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Modeling Hybrid Renewable Energy System for Micro Grid

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Abstract. This paper discusses issue of modeling renewable energy hybrid system for selected micro grid which is tied with bulk power system. The objective of the work is creating a tool for feasibility assessment of the energy hybrid system component operation and appropriate control strategy to provide its efficiency. The hybrid of solar, wind and generalized energy storage device is the basis of the examination. The integrated model uses statistical indices of solar irradiation and wind speed data to simulate power flow in the system. As the micro grid load demand is variable, power interchange with bulk power system is managed by system supervisor. The dispatch control strategy and the load profile of the micro grid must be used to estimate the correct sizing of the system with presence of a storage system. The proposed model has been applied to a case study.

Key words

Modeling, micro grid, hybrid energy system

1. Introduction

Environmental concerns and limited reserves of natural energy resources resulted in increasing use of the renewable energy sources. Wind turbine (WT) and photovoltaic (PV) generators are worldwide used to supplying customers in remote areas. At the same time, under using a singular form of the primary energy (solar or wind) stochastic nature of these sources may be cause a time with no or low electricity generated. Therefore electricity will not be supplied during that time. If more than one renewable source is used for energy generation, for example a combination of WT and PV generators, the energy generation will be less depended on one intermittent energy source. To make the system more stable, energy storage device (SD) must be included to accumulate energy during excess WT and PV generation and supply energy during deeply fall of generation. A combination of energy sources and storage devices is commonly called as hybrid renewable energy system. Such combination of energy units considerably improves supply security. Hybrid systems in remote areas may be used as support system for grid connected consumers and provide increased supply efficiency. However, high total cost of hybrid systems with respect to its duty factor is a concern in their wide using. Therefore, correct sizing of renewable energy hybrid configuration in selected area in consideration of dispatch requirements tends to minimize the total cost of electricity supply.

Several authors have studied the problem of using and optimal sizing of hybrid renewable energy systems [1-6]. The aim of this paper is to present the model of a hybrid energy generation system connected to the public grid. The model is based on mathematical modeling energy response of each hybrid component and stochastic modeling primary energy sources.

2. Modeling the Hybrid System

The hybrid renewable WT/PV/SD system outline is presented in Fig. 1. It shows its basic components along with the functional connections between them. All components of the WT/PV/SD system through the 1250 kVA step-up transformer are connected to the 15 kV bus. The 15 kV bus is connected to public grid as well to ensure discontinuous supplying the local load.

A 1000 kW Doubly-Fed Induction Generator (DFIG) is used in WT complex. Mechanical and electrical controls of the DFIG enforce the maximum electrical power input at corresponding winter speeds according to WT power curve provided by its manufacturer.

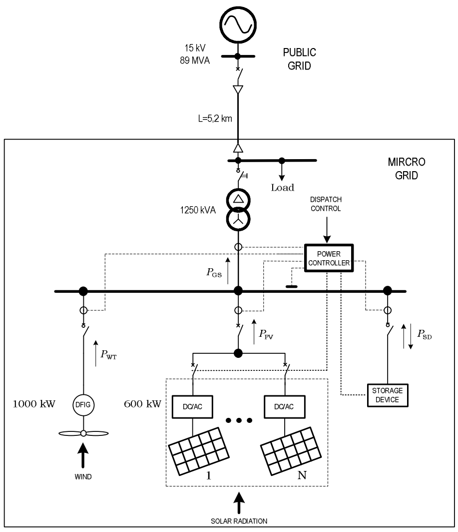

Fig. 1. The hybrid renewable energy system outline.

Photovoltaic generator consists of photovoltaic panels with aggregate capacity of 600 kW under standard test conditions of the panels. The photovoltaic generator is connected to AC bus through DC/AC inverter. The photovoltaic generator is equipped with control system that ensures sinusoidal input voltage and generator operation on so called Maximum Power Point (MPP) [6] for all solar radiations.
Storage device in the explored hybrid system is the component that should be selected. Sizing and type of the storage device depend on the exploitative characteristics and pricing of the hybrid system [2,6,7,8].

A. Wind turbine

The output power from the wind turbine can be obtained by using wind turbine power curve. The wind turbine power curve which given by manufacturer in consideration on turbine power controls is shown in Fig. 2.

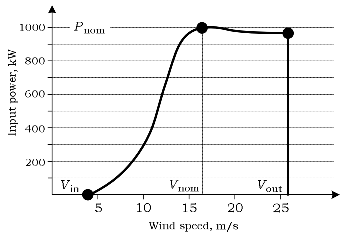

Fig. 2. The wind turbine power curve.

