SMALL GRID-ON AND GRID-OFF POWER STATIONS UTILIZING THE RENEWABLE SOURCES OF ENERGY.

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Abstract
Research and development in the area of utilizing the renewable sources of energy for production of electric energy is routed to the really applied systems, independent from the distributing system, or without necessity to build up it, respectively. Such systems are capable to substantially increase quality of human lives at areas without access to the conventional sources of energy, and involve them into full-value active social being, as well as contribute to the development of effective health service in such way, which so far couldn't be utilized. This paper deals with developing and application possibilities of this revolutionary challenge and analyzes the real opportunities in solving the mentioned problems.
Keywords: renewable energy, solar, wind, grid-on system, grid-off system

1 Introduction

The European Union established already in December 1995 three key objectives:increase of competitiveness, achievement of safety in supplying by energies, and environment protection. Since this time, intentions and directing of the energetics in individual countries of EU are reviewed continuously. For development of the renewable energy (RE) sources there have been established the concrete objectives until 2020. The climatic-energetic measures from January 2008 assume: 20 % decrease of emission, 20 % share of the renewable energy sources in final consumption of energy and 10 % share of bio fuels in traffic in 2020 [1].
Main possibilities of utilizing the renewable energy sources (include technologies for usage of Earth's **water**, **solar**, **wind**, **geothermal** energies and technologies usage of **biomass** (bio fuels, solid biomass, biogas).

Big challenge for utilizing the RE is the fact that they are suitable also for building up the small island power stations in localities without access to conventional sources of energy. Very often it means rural and outlying areas, where the access to energy is necessary for development. The most accessible RE in these areas are impinging solar radiation, wind energy, or available water sources, too.

2 Description and analyzing of the main technical problems related with power station from RE

The works were focused on the small power stations (supplied from solar and wind) with power to 5 kW.

2.1. Systems of photovoltaic power stations, connectable to distributing network

Photovoltaic (PV) power stations generate pure, renewable energy from sun and in near future they will allow that consumer using it can gain an independence from distributing system.
It refers primarily to small consumers with daily consumption of energy about 10 kWh. At present, when still problem of economically effective storing the surplus generated electric energy is not solved, this surplus energy is delivered into distributing system. Such systems of PV power stations are denoted in literature also as „Grid-On" systems (Fig.1).
PV power systems are noiseless and work fully autonomous. The system automatically „wakes up "when sun rises and shines on PV array, and automatically shut off (falls asleep), when sun goes down. These, as well as other tasks associated with energy conversion and safety, are ensured by the main component of system - PV inverter.
Because such systems don't use any moving or rotating parts, they practically work without need of maintenance and „should" prove long operating life (about 30 years).

