DOI: 10.24427/978-83-65596-73-4_4

# 4. HYBRID RENEWABLE ENERGY

## 4.1. Introduction

In the energy sector, in recent times, increasing attention has been paid to renewable energy resources because of the rising fossil fuel prices, global climate change and environmental pollution.

Renewable energy is associated with rapid technology development. Renewable resources are an organic alternative to fossil fuels and so there is a constant tendency to maximize the use of the former and minimize the consumption of the latter. Fossil fuel reserves have been reduced and are constantly running out. The European Union has enough of energy resources to meet only half of its needs. This situation creates economic dependence on energy exporting countries. Another equally important issue is the increasing environmental pollution by burning fossil fuels and induced global climate change. The projected global increase in energy consumption means that there will be proportional increase in emissions and hazardous waste.

Using renewable energy systems means facing new challenges, such as the stable power supply. It started to develop hybrid systems that integrate both the previously used traditional energy systems with the new ones. The new system predominantly uses renewable energy sources. Wind, solar, earth and air energy systems could be used as autonomous energy systems.

## 4.2. Analysis of wind resources

In power systems with a high percentage of wind power, short-term wind power forecast has become a technique used for system operation and for submitting bids in electricity markets whenever wind generators are allowed to make bids. Prediction tools use numerical weather forecasts and one of them also uses real time SCADA data from the wind farms. Starting from these inputs and by means of physical and/or statistical models, hourly predictions for a time horizon of about 48 hours are provided.

In general, the quality of a prediction depends mainly on two variables, the time between prediction and operation and the forecasting technique. Another important prediction factor is the forecasting process which is of smaller significance, though. Therefore, in general, the probability of over/under prediction might be considered equal.

## 4.3. Structure hybrid of renewable and conventional energy systems

Hybrid energy systems combine two or more parallel-operated energy conversion systems, two or more types of fuel per generation system to produce electricity or heat.

Hybrid systems combining distributed energy resources could be connected to a network, region or to the autonomous technological system and can be integrated into the residential, commercial and industrial buildings and industrial sectors.

Hybrid energy systems include distributed generation, renewable energy systems, hybrid energy generation technologies, energy storage systems, transmission network, distribution network, management systems, communication technologies and energy measurement systems.

Hybrid systems allow to:
- use different fuels more flexibly,
- use the energy more efficiently and reliably,
- increase the quality of energy supply,
- reduce environmental impact of energy generation,
- improve economic performance,
- increase flexibility of the energy supply according to the energy demand.

The operation of some renewable energy systems is changeable and interruptible. Combining two or more types of energy sources, including the use of energy storage systems, results in the continuous and efficient energy supply system.

Such power supply system is more reliable and the load (generation) schedule could be more stable and independent from a single energy source.

The components of hybrid energy systems:
1. Energy from fossil fuels:
    - internal combustion engines,
    - Stirling engines,

- Steam turbines,
- Brighton turbines,
- micro turbines.
2. Renewable energy sources:
   - photovoltaic, photovoltaic with concentrators,
   - water heating with solar energy,
   - solar power hubs,
   - wind energy,
   - earth energy,
   - water energy.
3. Fuel cells (FC):
   - solid oxide FC,
   - proton exchange membranes FC,
   - phosphoric acid FC,
   - fused carbon acid FC.
4. Power supplies:
   - lead acid batteries,
   - electrochemical accumulators,
   - reversible fuel cells,
   - super-capacitors,
   - electromagnetic field storage,
   - flywheels,
   - thermal,
   - compressed air.
5. Cogeneration power plant.

A hybrid energy system could combine several different energy storage and accumulation systems, as well as other systems that use fossil fuels, such as gas power plants, diesel engines, etc. Hybrid energy system could include a nuclear power plant and all renewable resources such as solar, wind, geothermal energy resources, etc. Together with hybrid energy systems, new technologies like fuel cells, heat pumps, mini-generators etc. are developing fast.

A number of power generators connected to an energy network supply energy to the users or generate the energy as autonomous hybrid energy systems An example of a large hybrid system is shown in the diagram in Fig. 4.1.

