Hybrid Power Systems with Renewable Energy Sources – Types, Structures, Trends for Research and Development

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Hybrid Power Systems with Renewable Energy Sources – Types, Structures, Trends for Research and Development

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Abstract: *The article deals with the state of the art of a hybrid power systems with renewable energy sources (HSRES). These systems are classified according to different criteria. It has been made a short review of the current state of their design, modelling, simulation and optimisation. The respective analysis has been made also. In conclusion, it has been made a summary of the future trends for research and development.*

Keywords: *renewable energy, hybrid power systems*

Introduction

Variability and random behaviour mark the main characteristics of renewable energy sources (RES). Nevertheless, there is certain regularity and cyclic recurrence in their behaviour. The intensity of the different energy sources into time is not the same. In general, when one of the sources is intensive, the other tends to be extensive, i.e. the sources complement one another. The distribution into time and the intensity of the energy sources depend on the meteorological conditions of the chosen area, on the season, on the relief, etc.

The following definition of a hybrid system with renewable energy sources can be suggested. *This is a power system, using one renewable and one conventional energy source or more than one renewable with or without conventional energy sources, that works in "stand alone" or "grid connected" mode* [1], [2], [3], [4]. The National electrical energy system is a hybrid system.

HSRES are used for energy production for distant, not connected to the common electrical distribution system objects, e.g. distribution systems for small islands [5], villages [6], hotels, houses [7], as well as the supply of telecommunication, meteorological and other stations, research laboratories, etc. In connection with the distributed generation these systems are being more widely used as grid connected systems. Their undisputed advantage is the more efficient way of use of the disposable renewable energy.

Classification of HSRES

According to the presence of conventional energy sources:

- Hybrid systems with conventional sources – mostly the systems, using conventional sources are more powerful and responsible;
- Hybrid systems without conventional sources – as a general, that kind of systems are relatively low-power and/or tend to be more irresponsible. If the systems are correctly designed and if energy storage is provided, they would be able to generate sustainable energy. These systems are independent of energy sources, which make them especially preferred. Hence comes the need to develop reliable optimisation models.

According to the number of the sources – The number of the energy sources is one of the factors that define the complexity of the HSRES as well as its sustainability and efficiency. The large number of sources makes the system more complicated, but at the same time leads to an increase in the sustainability and energy efficiency.

According to the type of the produced energy:

- Mechanical – each turbine, regardless of its kind generates mechanical energy, which later is converted to electrical. That mechanical energy can be also consumed directly, e.g. for pumping water;
- Electrical – the electrical energy can be easy distributed and converted to another type. It can be stored and consumed, when is needed. All these features rouse a deep interest for the electrical HSRES;
- Thermal – it is used for heating and warming up water. Here can be assigned both the systems with solar thermal collectors and the ones, using geothermal energy;
- Light – providing daylight in buildings through the medium of a concentric collector and optic cable [8];
- Fuel production – a case in point can be hydrogen production by means of electrolysis [9] ;
- Mixed – a typical example is a power system with solar thermal collector, combined with wind turbine and photovoltaics [1], [2], [3], [4].

According to the rated power:

- Low power (less than 1 kW) – they are used for telecommunication, meteorological and other stations, etc;
- Middle power (more than 1 and less than 10 kW) – used for the supply of houses, hotels, etc;
- High power (more than 10 kW) – used for the supply of isles, towns and villages, which are remote from the electricity distribution system, etc.

According to the energy storage:

- Without storage – they are not profitable, because the needs do not coincide with the energy availability. Thus, certain amount of the available energy remains unused and also the load can easily remain without supply;
- With storage – the surplus of the generated electric power is stored and used when needed. In this way,

the fluctuating nature of the RES is buffered which enables the hybrid system to work more effectively. The stored energy can be electrical (batteries, superconductive magnetic energy storage (SMES)), thermal (boiler), mechanical (flywheel), fuel conversion (hydrogen) and potential (water tower). The fuel cells (FC) provide a clean technology that uses hydrogen (from a fuel source) and oxygen (from the air) to generate electricity and heat, the only basic emission being water vapour. FCs suitable for DG operate between 80 and 1 000 ºC and in CHP mode can deliver efficiencies of over 80%. Small (1-10 kW) FCs could be developed for residential power generation.