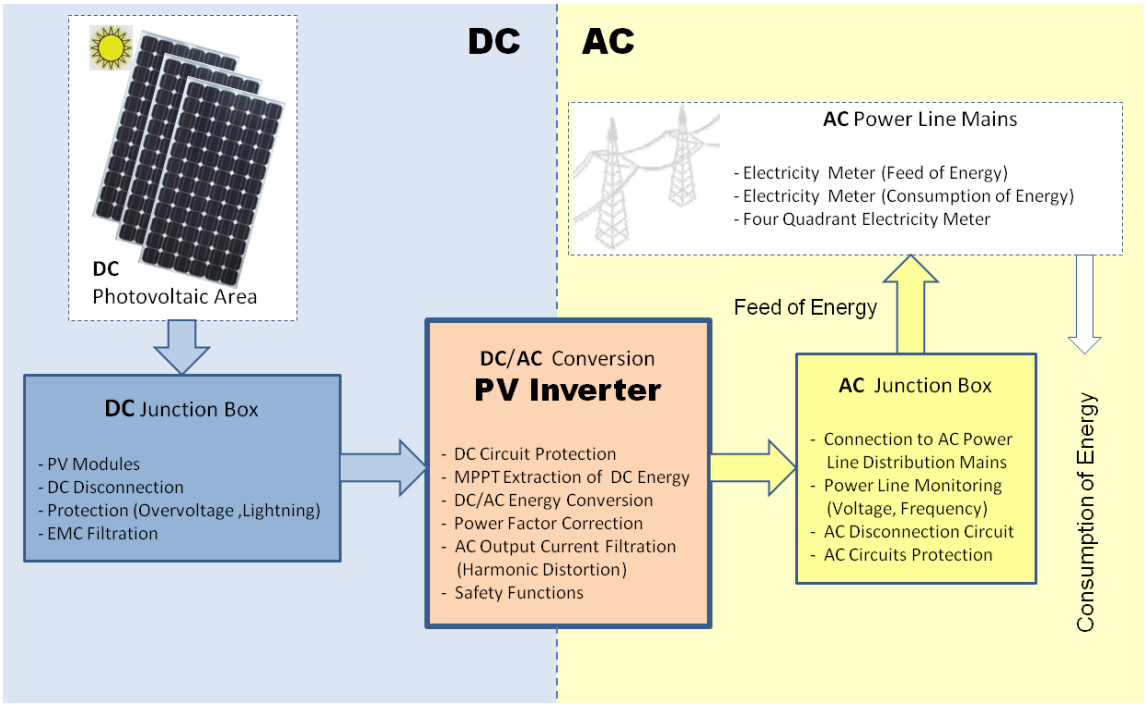

Fig. 1 *Principle diagram of PV power station, connectable to distributing network (Grid-On)*

The main task of such power station is effective extraction of DC energy from solar area (MPPT) [10], conversion of DC energy into AC current (energy) and its delivery to the distributing network (Fig. 1, 2).

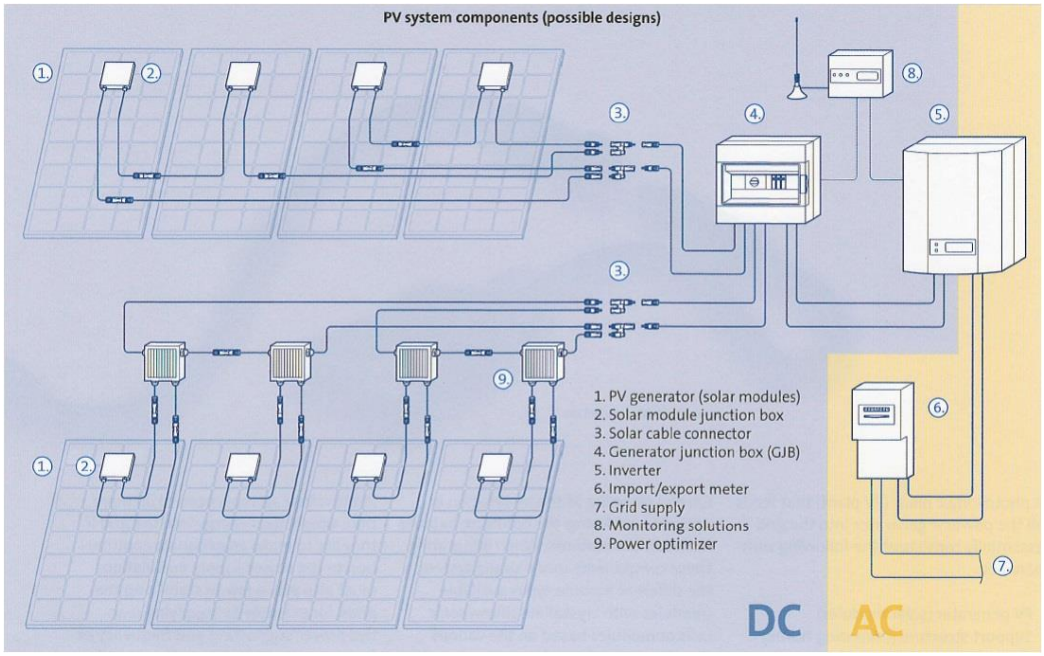

Fig. 2 *Example of wiring schema interconnecting PV station (Grid-On) and central inverter* [2]

In term of EU legislation, the maximum power connectable to one phase of **LV** system is 4,6 kW. Therefore, it is allowed to connect maximum of 3 such one phase PV inverters to the 3-phase **LV** system, with summary output of 13,8 kW [4]. However, these values can be adjusted by the national legislation.

PV systems of Grid-On stations can be divided into:

- Systems using the „central“ PV inverter (Fig. 2)
- Systems using two or more „string“ PV inverters (Fig. 4)

- Systems using „module“ PV inverters (micro-inverters) (Fig. 4)
- Combined systems (option of combining the above mentioned technical solutions).

The PV inverters, connected to the distributing network, are subject to high requirements, primarily regarding to the efficiency of energetic DC/AC conversion, but also in respect of operation safety and prevention against electric stroke.