The hybrid energy system using two sources of energy is called a double source system whereas the one that uses several sources is referred to as a multi-source system.

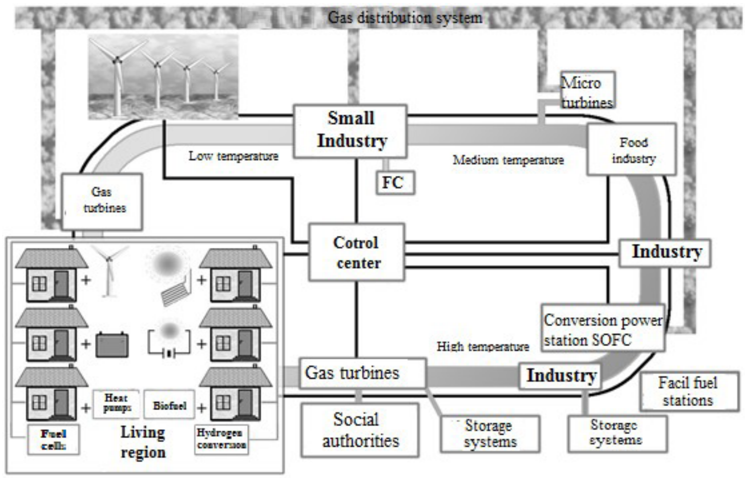


**Fig. 4.1.** Hybrid energy systems integration into the energy network (Source: Gudžius & Morkvėnas, 2009)

Main components of the hybrid energy system:
- renewable energy resources,
- energy storage system,
- fossil fuel generators,
- power electronics,
- control system.

Advantages of hybrid systems:
- high efficiency,
- high reliability,
- low emissions,
- reasonable price.

## 4.4. Hybrid power generation systems using wind energy

Wind energy is one of the most important sources of renewable energy, which develops rapidly in Europe and all over the world. However, there are critical points in this energy system power regulation. To solve this problem, a hybrid system consisting of a diesel generator and an electrochemical accumulator can be used.

Typically, hybrid wind-driven power generation systems are designed to supply electricity to end-users who are not connected to a power grid. In the absence of wind power plants, diesel generator sets are often the only source of power generation, owing to their high reliability. The introduction of hybrid wind-driven generating systems reduces dependence on diesel fuel, which pollutes the air and involves transport costs.

Wind-diesel hybrid power generation systems have been developed and implemented since the end of the 20th century. A large number of such systems have been installed because of their reliability. The popularity of the hybrid energy systems resulted from the reduced maintenance cost and service minimization, which is very important in remote areas.

The main characteristic of the hybrid wind-diesel power generating system is the wind penetration factor, which shows the ratio of wind power to the total hybrid system power. For example, 60% wind penetration factor means that wind power plants generate 60% of the total power produced by the hybrid system. Wind penetration factor can be separately indicated for the short-term and long-term intervals. In some systems, wind penetration factor could be 90% and even higher (Table 4.1).

**Table 4.1.** Autonomous regions using commercial wind-diesel hybrid systems with wind turbines (parks) (Source: own elaboration based on Gudžius & Morkvėnas, 2009)