According to the connection to the distribution grid:

- Grid connected – they must be synchronised with the distribution system;
- Stand alone – used for the supply of remote objects.

Electrical HSRES

According to the type and configuration of power buses, hybrid systems can be defined as AC, DC and mixed. They also can be classified as serial and parallel.

Figure 1 is up to show the serial structure of a hybrid system. It is typical for this case that the energy flows are unidirectional and passes through the structure of the system (from DC to AC bus in the given example).

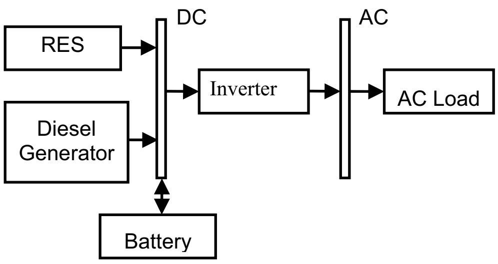

Fig.1. Serial structure of a hybrid system.

Figure 2 represents the parallel structure of a hybrid power system. The energy flows in both directions.

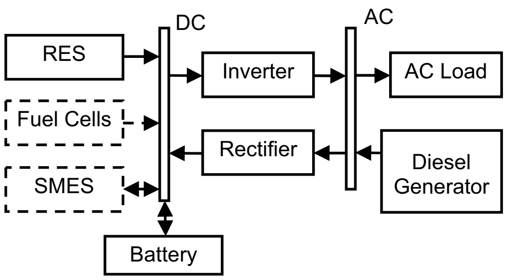

Fig.2. Parallel structure of a hybrid system.

HSRES face many difficulties due to the characteristics of the renewable energy sources and especially their variability. On the other hand, hybrid systems should meet the same requirements as the conventional power systems.

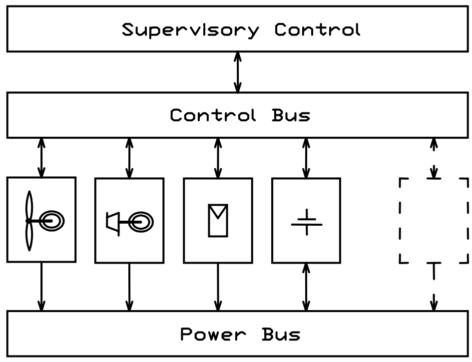

Fig.3. Modular structure of a hybrid system.

With the purpose of unification have the modular HSRES been created [5]. They possess standard power (for example ~230V/50Hz) and information bus and are subject to uniform supervisory control. The units are connected parallel.

The modular systems have a high level of modularity and flexibility. They should be sustainable and are supposed to show stable parameters of produced energy (according to the relevant standards). Figure 3 shows the general structure of a modular hybrid system. Local mini- and microgrids with distributed generation can be created using modular technology.

In the modern systems more widely used are the Flexible AC Transmission Systems (FACTS) of a different type (SVC, STATCOM, SPS, TCSC, UPFC), which increase the flexibility and stability of the system. In the future can be expected integration of inverter and FACTS functions [17].

Common Types of Hybrid Systems

The Wind – Diesel System is a typical representative of a powerful hybrid system (figure 4). It is commonly used to supply objects beyond the scope of the electricity distribution system (buildings, villages, etc)[6], [11].

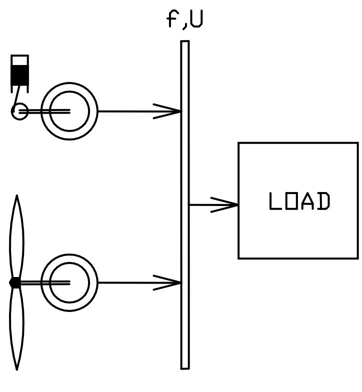

Fig.4. Wind – Diesel system.