The statistic indices of wind speed can be estimated by using probability distribution function for a specific site [8,9]. Weibull probability density function (pdf) is used for description of wind speed variation:

$$f_V = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp\left(-\left(\frac{V}{c}\right)^k\right), \tag{1}$$

where

V – wind speed;

$k = \left(\frac{\sigma_V}{\mu_V}\right)^{-1.086}$ – shape factor;

$c = \frac{\mu_V}{\Gamma\left(1+\frac{1}{k}\right)}$ – scaling factor;

μ_V – mean wind speed;

σ_V – standard deviation of the wind speed probability function;

Γ – Gamma function.

For analyzed area by wind characteristics measurements have been obtained the next quantities - $\mu_V = 5{,}9$ m/s and $\sigma_V = 3{,}6$ m/s. The Weibull probability density f_V and cumulative distribution F_V functions calculated on the wind speed probability function parameters are presented in Fig. 3.

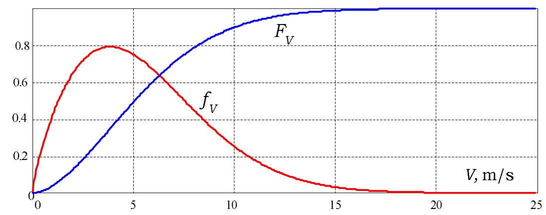

Fig. 3. Weibull probability functions f_V and F_V .

On the basis of the wind stochastic parameters by using Weibull random number generator software (i.e. [11]) can be obtain pseudorandom wind function for the considered time horizon.
In order to stochastic modeling WT power input the approximation of the WT power curve (see Fig.2) was implemented by the formulas:

$$P_{WT} = \begin{cases} P_{nom} \cdot \dfrac{V^{1,8} - V_{in}^{1,8}}{V_{nom}^{1,8} - V_{in}^{1,8}} & \text{if } V_{in} \le V < V_{nom} \\ P_{nom} & \text{if } V_{nom} \le V < V_{out} \\ 0 & \text{if } V_{nom} \le V < V_{out} \end{cases} \tag{2}$$

The pseudorandom wind and appropriate power input as time functions for the examined area and WT ratings (P_{nom} =1000 kW, V_{nom} = 16 m/s) are shown in Fig. 4. Simulation was carried out considering 15-minutes wind speed data averaging.

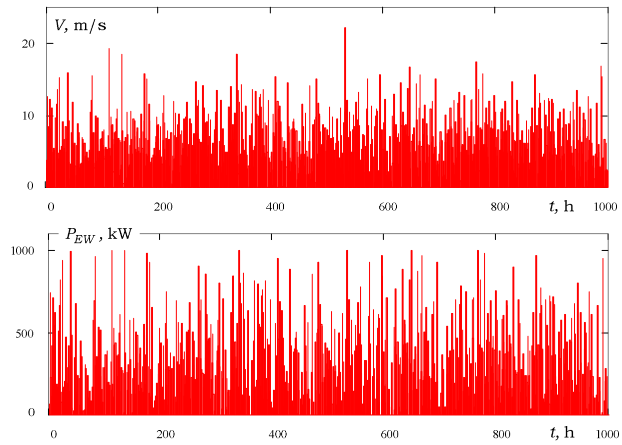

Fig. 4. Simulated wind speed and WT power input time dependencies.

B. Photovoltaic Generator

PV generator performance is considered in the model through by the maximum power output at different PV module temperatures and various irradiation levels. This model makes possible obtaining output power of PV generator depending on climatic conditions at a specific site. The output power of a PV panel can be calculated using the following equations:

$$P_{PV} = N \cdot U_{mp} \cdot I_{mp}\ , \tag{3}$$

where

$$U_{mp} = U_{mpp} + K_V \cdot (T - T_s) \tag{4}$$

$$I_{mp} = I_{mpp} + I_{SC}\frac{G}{G_s} + K_I \cdot (T - T_s) \qquad (5)$$

In these equations:

T, G - current temperature and irradiation level;

N - number of cells in the panel;

V_{mpp} , I_{mpp}, K_V , K_I , I_{SC} , G_s , T_s - specific data of the photovoltaic cell [1,8].

