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HYBRID ENERGY SYSTEM - OPTIMIZATION AND NEW CONCEPT

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Abstract. *Paper presents a research related to the design of a new concept of hybrid energy system. It describes actually used concepts and the benefits of new design. Subsequently, the problems of the proper systems setting and working conditions are discussed and the new concept of the systems settings is presented. Research is further enhanced by comparing with the simulation model assuming the weather data acquired for the test location. The measured data are compared with the results of simulation.*

Keywords: hybrid energy system, MATLAB simulation, optimization

HYBRYDOWY SYSTEM ENERGETYCZNY – NOWA KONCEPCJA I OPTYMALIZACJA

Streszczenie. *Artykuł przedstawia projekt nowej koncepcji hybrydowego systemu energetycznego. W pracy przedstawiono aktualnie stosowane koncepcje i na ich tle zalety nowego podejścia. Następnie dyskutowano odpowiednie ustawienia i warunki pracy systemu oraz przedstawiono nową koncepcję systemu. Dodatkowo badania są zilustrowane porównaniem z modelem symulacyjnym, przy założeniu, że dane pogodowe pozyskane zostały dla testowej lokalizacji.*

Słowa kluczowe: hybrydowy system energetyczny, symulacja w MATLAB-ie, optymalizacja

Introduction

The paper deals with the hybrid energy system consisting of a wind turbine, photovoltaic panels and batteries. System is recently in the phase of optimization and initial testing. Therefore, only the preliminary results are demonstrated in this paper. Further research will be aimed on proper configuration of all individual subsystems and processing the measured data. Subsequently, the optimization steps will be performed. Part of the research is focused on the effect of different subsystems on the overall efficiency and the possible ways, that can lead to improvement of the system performance.

1. Description of the Hybrid Energy System

The hybrid energy system is situated on the roof of the Department of Electrical Power Engineering building at Faculty of Electrical Engineering and Communication Brno University of Technology. Department's location is 49°13'38.413"N, 16°34'26.217"E. According to the PVGIS [2], the predicted annual solar irradiance is between 1085 and 1111 kWh/m^2. The estimated average wind speed, measured at 10 m above the surface, is between 3 and 3.5 m/s.

The system is designed as a combination of three–blade, horizontal axis wind turbine, PV panels and deep cycle gel battery banks suitable for application in solar and wind systems.

Wind turbine Whisper 200 has nominal power 1kW at 11.6 m/s of the wind speed. It contains permanent magnet synchronous generator (PMSG) with 48 V AC output, connected to the passive 3-phase 6-pulse rectifier and then to the DC/DC regulator (Tristar MPPT-60).

Nine Solarwatt M250 60 GET AK photovoltaic panels provide the peak power 2250 Wp and are connected in three strings to another DC/DC regulator (Tristar MPPT-60). Both DC/DC regulators are connected to the two battery banks (48 V DC, 200 Ah) each consisting of serial connection of four deep cycles gel batteries (FG12-200DG).

Two power inverters (Studer XTM 2600) are working in master-slave mode, providing the AC power from the entire system.

2. Performed Measurements

The weather data acquisition is performed by the CMP21 radiometer, which measures the normal radiant flux density and the outdoor temperature. Wind data are measured by Mierij Meteo system. The Unitronics Vision V1040 PLC serves as the data logger, which gathers measured data and stores it to an EXCEL file at the end of an each day. Gathered data are represented by the samples of the immediate values in the periods of 30 seconds. This time is adequate for the time constant of the radiometer. Additionally, the actual weather data are available on the website, which refreshes each 10 seconds. More detailed description of the data acquisition system is presented in [3].

The measured data are further processed with a MATLAB script to obtain the selected values (daily, monthly statistic) and to plot the graphs.

According to the analyzed data, the average wind speed and the solar irradiation for individual months are shown in Tab. 1. The monthly solar irradiation corresponds with the estimated results with the PVGIS [2]. The difference between the measured and estimated value of the solar irradiation in the May 2014 is caused by the incomplete data set caused by the datalogger malfunction.