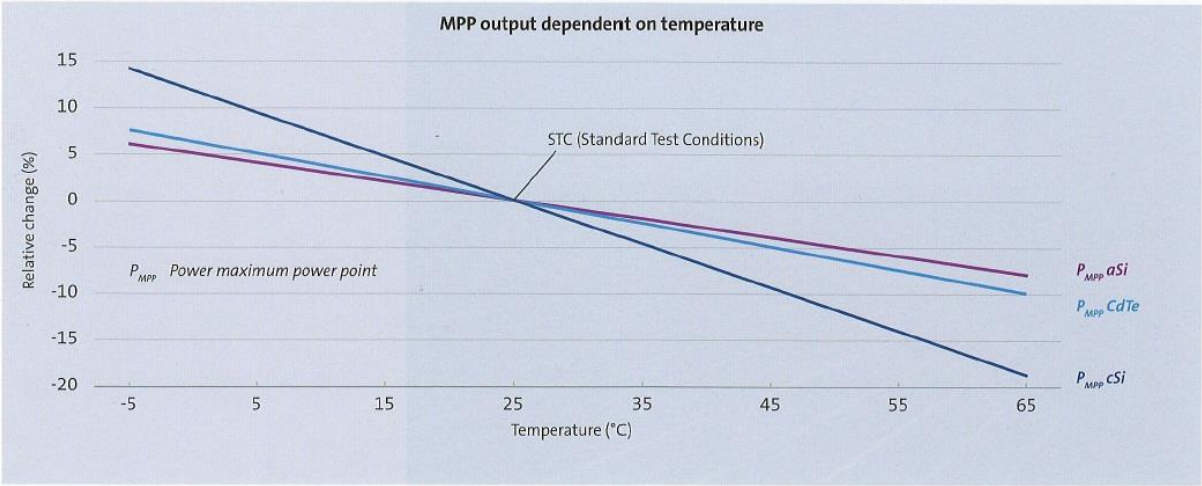

Fig. 3 *The temperature dependence of PV cells* [2]

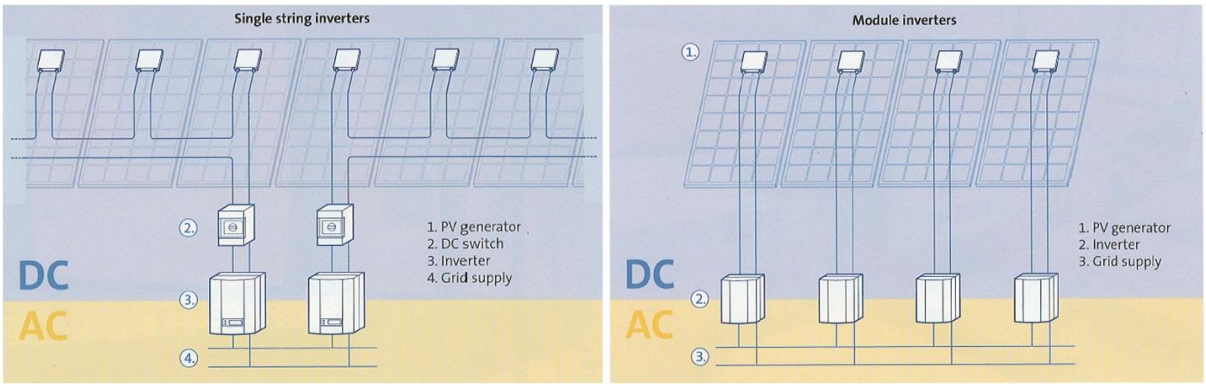

Fig.4 *Principle of wiring the PV power system with „string“ and „module“ inverters* [2] [11] [12]

2.2 Island systems of small PV (resp. hybrid) power stations

Contemporary and permanently ongoing problem in real utilization of RE is, that surpluses of electric energy produced from RE still cannot be economically effective stored, although new technologies solving this problem are verified in the world. Therefore, at present time these surpluses of generated electric energy in order to support development in this area, are delivered to the distributing network, which absorbs them (as described in Grid-On systems).

The final objective in utilizing the RE for generation of electric energy however, it is not delivery to the distributing network, but its direct consumption by the producer. Ideally it would be directly at the place of its production. In such case, present energy losses in lines of the distributing network would be prevented. Systems of such concept are called “island” (Grid-Off) and are independent from distributing network (Fig. 5).

An important factor supporting the rise, need and expansion of island systems of power stations using RE is therefore the fact, that so far didn’t exist any economically more effective alternative improving the quality of human life in the areas, which are not covered by electricity supply.