As it is known from field measurements [12] solar irradiation over a long time horizon as a random function can be approximated by **β** probability density function:

$$f_G = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\left(\frac{G}{G_{\max}}\right)^{\alpha-1}\left(1-\frac{G}{G_{\max}}\right)^{\beta-1}, \qquad (6)$$

where G_{max} – maximum irradiation for the time horizon in the explored area.

Parameters of the probability density function are calculated form the next formulas:

$$\alpha = \mu_G\left[\frac{\mu_G(1-\mu_G)}{\sigma_G} - 1\right];$$

$$\beta = (1-\mu_G)\left[\frac{\mu_G(1-\mu_G)}{\sigma_G} - 1\right],$$

where

μ_G – mean irradiation;

σ_G – standard deviation of the irradiation probability function;

For analyzed area the solar irradiation is characterized by the next quantities - $\mu_G = 172$ W/m^2 and σ_G 129 W/m^2. The β probability density f_G and cumulative distribution F_G functions calculated on the solar irradiation probability function parameters are presented in Fig. 5.

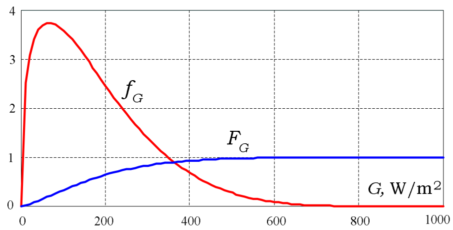

Fig. 5. β probability functions f_G and F_G .

A pseudorandom solar irradiation time function for the considered year season can be obtained using the solar irradiation stochastic parameters through **β** random number generator software. Having previously calculated solar irradiation time function and probability ambient temperature time horizon for examined area, the PV power model given by (3), (4), (5) makes it possible to easily calculate the PV power input considering specific PV installation data. The pseudorandom solar irradiation and appropriate power input as time function for the examined area are shown in Fig. 6. Simulation was carried out considering 15-minutes solar irradiation data averaging.

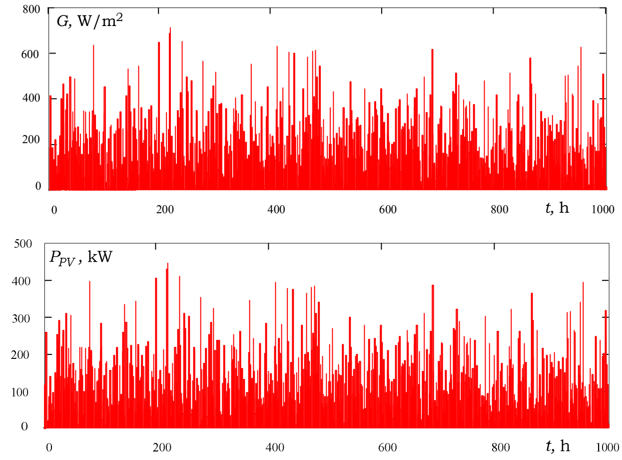

Fig. 6. Simulated solar irradiation and PV power input time dependencies.

For short term predict (daily or weekly time horizon) the solar irradiation time function can be more determined through daily irradiation characteristic for an analyzed season of the year.

C. Generalized energy storage

The generalized energy storage (SD) is modelled on the basis of next energy relations:

$$E_{SD}(t) = E_{SB}(t-1)(1-\nu) + [(P_{WT}(t) + P_{PV}(t) - P_{SR}(t))\Delta t]\eta;$$
$$E_{SD\min} \le E_{SD}(t) \le E_{SD\max}, \qquad (7)$$

where

$E_{SD}(t)$ *i* $E_{SD}(t-1)$ – energy charge of SD at the time *t* and (*t*-1);

$E_{SD\min}$, $E_{SD\max}$ - minimum and maximum permissible level of the SD charge (kWh);

$P_{SR}(t)$ - current required level of the hybrid system output power;

$\Delta t = t-(t-1)$ - time step of power averaging;

ν - self discharge rate within step time Δt;

η - SD efficiency.

D. Simulation example

The simulation uses statistic indices for wind speed variation in the specific site as it has been presented in previous chapters. Pseudo stochastic power output has been generated on the basis of those data and analyzed wind turbine power curve by means of MathCAD software [11]. Solar irradiation characteristics for examined case study have been taken from a summer sunny day. Time step of power averaging in the simulation is equal to 15 minutes. Simulation has been carried out for 48 hours time horizon. The storage device size ($E_{SD\max}$) was assumed to be 1500 kWh and minimum permissible level of the SD charge ($E_{SD\min}$) was assumed to be 200 kWh.