The Wind – Photovoltaic (PV) – Diesel System [7], [10] is suitable for terrains where both solar and wind energy have balanced potential (figure 5). It possesses high-energy effectiveness, but at the same time, this type of system appears to be more complex.

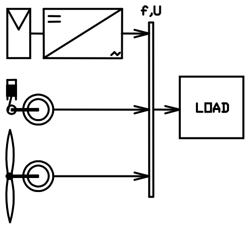

Fig.5. Wind – PV – Diesel system.

As to the Wind – PV System, its resources have predominantly favourable distribution into time (figure 6). When the wind gets stronger, the solar radiation is usually lower, and vice versa. This trend has been observed likewise during the earth's yearly round. If the system is situated on appropriate place, designed correctly and energy storage supplied, it can work in a highly effective and steady way.

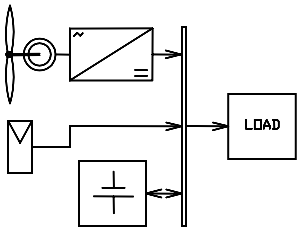

Fig.6. Wind – PV system.

Another profitable system providing complex supply is the Wind – Photovoltaic System combined with a solar thermal collector. The electric power generated by the RES is consumed on the one hand by the loads, and on the other – by the solar circulating pumps. The surplus electric power generated by the wind turbines can be used to heat up the water additionally, instead of the alternative to lose it in the dump load. This system is especially suitable for mountain chalets, villas and hotels [2], [3].

The configurations described above do not reveal all the possibilities for HSRES structure. The option which structure to choose depends on a large number of factors – renewable energy potential, purpose of the system, energy needs, price, etc.

Design of Hybrid Systems

The first step in the design of hybrid systems is the analysis of the renewable energy potential, which is external to the system. Based on both the received meteorological measurements and some internal to the system factors the most suitable configuration of a HSRES is being sought after. Such a configuration should assure the sustainable work of the system, knockdown price, top return on investment, maximum efficiency, etc.

Among the internal factors are:

Energy consumption – not only the consumption quantity should be examined, but also its distribution into time.

Energy storage – this storage is usually carried out by batteries. When the consumption is intensive and the batteries capacity is not picked out correctly, an interruption in the power supply may appear. Also if the capacity is too high, the battery cannot be fully used. When choosing a battery, the stored energy should vary between 30% and 85% of its rated capacity [12].

Units selection – this selection is carried out according to the specific methodology of the unit type (turbine, photovoltaic panel, etc.).

Based on the above-mentioned, one general conclusion could be drawn: the design of HSRES is a difficult, multifactor task, whose main goal is to achieve an optimum. This task is done according to some technical, technological and economical criteria. Creating a computer model of the system and using computing machinery makes the design process easier and more effective.

Control

When controlling the energy systems with RES, it should be taken into account that part of the input indicators cannot be controlled. This makes the limited and determines the introduction of feedbacks in order to increase the system stability. The control can be centralised, scattered on the units or combined.

Batteries, generator with conventional fuel and their joint work are more often subject to control. However, the control system can be even more complicated.

According to their course of action, control systems are determined as passive or active.

Passive systems are used with the simple HSRES. Most of the existing systems are passive; they work on the "on/off" principle.

Active systems are used with HSRES consisting of a large number of components. They measure and calculate the input data (meteorological, energy flows). These systems are flexible and can work in different modes.

The information is transmitted by cable, wireless or optically. Cables can be different types – coaxial, phone, twisted pear or the power cables (power line communication). Wireless connection is established by radio modems and wireless controllers. As to the optical lines, they are built up by optical cables, amplifiers and media converters. The way of transmission of the information depends on the data amount, distances, unit interfaces, and the cost of the lines.