These systems requires another system component - accumulator. This absorbs surpluses of energy at time of its generation and delivers energy at time when PV, or wind generator resp. don't produce electric energy (night, cloudy, windless). It must accumulate sufficient electric energy in such way, that energy consumption should be covered not only during generation of energy, but also at time when RE are not active.

In order to effectively utilize the RE, so called „Hybrid island systems" of power stations are used more and more. These utilize at least 2 kinds of RE (e.g. sun, wind), or only one RE and backup source, and by this decreases requirements on batteries´ capacity at the same demands on electric work of the system. At time without sunshine, required energy can be delivered from the accumulators charged by wind generator. At same time, if required, such system may be supplemented by the backup source, for example some suitable diesel-generator.

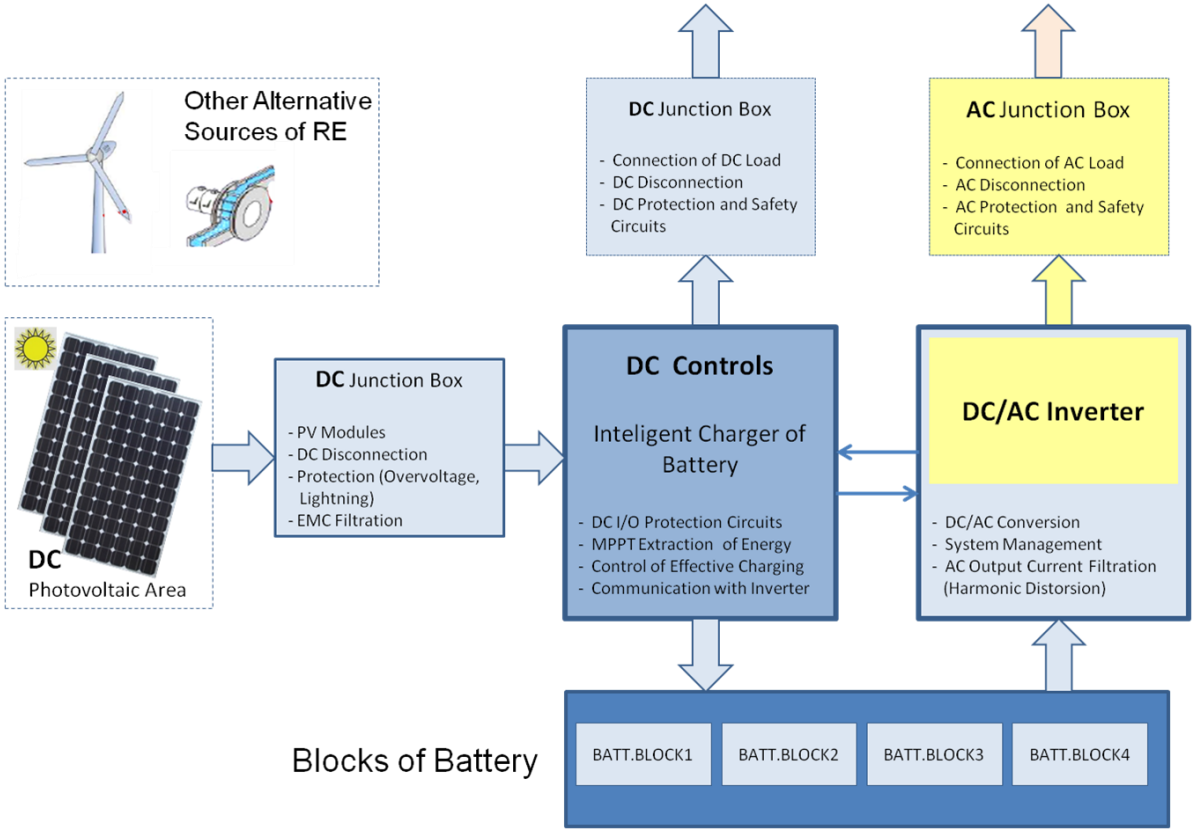

Fig.5 *Principle diagram of island system of small PV (hybrid) power station*

Such system in case of the proper design is capable to fully satisfy the energetic needs of family house or other object, and to be entirely independent from the distributing network. The example of principle wiring of the system is showed on Fig. 6.

One of the most important tasks in Grid-Off system of hybrid power station is its energetic management. In most of system applications, these tasks are undertaken DC/AC inverter itself, which is in the island system the most important, even though not the most expensive component.