Tab. 1. Monthly results from the weather data acquisition

Month	Average wind speed (m/s)	Maximal wind speed (m/s)	Measured solar irradiation (kWh/m^2)	Estimated solar irradiation (kWh/m^2)
December 2013	2.552	16.8	11.03	25.7
January 2014	2.102	13.7	17.87	26.2
February 2014	2.505	13.7	37.76	43.7
March 2014	2.483	17.5	98.73	89
April 2014	2.263	17.8	126.13	138
May 2014	2.770	19.7	93.99	163
June 2014	2.271	13.8	157.54	169

In the Fig. 1 the waveforms of the voltages and currents from PMSG before (CH1-CH3) and after the rectifier (CH4) are shown. A resistor was as the load. The reason for this measurement was mainly to verify the generator function in the initial testing phase. The waveforms have been measured by HIOKI 3390 power analyzer. The results from these measurements are further used for validation of the simulation model described subsequently.

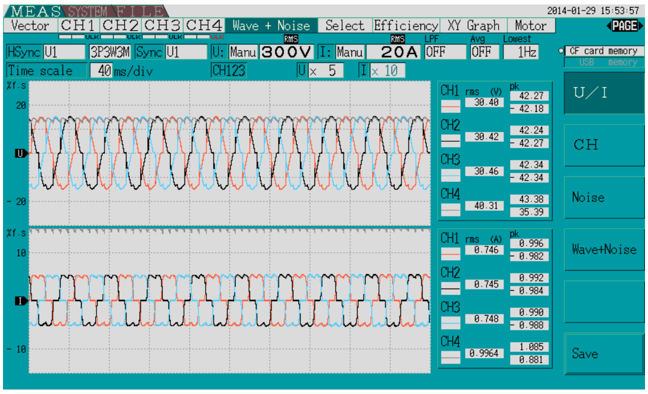

Fig. 1. Measured Waveforms of AC (CH1-CH3) and rectified (CH4) voltages and currents at the output of PMSG

In Fig. 2 the results from the wind speeds and directions analysis for a selected month are shown. Based on the performed analysis can be stated that the prevailing wind direction is north-west. In other months alternates prevailing direction north-west and south-east.

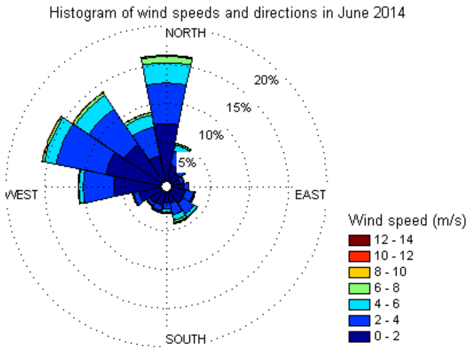

Fig. 2. Wind speeds and directions in June 2014

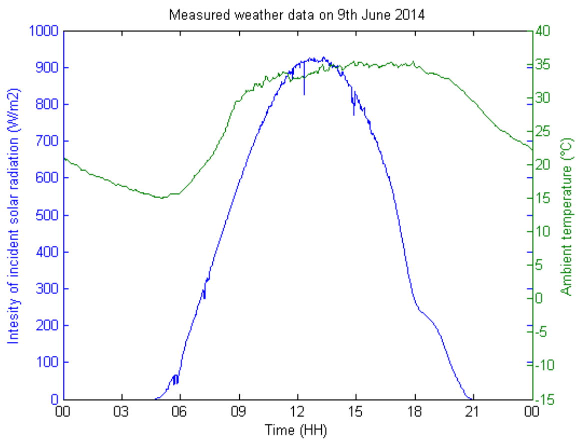

Fig. 3. Daily history of the measured weather data

Fig. 3 shows the daily history of the ambient temperature and the intensity of perpendicular solar radiation on the planar surface.

3. Simulation model of the wind turbine

Next part of the research is aimed on simulation of individual subsystems. For these purposes a model of wind turbine in MATLAB/Simulink (Fig. 6), which is based on the model described in [1], has been created.

This was done with the use of the blocks from the library of SimPowerSystem. Wind turbine model simulates the output torque in per units related to the nominal power of the wind turbine. Practically, the library block simulates the wind turbine power characteristics according the input parameters, which are the wind speed, pitch angle and angular speed of the generator. Because of the absence of the wind turbine's pitch regulation a constant angle has been assumed. Used power characteristics for the Whisper 200 wind turbine is shown in the Fig. 4.

Drive train is based on a two-mass model. In the simulation, it is necessary to simulate the dynamic behavior of the wind turbine and transient effects of the device. The output from the PMSG is rectified with the use of the three phases, six pulse diode rectifier and for verification purposes a resistor is connected as a load. The aim is to reproduce the measured waveforms shown in the Fig. 1.