Actually, control systems work by means of controllers, programmable controllers, software, etc. The control algorithm is periodically executed – this is a sequence of activities that keep the system in a certain mode of work. Its complexity depends on the structure of the system and on the tasks set before it. Figure 7 represents an example of a control algorithm for Wind – Photovoltaic – Diesel system. The control system protects the battery from overcharging. It switches the exceeded energy to a dump load. If the stored energy drops below 30% of the battery capacity, the diesel generator switches on.

Examples for working control systems are: Schneider Electric DC Panel – Square D QO [7], Mechron's Cycle Charge [11], products of Xantrex [13], etc.

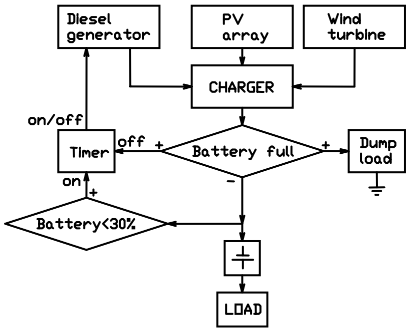

Fig.7. Example of a control algorithm.

Optimising and Modelling

To find an optimal configuration and control of HSRES an analysis of the multifactor target functions should be conducted. Some of those functions are:

Cost of energy

(1) $COE = f(L, CU_i, n_i, COF_i, QF_i, RE, T_i, P_i, ...)$,

L – Energy consumption, CU_i – Overall cost of each unit, n_i – Number of the units of the same type, COF_i – Cost of the fuel, QF_i – Fuel consumption of the units €/kWh, RE – Available renewable energy, T_i – Life of the unit, P_i – Rated power of the units.

The return on investment is inversely proportional to the cost of energy, i.e. minimizing the energy cost leads to maximizing the yield upon investment.

System sustainability

The objective is to find a configuration with maximum stability, i.e. minimum number of supply interruptions.

(2) $Err = f(L_i, RE, P_i, SE_{min}, SE_{max}, ...)$,

Err – Number of supply interruptions, L_i – Load with its own priority, RE – Renewable energy, P_i – Power of the unit, SE_{min}, SE_{max} – Minimum/ maximum stored energy.

Fuel consumption / Use of RES

The objective is to find a configuration with maximum use of renewable energy and minimum fuel consumption.

(3) $\max(REU = f(L, RE, P_i, SE_{min}, SE_{max}, ...))$,

(4) $\min(FC = f(L, RE, P_i, SE_{min}, SE_{max}, ...))$.

Optimisation done according to this criterion increases the ecological conformity of the system, but at the same time reduces its stability and leads to a rise of the overall cost.

It is possible to combine different optimisation criteria – for example (1) and (2). In this case the target function is:

(5) $opt(\min(COE), \min(Err))$

It is also possible to charge different importance to every criterion, which will lend variety to the operation modes of the hybrid systems.

The above-mentioned arguments considering target functions are the most important factors, which those functions depend on.

An optimized sizing method has been developed and it is based on an energy behaviour simulation coupled with a cost optimization. The simulation uses a numerical method based on an energy balance and a storage continuity equations conducing to various possible configurations for the HSRES system. The production cost is calculated taking into account the inflation rate and the configuration producing the kWh with the lowest cost is chosen [15].