It must perform the tasks of energetic conversion, protection and safety, communications tasks in system, as well as tasks of possible communication with surroundings.
One of possibilities of effective utilization of mentioned systems of island power stations is its fast installation at places without access to the distributing system.

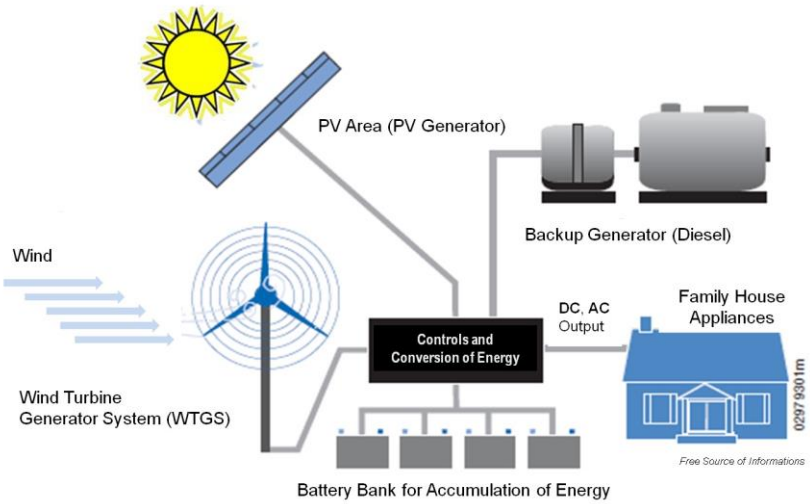

Fig .6 *Principle wiring of Grid-Off system for small hybrid power station with RE* [3]

Such utilization is possible only provided that complete system as well as selected application, are implemented in the suitable mechanical execution, allowing movements by means of railway, ship, or road transportation. So called "container" execution of Grid-Off system can be also a suitable alternative (Fig. 7).

Fig. 7 *Container execution of Grid-Off system for small hybrid power station with RE*

Problems related to the design of Grid-Off system for hybrid power station

Grid-Off systems of power stations with RE may by essential way improve the life's quality of people living in areas without access to conventional energy sources. These can help them to involve fully valuable into active social activities, but also contribute to the development of effective health aid in the way which there until then could not be utilized. That is why in the world a great attention is paid to this sector of active utilizing the RE.

The leading role is played by renowned world's companies. One of the most known and most experienced companies is German company **SMA**, which together with others set the trends in development, construction and

utilization of the Grid-Off power systems. Therefore it is suitable to deal with and inspire ourselves by their designs and applications.
In this document, there are used and stated some motives, technical approaches and solutions, drawing from free and available sources of **SMA** Company [5]. Choice of them was selected intentionally, with objective to explain technical issues at designing of Grid-Off hybrid power station. The Fig.8 shows the inspiring wiring of Grid-Off hybrid system power station.

The main components of system are the following:

- Renewable energy sources (RE): PV generator, wind generator, hydro generator
- Backup energy sources: diesel-generator, or distributing system resp. (theor. possibility - model)
- DC/DC regulators for charging batteries (accumulators) by PV generator
- DC/AC inverter to converse direct (DC) energy to alternative (AC) energy, which also executes tasks of system administration, control and internal communication
- Components for storing of energy (accumulators)