This has been already fulfilled with adequate accuracy (results from the simulation are shown in the Fig. 5) and the model is prepared for further optimization. In order to predict the behavior of the wind turbine and to estimate the requirements for the control system, the input wind speed is set as a time-variable. Verified and optimized model is used for estimation of the produced energy from the wind turbine within the various ranges of wind speeds and provides the simulation apparatus for further research.

Additionally, other individual subsystems like PV panels, battery, inverters and DC-DC converters will be simulated, and finally the behavior of the entire system will be predicted. The research includes testing the different system subsystems and their influence on the system's performance. [5]

During this testing the evaluation of the weather data will be continued to obtain more detailed information about the installation's location and improving the created models with implementation of the measured data. It is planned to supplement the weather data acquisition device with the additional sensors to measure the humidity, atmospheric pressure, rain precipitation and temperature at different points (PV panel, batteries, inverters, etc.) that can affect the system and its efficiency. Furthermore, more detailed comparison of simulated results from the created models with the measured data will be performed. Evaluated results will be used for the model improvement.

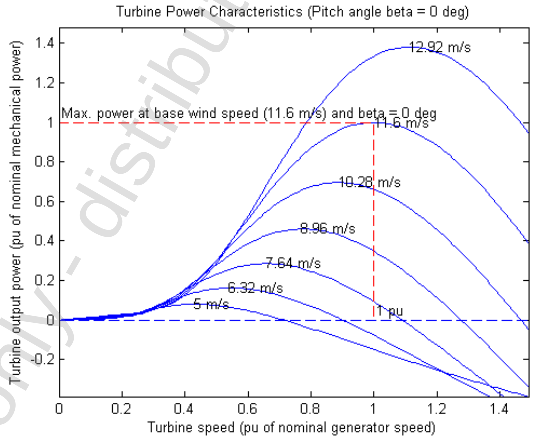

Fig. 4. Whisper 200 wind turbine power characteristics

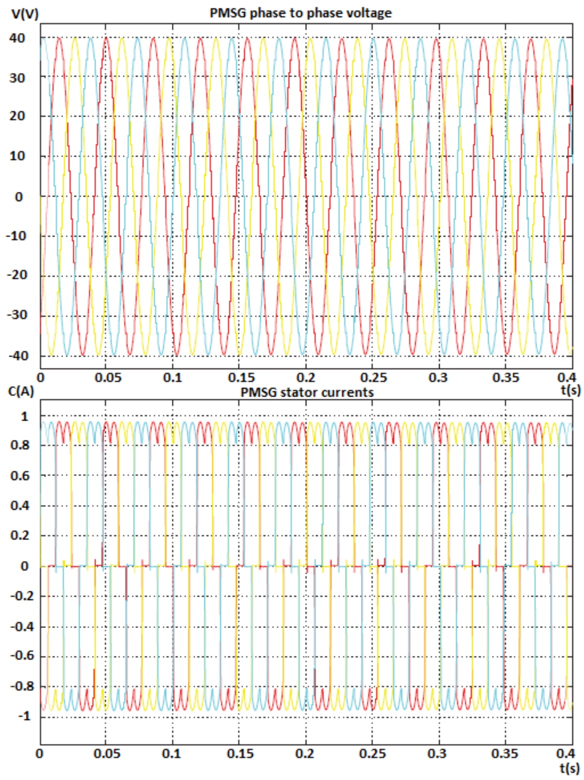

Fig. 5 Simulated results from the Simulink model

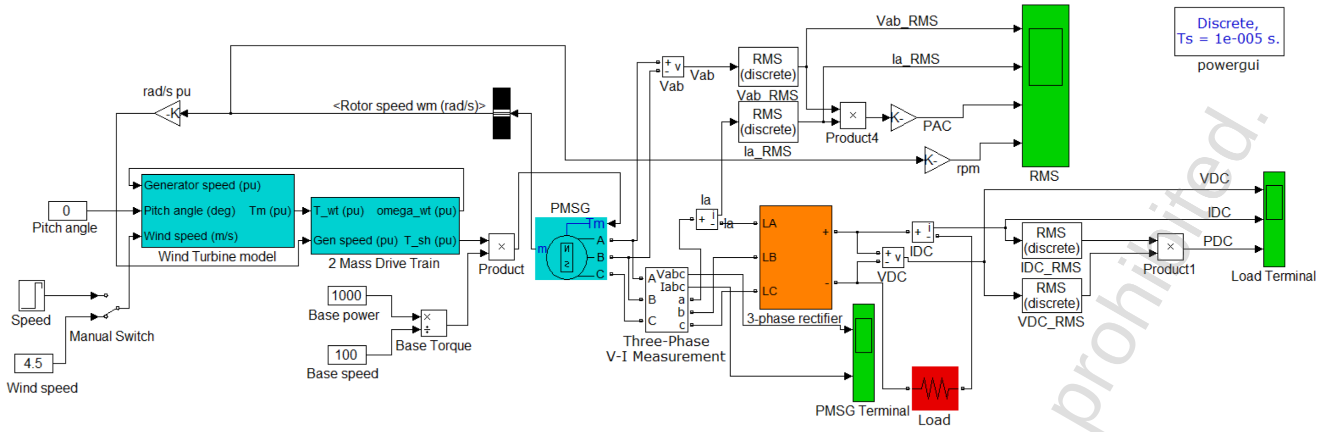

Fig. 6. Wind turbine model with PMSG in Matlab Simulink

4. Optimization of the system

The main problem of the research on described hybrid energy system is related to the communication between the individual power converters and their proper settings. Generally, the hybrid energy systems with accumulation can be configured in several ways:

1) Energy from the renewable sources is accumulated or consumed in the load and the system is not connected to the public electricity network.