Figure 7 presents the power flows in the microgrid components under constant dispatch limit on the hybrid system power generation (P_{GS}) into public grid on the level of 800 kW during 48 hours without using the SD.

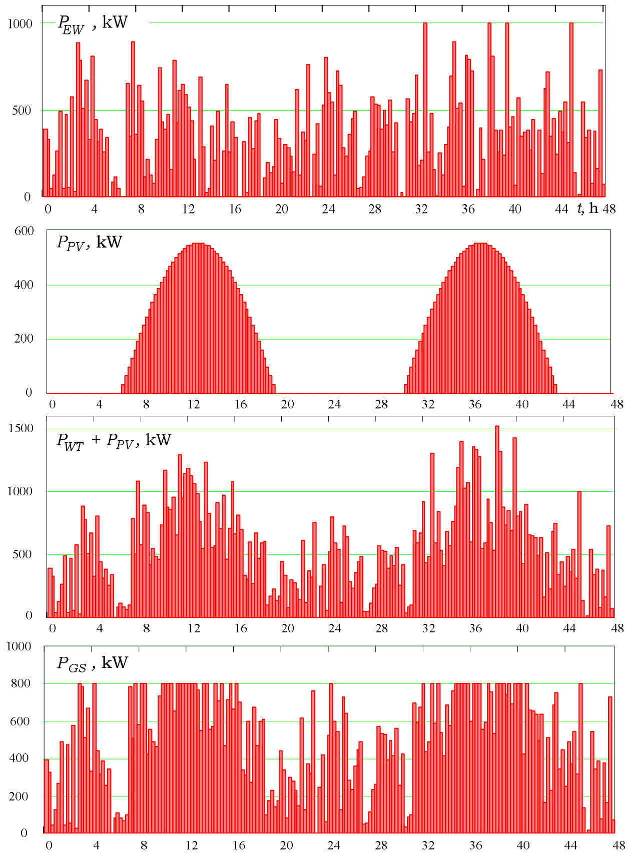

Fig. 7. The microgrid simulated power flows without SD.

For comparison, Fig. 8 presents the power flows in the microgrid components under the same conditions and dispatch limit on the hybrid system power generation but with using SD.

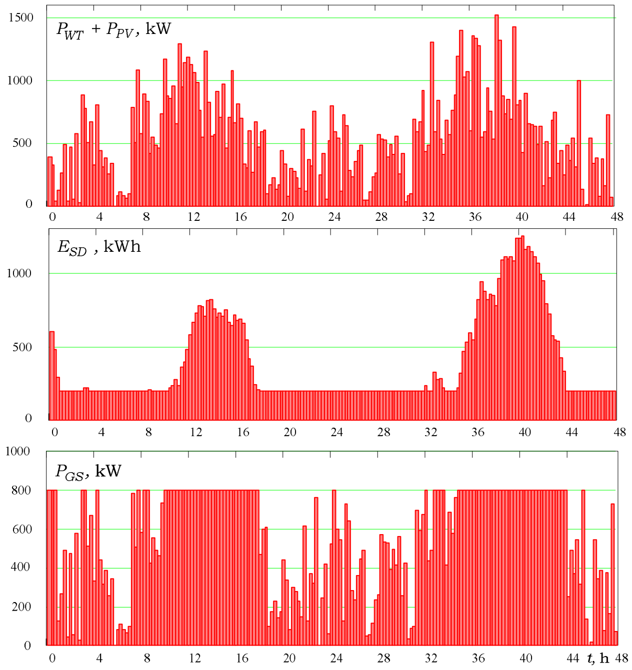

Fig. 8. The microgrid simulated power flows with SD.

As it can be observe from the results of simulations on Fig.7, under the dispatch limit in the analyzed conditions the power generating possibility of the hybrid system $P_{WT} + P_{PV}$ cannot be fully used because of limiting the hybrid system power input P_{GS}. Due to SD operation (Fig.8) the power generation into the public grid P_{GS} is more stable than for the case without SD operation.

3. Conclusion

Presented paper provides a model for simulating various energy dispatch strategies within a grid-connected hybrid renewable energy system. The climate characteristics were implemented in the mathematical model through its statistic indices. An example of hybrid renewable energy system operation condition was analysed taking into account a dispatch limitation. Presented simulation results clearly depict that the proposed model can be useful tool for sizing components of a hybrid renewable energy system and prediction of its energy management in selected sites.

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