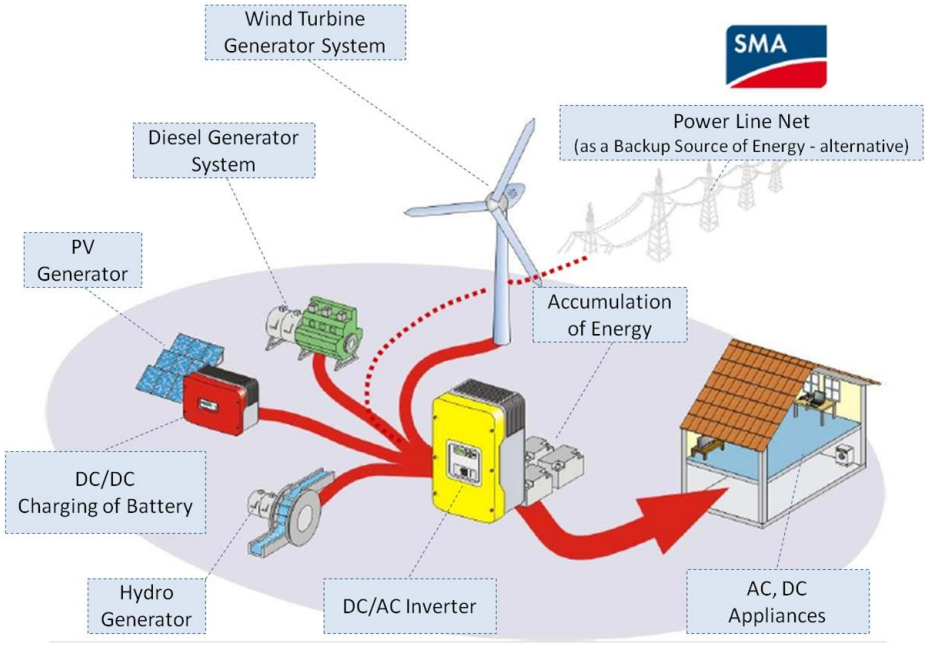

Fig. 8 *Example of wiring the Grid-Off hybrid system power station* [5]

System Accessories:

- DC, AC power interconnecting leads (conductors, cables, connectors, ...)
- DC switch board of RE generators, its fusing circuits and DC disconnectors,
- AC switch boards, its fusing circuits and AC disconnectors,
- Inlets, fusing and disconnecting of backup sources,
- Components for internal monitoring of Grid-Off system and its internal communication
- Components for external communication with master system (alternative)

Structure and interconnection in the system

Main tasks of the island (Grid-Off) system include its ability to work independably from the distributing network and possibility of simple connection and interconnection of selected kinds of RE for production of electric

energy. With respect of building up the application of island system, it is important to know its future structure and decide on the way of „interconnecting“ its individual parts and components (Fig. 9).

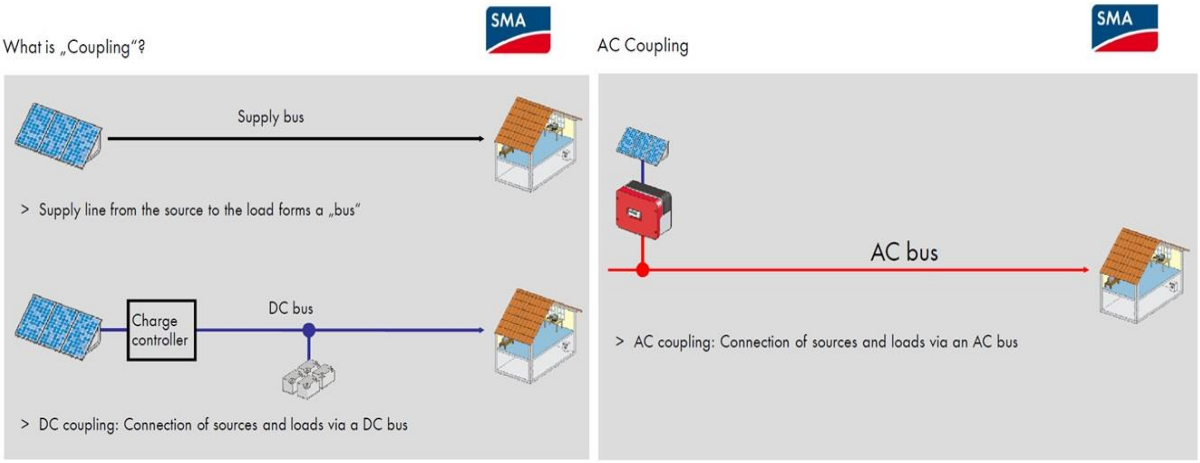

Fig. 9 *Examples of selecting the interconnections in Grid-Off system hybrid power station* [5]

It is necessary to realize that depending on the projected output of island power station, transmission lines lead relatively big currents, which cause the losses on them.