| Region | Country | P diesel gen., MW | P wind parks, MW | Population | Instalation data | Wind penetr. factor, pik | Notes |
|---|---|---|---|---|---|---|---|
| Mawson | Antarctica | 0.48 | 0.60 | | 2003 | >90% | |
| Bremer Bay | Australia | 1.28 | 0.60 | 240 | 2005 | >90% | |
| Coral Bay | Australia | 2.24 | 0.60 | | 2007 | 93% | |
| Denham | Australia | 2.61 | 1.02 | 600 | 1998 | >70% | |
| Esperance | Australia | 14.0 | 5.85 | | 2003 | | |
| Hopetoun | Australia | 1.37 | 0.60 | 350 | 2004 | >90% | |
| King Island | Tasmania | | 2.50 | | | | Electrochemical storage sys. |
| Rottnest Island | Australia | 0.64 | 0.60 | | 2005 | | |
| Ramea | Canada | 2.78 | 0.40 | 600 | 2003 | | Rebuild. to wind-H2 sys. |
| Alto Baguales | Chile | 16.9 | 2.00 | 18,703 | 2002 | 20% | 4.6 MW hydro |
| Frøya | Norway | 0.05 | 0.06 | | | 100% | |
| Batanes | Philipines | 1.25 | 0.18 | | 2004 | | |
| Graciosa Island | Portugal | 3.56 | 0.80 | | | 60% | |
| Cape Clear Island | Ireland | 0.07 | 0.06 | 100 | | 70% | |
| Fuerteventura | Spain | 0.15 | 0.23 | | | | |
| Foula | U.K, | 0.05 | 0.06 | 31 | | 70% | |
| Rathlin Island | U. K. | 0.26 | 0.99 | | | 100% | |
| Toksook Bay, Alaska | USA | 1.1 | 0.30 | 500 | 2006 | | |
| Kasigluk, Alaska | USA | 1.1 | 0.30 | 500 | 2006 | | |
| St. Paul, Alaska | USA | 0.30 | 0.68 | | | 100% | |

# 4.5. Examples of wind diesel hybrid power systems

Various technical solutions can be used to control the variable power of wind parks: power control using variable speed wind turbines (Enercon, Denham), controlling the load by the heating systems (Mawson), accumulating energy with rotating flywheels (Powercorp, Coral Bay) and electrochemical accumulators (VRB-ESS). In addition, excess wind energy can be used to produce hydrogen (Ramea).

# 4.6. Model of hybrid system with wind power balance

The power generated by the wind park varies over time and depends on the wind speed in the area of their location.

Overnight, the power of the wind park can vary by more than 50% of installed capacity, and the rate of change may exceed 2.6% per minute, for example, the increase or decrease in power of a 100 MW wind park may be 2.6 MW per minute.

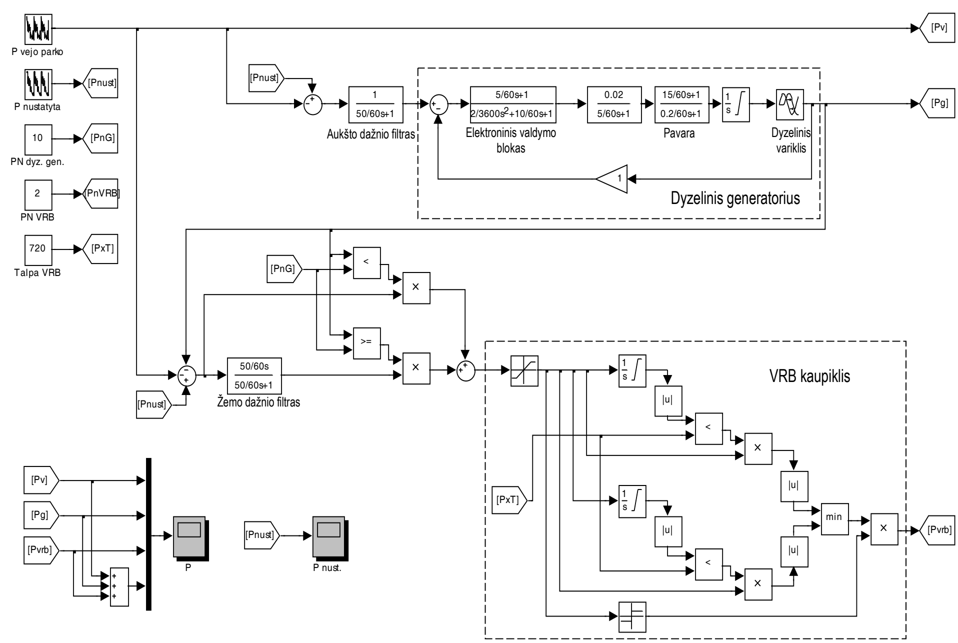


**Fig. 4.2.** A power balancing model of a hybrid wind park with diesel generator and VRB storage system (Source: Gudžius & Morkvėnas, 2009)

Large variations in generating power could cause energy balance problems between the energy flow systems, and in weak networks or in small autonomous power systems, voltage stability and frequency regulation problems.