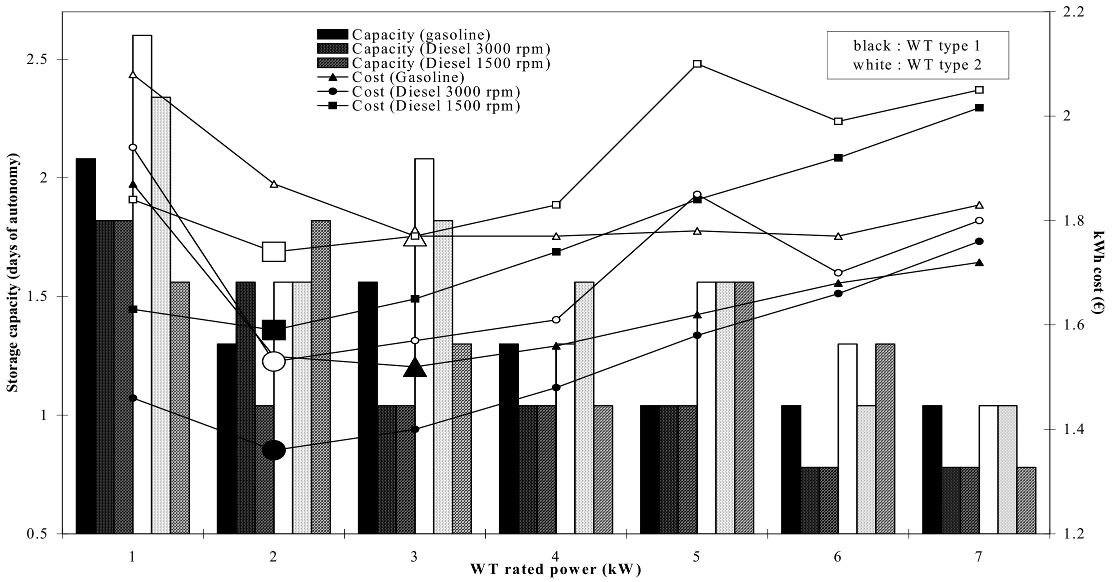

Fig.8. Optimal configurations for a hybrid wind/diesel/storage system and kWh cost

Various parameters are optimized, not only the size of the components but also the threshold of engine generator run on or off, the strategy of energy flows control, … as an example, we show on figure 8 the results of this method applied to a wind-diesel-storage hybrid system for two types of wind turbines; the optimal rated power of the wind turbine and storage capacities with corresponding kWh cost are plotted. [16]

Modelling of a hybrid system means creating a computer model of its components, as well as of the factors that influence it [14]. The modelling and simulation of an already designed or still being designed system allow its behaviour to be examined for a short period time under different circumstances.

Some simulations are performed by specialized software. Several products that simulate and optimize hybrid systems are shown below:

Hybrid2

Hybrid2 [14] is designed to study a variety of hybrid power systems with different components. The program also includes economic analysis tool. The results are provided in two levels of output, a summary and a detailed time step by time step description of power flows.

HOMER (Hybrid Optimization Model for Electric Renewables)

It is a computer modelling software, that models the work of both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation. The package models both conventional and renewable energy technologies. It performs optimisation and sensitivity algorithms, that allow choosing a better configuration of the designed system.

RAPSIM (Remote Area Power Supply Simulator)

A computer modelling product, designed to simulate alternative power supply options. The program helps sizing PV, wind, diesel stand-alone and hybrid systems.

For development of new models can be used programming languages, as well as Matlab and other environments for computer modelling.

Flexible Hybrid Systems

Hybrid systems, which can change their structure, mode (stand-alone or grid-connected) and control, can be defined as flexible.

The Laboratory for Renewable Energy Sources by the Technical University of Sofia, Bulgaria, was created within the framework of Project TEMPUS 09704-94. Its main purpose is education and research. It disposes of an experimental flexible hybrid power system (Figure 9), that comprises the following elements: digital meteorological station, wind generator, photovoltaics, lead-acid battery, inverter-rectifier, solar thermal collector with vacuum tubes, monitoring system based on hardware from National Instruments.

The system is flexible, because the disposal units can work in a different combination. Moreover, monitoring system has been developed [2]; it allows monitoring the operation of the system, as well as the meteorological conditions for a long period of time. The measured indicators (current, voltage, power, meteorological data, etc.) are kept in a database [4]. The collected information allows analyzing the system work under different weather conditions and operation modes, as well as choosing suitable control strategy.