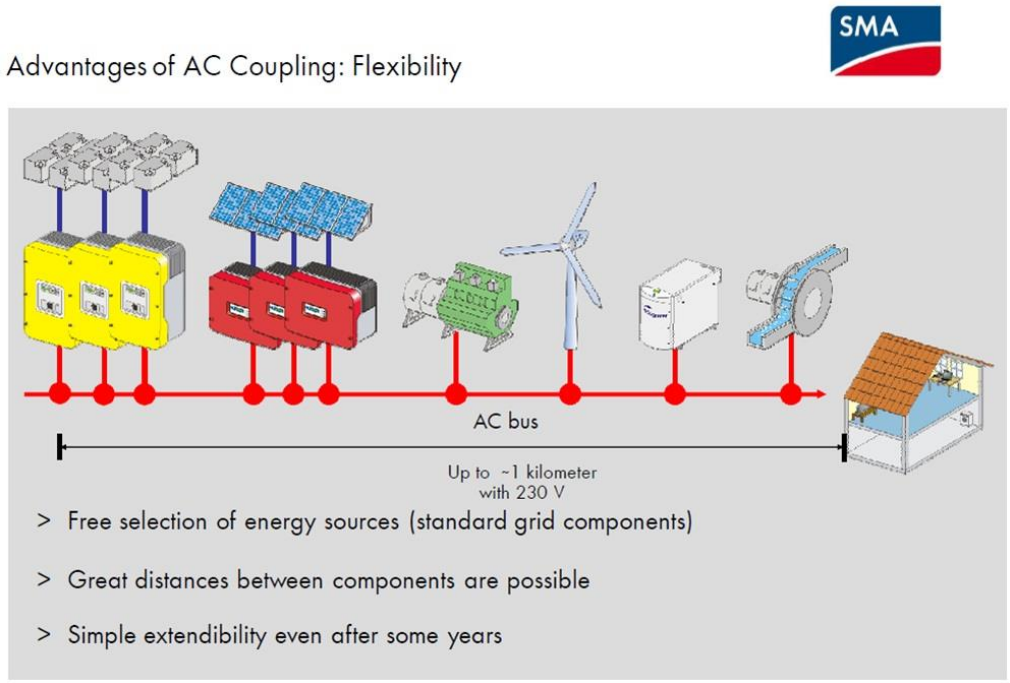

Fig. 10 *Examples of AC interconnections in Grid-Off system hybrid power station* [5]

Therefore, it is necessary to limit their lengths as much as possible. This is a significant factor in decision-making on suitable structure and interconnections, at which RE generators as well as backup sources may (must) be sufficiently clear of each other. Regarding the appraisal of potential DC losses, as well as with regard to the simplicity of island system’s structure being created, usage of AC interconnections appears as more advantageous and more flexible (Fig. 10).

One of big advantages of showed scheme with AC interconnections is the fact, that standard and already manufactured Grid-On components can be used also in Grid-Off system, because all tasks of the distributing network are performed by main inverter. This within DC/AC conversion (battery-AC system) actually forms an AC „local“ distributing system, to which all other system components are synchronized.

Main advantages of AC interconnection:

- Freedom in selection of energy sources (standard Grid-On components):
- Possibility of relatively long interconnecting distances between system components
- Simple expansibility after years of operation, as well as at required changes.
- Simple design of system, modularity and transparency of system.
- Usability of standard installation technologies (heredity from Grid-On systems).

Main rules for simple design of the island systems

a./ **Before design** of Grid-Off hybrid system's application itself it is necessary to check:

- *What is the maximum annual consumption (kWh) and maximum power (Pmax) of system?*
  These values can be obtained by summation of daily consumption of all DC, AC appliances.
- *What is the place of intended application of Grid-Off system?*
  This information is necessary for determination of conditions for solar radiation, windy conditions and operating temperature.
- *What RE sources will be used?*
  According to the site of application, energetic possibilities for optimum utilization of RE (sun, wind, water) shall be found out, primarily share amount of PV energy.
- *What arrangement shall be simulated and secured by the system?*
  According to the site, it is necessary to decide on the customer's application. There has to be defined an arrangement (1-phase, 3-phase, other), voltage, frequency. At same time, the factors resulting from the local legislation must be taken into account.
- *What backup system may be used in Grid-Off system?*
  By analyzing the local legislation shall be checked, if for backup is it possible to use also the distributing network, or only other generators.

b./ **During designing** the customer application of hybrid Grid-Off system it is necessary to determine:

- *What system components will be used in Grid-Off power station?*
  Depending on the power, availability of RE and intended application, there has to be determined the main components of system, their quantity and also suitable interconnecting scheme must be chosen.
- *What are to be accumulators in the island system?*
  Based on the energetic balance of RE sources and way of backing up, the annual capacity of accumulators in kWh will be calculated.
- *What PV array will be used in the system?*
  Based on the information on power of Grid-Off system and solar conditions, the share of PV power and its design from PV panels must be determined.
- *What wind generator will be used in the system?*
  According to the information on system power and windy conditions, its power and particular configuration is to be defined. [8] [9]
- *What power and configuration of backup system should be?*
  It should be about 80-120 % of main inverter's power. Here also possibilities of its remote control (diesel-generator) and way of its wiring into the island system (parallel to network, constituting network) must be appraised.