Electric power stations with diesel generators or gas turbines, hydraulic or pumped storage power stations and power storage can be used to balance the power of a wind park.

Diesel power generators are used to balance the power generation of wind parks, but in order to reduce fuel consumption and environmental pollution, energy storage devices that react quickly to short-term power variations are installed.

The developed hybrid power balance model (Fig. 4.2) allows modeling the power output of a wind park with a diesel generator or a gas-powered electric and electrochemical energy storage device. The block diagram of a diesel generator is illustrated in the Fig. 4.2; instead of a diesel generator, a dynamic model of a power plant with a gas turbine can be used.

## 4.7. Modelling of a hybrid system of wind park balanced with diesel generator and VRB battery power

Graph of the wind park power generation are the input signals of the model which predict power Diesel generator (DG) and the electrochemical energy storage device (VRB battery) and compensate the difference between the power of both energy source. To have optimal control of the power output, the VRB and DG control algorithm divides the input signal according to the set criteria into low frequency and high frequency components. The control algorithm is analyzed by using the low frequency filters method.

The power of the VRB battery is controlled by the wind power variation filtered by high-frequency filter. In this way, wind power variation for frequencies higher than 0.02 Hz is absorbed by the VRB batteries:

$$\Delta P_{VRB} = \Delta P \frac{50s}{50s+1} \tag{4.1}$$

For the variations of the power less than 0.02 Hz compensation, the diesel generator should be used:

$$\Delta P_{DG} = \Delta P \frac{1}{50s+1} \tag{4.2}$$

When the output of the diesel generator reaches the limit (full load or minimum power), the full power control is taken over by the VRB accumulator.

The diesel generator's power regulator model describes an electronic control unit, a hydraulic-mechanical transmission and a diesel engine. Drive output – fuel feed valve position. A typical diesel engine design limits fuel feed in one cycle. The amount of energy released during the cycle is directly proportional to the amount of fuel consumed during the cycle. Assuming that the speed of the diesel generator is constant, its power is proportional to the energy delivered by the engine.

The power change time constant for the VRB battery is very small. As the power of the wind park changes considerably slowly, the model assumes that the battery power can change suddenly. The parameters set in the VRB batteries are the maximum power and capacity (the quantity of stored energy).

The power of the wind park, after changing the wind speed to 1 m/s, may change up to 15% of the installed power. In order to minimize the impact of the wind park on the operation of the power system, it is necessary to create a model for the calculation of the operating modes.

The hybrid energy system model gives the possibility of modeling the power balance of the wind park with a diesel or gas generator and an electrochemical energy storage device (VRB battery).

The above presented principles of the wind power balancing algorithm allow to optimally balance wind power variation.

## 4.8. Analysis of hybrid energy systems operation

The application of a hybrid system solves problems connected with power system balancing, frequency regulation, stability and reliability. The hybrid system can be connected to the transmission or distribution network or can operate as a power supply to the autonomous electrical system.

## 4.9. Application and analysis of wind park hybrid systems with set power schedule

Using the model, the power balance of the wind park was investigated. The analyzed system consisted of a 16 MW wind park, a 4 MW diesel generator and a VRB battery with the capacity of 2 MW x 6 h. Primary data' of the power variation in the output of the wind park, measured during a period of 24 hours, and the predicted (set) power were compiled in the graph (Fig. 4.3).