A lot of experiments with the described hybrid system have been conducted. As examples, the results for a period of 24 hours are presented thereinafter [4]. It has to be mentioned that in order to increase the possibilities of the hybrid system the wind generator is simulated by a motor-generator group with an asynchronous generator of the same rated power. In that way is used the capability to explore the system behaviour having preliminary defined wind energy potential [3]. To make it more comprehensible, it is assumed that the charging powers are taken for positive and the discharging – for negative.

Figure 10 shows the generated and consumed power, as well as the overall power of the DC bus. The results are summarized in Table 1. Under the existing conditions the produced energy is 2,061 kWh and the consumed is 3,305 kWh. This means that the battery has lost 1,244 kWh of its energy.

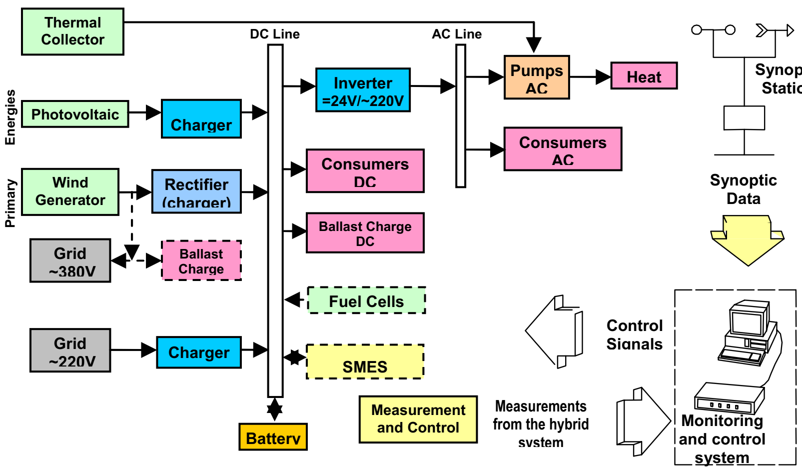

Fig.9. Flexible experimental hybrid system of a mixed type (the elements, marked by dashed line will be accomplished in the future).

Table 1

Produced and consumed energy during the period

Sources	
Photovoltaics	1,273 [kWh]
Wind generator	0,788 [kWh]
Subtotal Ech	2,061 [kWh]
Consumers	
DC loads	- 0,0091[kWh]
Inverter	-3,296 [kWh]
Subtotal Edisch	-3,305 [kWh]
Total Ebat	-1,244 [kWh]

The flexibility of the described hybrid system allows research of different unit combinations and development of methods for design and control under different conditions, as well as validation of the results.

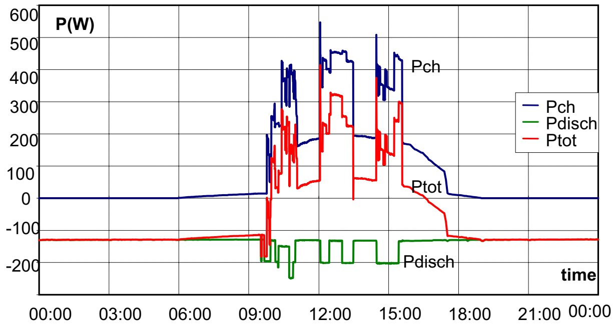

Fig.10. DC Power – produced, consumed, overall

Conclusion

In the present article hybrid systems with renewable energy sources are considered. They are classified and some special features and problems on their design, management and simulation are reviewed.

In recent years, a trend to a decrease in the cost of renewable energy technologies has been observed, which comes together with the arisen tendency towards distributed generation of energy. Those two factors provide the opportunity many solutions to be reconsidered.

The state of the art shows that in the near future in the structures of the hybrid systems will appeared the fuel cells and the SMES. The FACTS technologies will interfered with the traditional power electronic converters.

Research work in this field shows that further studies should be conducted in the sphere of HSRES with different configuration comprising a great number of sources and producing both electricity and heat. Using an existing computer model of hybrid systems or creating a new ones allows an extensive research on their work under different conditions and configurations and facilitates their design. It is advisable to use flexible experimental systems in order to validate the obtained results.

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