2) System is connected to grid. It is not authorized to provide the excess energy to the grid, but can use the energy from the grid to recharge batteries or supply power to the loads.
3) Hybrid energy system is designed as the active component with the possibilities not just to provide the excess energy to the grid, but based on the communication command can also force the system to provide the accumulated energy to the network and improve the power quality.

The configurations 1 and 2 described higher are demonstrated in the Fig. 7 and Fig. 8. Problem of these concepts are in the improper internal logic of the power inverters settings in the current experimental set-up.

In the hybrid energy system described above, it has been found out, that in the case when the accumulation element of the system needs to recharged, the system primarily uses the electricity from the grid to recharge the batteries, even if there is available energy in the renewable sources (Fig. 8). This setting is improper and reduces the operational efficiency of the entire system.

Concept of the active hybrid energy system is currently the main goal of the research. Due to the actual legislative in the Czech Republic (CR) is not possible to operate the hybrid energy systems in this way. Further research will be focused on defining the prerequisites and limiting conditions that will allow achieving the positive effect on the electricity grid.

With the use of the concept described in the third point above, the stochastic character of the individual sources and their negative effect on the electricity grid can be reduced. In the result, the integration of the renewable sources can be increased without additional negative effect on the electricity grid.

Innovative concept of the hybrid energy system is used to maximize the energy production of the energy sources by the combination of properly sized accumulation element and by the optimized control system with the possibility of using the electricity grid.

In the case of fully loaded batteries and the renewable power generation, the energy will be transferred to the grid (Fig. 9).