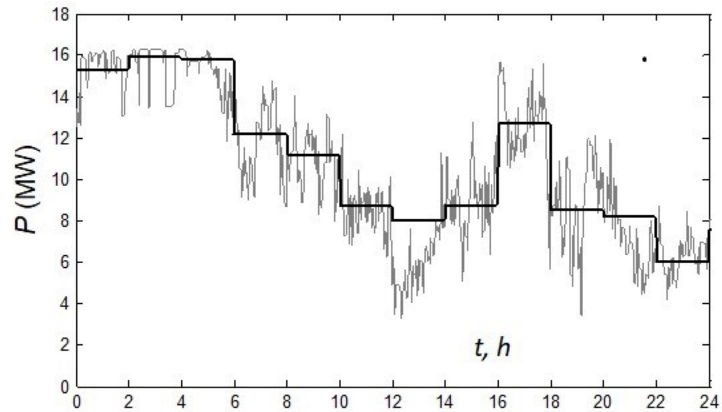


**Fig. 4.3.** Prognosis and measured power variation of a wind park (Source: Gudžius & Morkvėnas, 2009)

The operation of the hybrid energy system model has been investigated in two cases:

1. The hybrid energy system follows a predetermined schedule, adjusting the power of the diesel generator and the VRB battery so that the total output power is equal to the set power.
2. The hybrid system works with constant power. In this case, the diesel generator and the VRB battery reduce the power frequency variation.

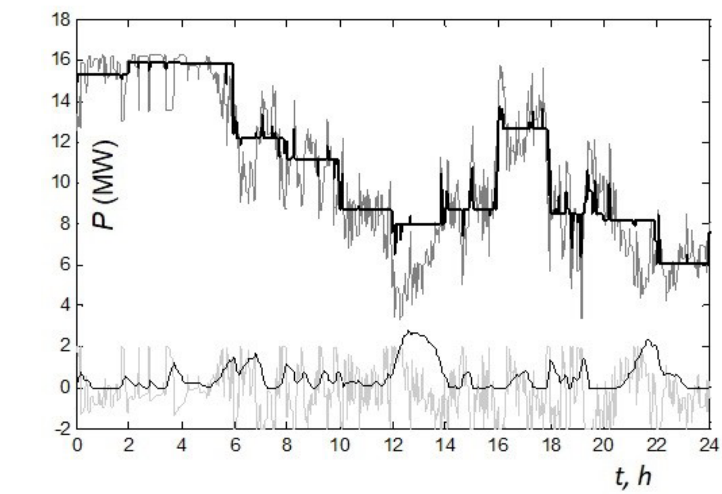


**Fig. 4.4.** Hybrid wind park systems power variations, when the diesel generator and the VRB battery follow a predetermined schedule (Source: Gudžius & Morkvėnas, 2009)

The variation curves for the power of the first hybrid system can be seen in Fig. 4.4. The VRB receiver absorbs high-frequency oscillations, and the diesel generator compensates for slower power deviations from the predetermined power of the hybrid system. The power of the energy system is sufficiently effective for the set power, and the deviations are short-range and of low amplitudes.

# 4.10. Application and analysis of wind park hybrid systems without set power schedule

When the hybrid energy systems power factor is not set, the VRB battery or diesel power stations, or both could compensate the variation of wind park power.

Schedule of the hybrid power system will be most stable if the diesel (gas) power station and the VRB batteries compensate the wind park power variation (Fig. 4.5).

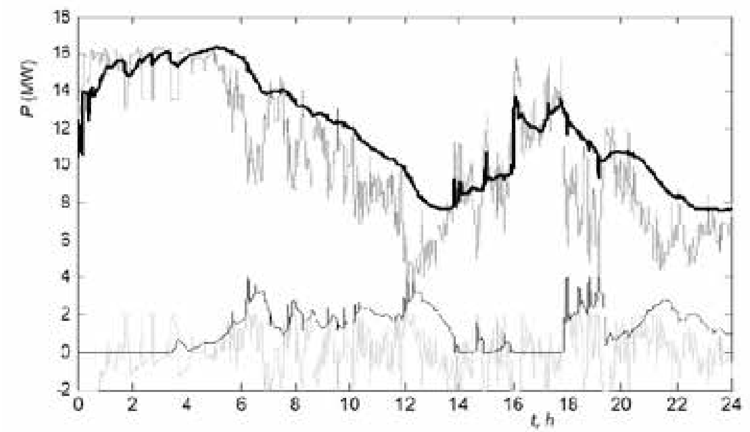


**Fig. 4.5.** Hybrid systems power variations, when the diesel generator and the VRB battery work without regulation of schedule (Source: Gudžius & Morkvėnas, 2009)

# 4.11. Integration and markets

The integration of this technology in electrical energy markets has two analytical factors that must be optimized due to the nature of this type of generation:

- maintenance of the transitory stability of the system in the field of rapid dynamics (up to 30s) and slow ones (< 30s),
- demand coverage (forecasting and scheduling).

