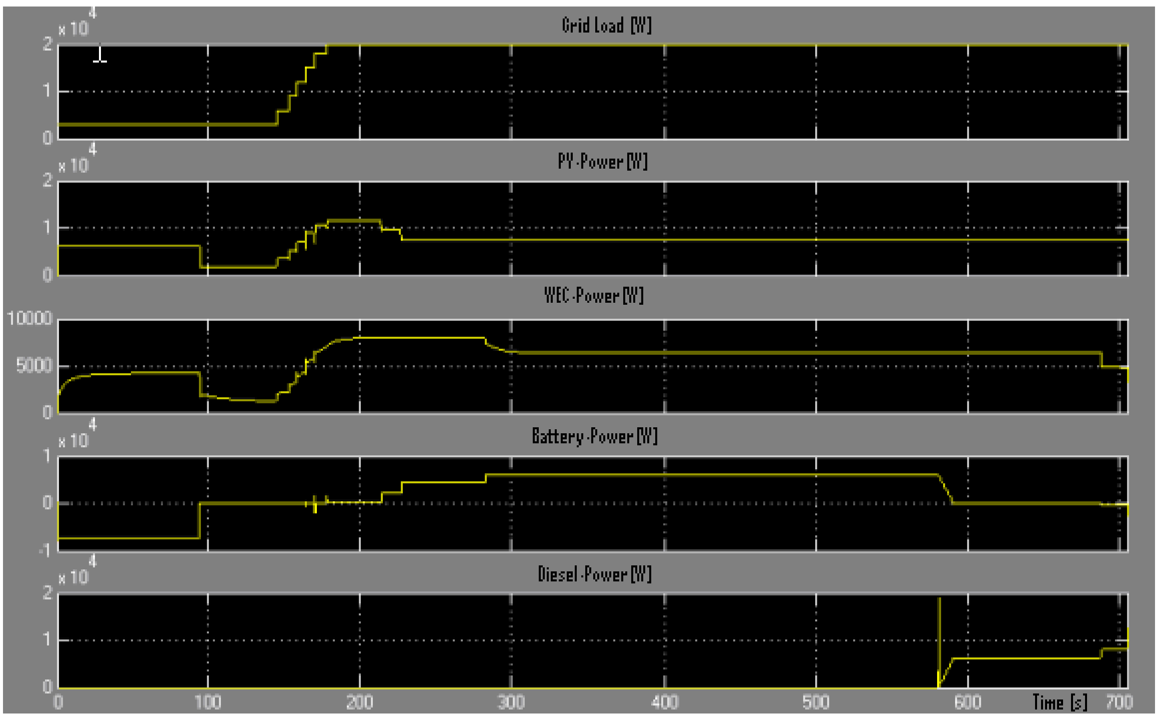


Fig. 4: Experimental results of the HPS.

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[2] M. Vandenbergh, S. Beverungen, B. Buchholz: Expandable Hybrid Systems for Multi-User Mini-Grids, 17th European Photovoltaic Solar Energy Conference, Munich, Germany, 2001.