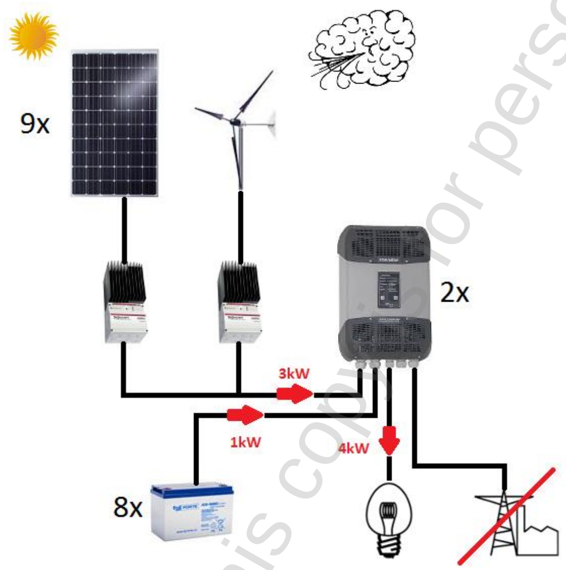

Fig. 7. Hybrid energy system as the standalone off-grid application

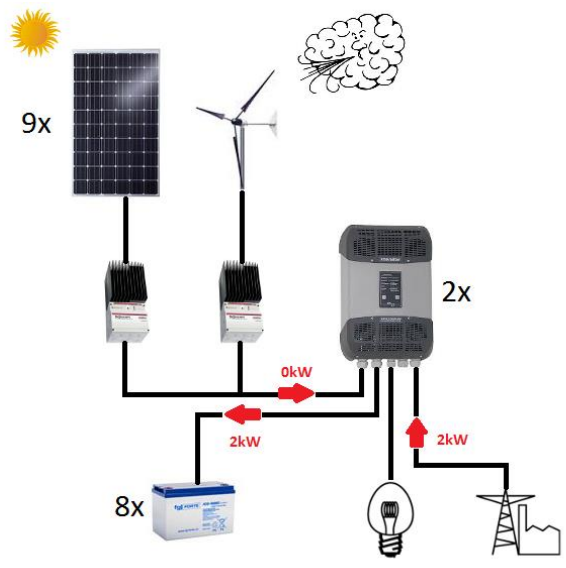

Fig. 8. Improper settings of the inverter internal logic uses grid instead of renewable energy sources to recharge the batteries

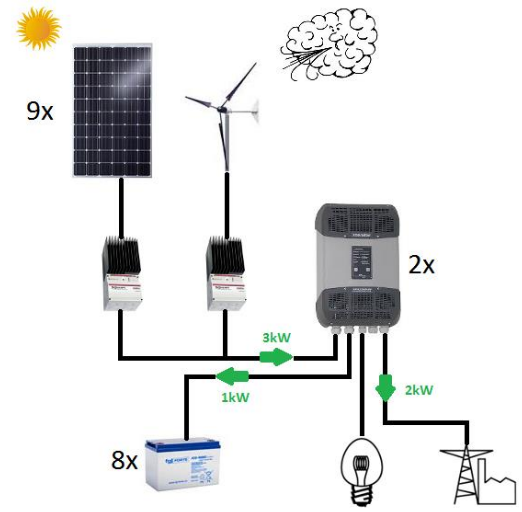

Fig. 9. Hybrid energy system providing the excess energy to the network

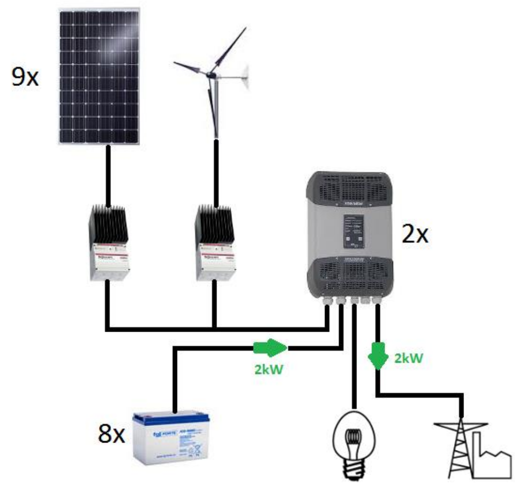

Fig. 10. Force grid-feeding using the accumulated energy in the batteries

When the grid energy is insufficient, the accumulated energy can be on demand force-feeded to the grid (Fig. 10).

Considering the use of the hybrid energy system described above the fully loaded batteries can provide 19.2 kWh of energy before fully discharged. Due the life expectancy shortage, only 60% of the full discharge should be presumed. That gives 7.68 kWh of the available energy. With the use of the master-slave working mode of the power inverters, continuous power of 5 kW can be fed to the grid for 1.5 hours. The implementation of the innovative logic to the existing systems allows the active electricity grid support. Therefore, the regulation power in conventional energy sources needed for voltage regulation can be reduced, because primarily can be used the accumulated energy in the hybrid system.

Conclusions

In the paper the research dealing with the design of the hybrid energy system using renewable energy sources has been presented. It proposes a new concept for its operation, which considers the implementation of innovative settings to transform the passive hybrid systems to active. Active hybrid energy system can provide the energy to the electricity network according to operator's requirements. Innovative settings of the inverter's internal logic include the limiting conditions to ensure that the supplied energy will not negatively affect the electricity network. The part of the research is aimed on limits of the protections used in these systems. Current limits are strictly set due the massive dynamic changes of the power generated from the renewable resources. With stabilizing the energy production using the accumulation is provided the predictable energy source and the current legislative restraints of installed power and limits of protection's settings can be changed. Also the inverters can be programmed to support the grid with the active and reactive power according to the actual voltage and frequency. Conditions specifying these functions are nowadays discussed in several countries (e.g. Germany, Czech Republic) in connection with the operation of the renewable energy sources (PV, wind turbines). Presented concept is development of the actual requirements based on the optimization of the systems to maximize the energy production and increase the operational efficiency of the entire systems.

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