The maintenance of the transient stability must respond to different incidences of this type of generation (voltage failures, massive disconnections, short-circuit currents, permissible margins in frequency, inertia and damping). Voltage failures cause possible massive losses of power not supported by the electrical system in the case of three-phase and two-phase faults.

Regarding the frequency margins, current wind turbine technologies support frequency variations at a sufficient margin to maintain the system security. Concerning the inertia and damping of the electrical system, wind turbines with electronic converters present a power control with an extraordinarily fast power response isolating the mechanical and electrical systems. The high penetration of wind generation and the displacement of the conventional resources would lead to a significant decrease of the inertia in the electrical system.

Regarding the demand coverage, wind energy does not provide a guarantee of power. Its maximum slope of verified power is 10% of the installed power, increasing the requirements of another manageable generation.

Regarding the prediction, wind generation suffers considerable errors if the forecast is made long before the production time (average error referred to production time): 18% within 24 hours and 15% within 12 hours. These forecast errors lead to a stronger engagement of the deviation management service and the power-frequency regulation.

High production of energy with the use of wind resources displaces the manageable generation to provide more complementary services and therefore increasing the costs of these services. The generation through wind systems can also participate in this control of voltage at the connection point by the supervision of the system operator.

The management of these incidents needs to coordinate the generators in controlled groups. These control centers are responsible for managing the congestion in the evacuation of the generated energy, providing stability to voltage gaps, controlling short-circuit power, managing the viability of power balances and managing non-integrated surpluses.

## 4.12. Analysis of the results

The analysis of the hybrid system consisting of a 16 MW wind park, a 4 MW diesel generator and a VRB battery with the capacity of 2 MW x 6 h shows that the system effectively balances the variation of wind park power. It was determined that both hybrid energy system operation algorithms were the schedule of power generation is predetermined. Both hybrid energy system operation algorithms followed predetermined schedules. When the hybrid energy system operated at constant power, it was efficient and with the stable schedule.

It has been calculated, that the analyzed hybrid energy systems wind park will produce 254 MWh per day. The diesel generator can compensate for power variation and should generate 30 MWh of electrical energy. The VRB batteries energy storage will be 10 MWh.

The analysis of the hybrid system model shows, that diesel generators are not suitable for total compensation of the rapid wind park power changes, as frequent changing of the diesel generators' load is economically unreasonable. As a sudden power compensation, an energy storage system such as the VRB battery or analogous can be used.

In the case of the autonomous operation of the hybrid energy system, a diesel generator or a gas power station should act as the master generator, to keep all the load when the wind blows. The algorithm of the diesel generators and VRB batteries control should follow not only power schedule but also the changing of the frequency and it should also ensure using and generating power balance.

In the case of switching off the wind park generation, master generators (diesel or gas power stations) should keep all the power of the user load in the autonomous hybrid energy system.

# References

Adomavičius, V. (2013) *Mažosios atsinaujinančiųjų išteklių energijos sistemos*. Kaunas, KTU Technologija.

Ghosh, T. K. & Prelas, M. A. (2011) *Energy Resources and Systems. Volume 2: Renewable Resources*. Springer.

Gudžius, S. & Morkvėnas, A. (2009) *Studija hibridinių energijos* šaltinių *ir jų sistemų modeliai*, KTU.

Petrauskas, G. & Adomavičius, V. (2012a) *Saulės energijos naudojimas elektrai gaminti*. Kaunas, KTU Technologija.

Petrauskas, G. & Adomavičius, V. (2012b) *Vėjo energijos naudojimas elektrai gaminti*. Kaunas, KTU Technologija.

REE (2007) *Integración de la energía Eólica en condiciones de Seguridad para el sistema.* Red eléctrica de España.