The rules for simple design are used for the first approximation. During the designing it is necessary to perform calculations using several parameters (variations of solar and wind conditions, orientation and inclination of PV panels, location and configuration of wind turbine, the most unfavorable conditions of RE, location and control of backup sources). The main task which has to be solved is the right solution in conformance with the relevant requirements stated in standards for design verification [11].

The outstanding assistance in designing the applications of Grid-Off system power stations with RE is provided by various types of designing and expert systems, based on computer aid.

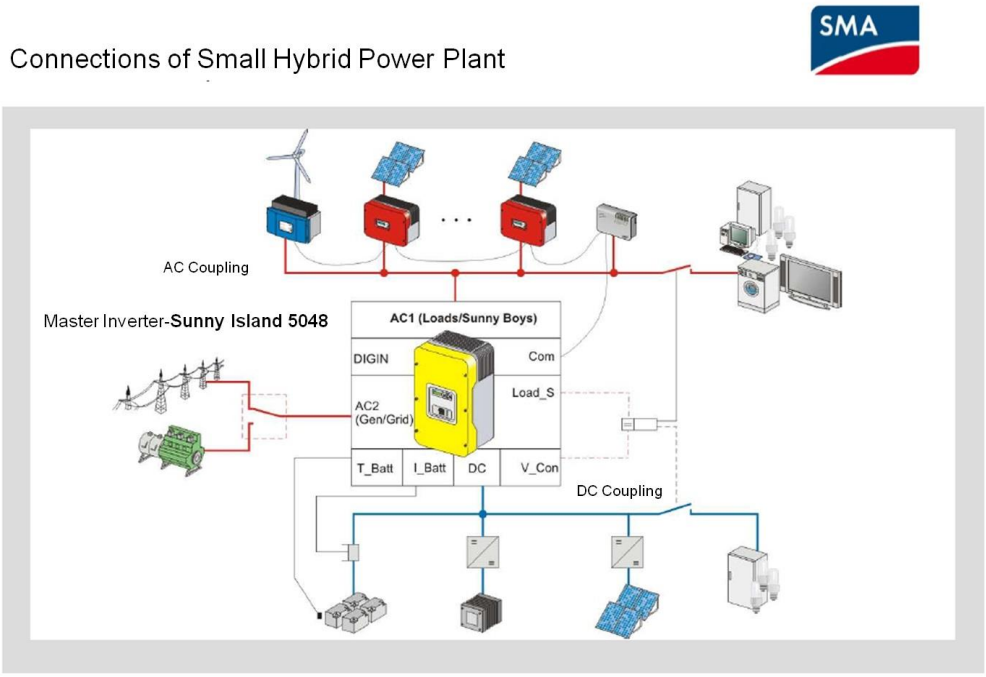

Fig. 11 *Example of implementation of 5 kW hybrid island system with SMA inverters* [5]

3. Description of achieved results

The hybrid version of small hybrid electric power plant was built with two types of RE generators: solar generator (1kW area: 4 pieces of 250 W PV panels) and 400 W wind turbine generator system.

Fig. 12 *Small Grid-Off power plant from RE awarded on the exhibition Elosys 2013 in Trenčín*

The SMA inverter Sunny Island 5048A was used as a master controller. The 48 V system was equipped with Hoppecke batteries (capacity: 30 kWh) and assembled into container according to diagram stated on the Fig. 11 (except backup generator and other unimportant components for first purpose).After first verification which has done on the Grid-Off system we are able to say that the system works properly in conformance with the theory and relations mentioned on this paper.

The above-mentioned and containerized small hybrid Grid-Off electric power plant has been awarded on the Slovak National Exhibition ELOSYS 2013 in Trenčín (*"Ecological act of the year 2013"*: see Fig. 12).

4. Conclusion

The researchers around the world bring significant results oriented on increasing efficiency of the solar cells. They leave no doubt to real utilization of the sun in the human life, specifically for the producing of electricity

for own consumption. In connection with other RE sources and new possibilities to utilizing them the new challenge is opening. It is the challenge oriented on the research and design of new applicable and real solutions in economy and human life. It was the subject of this paper too.

The works on the project are still running. The bigger and more complex (with backup generator) Grid-Off power plant from RE is scheduled to be simulated and tested by the partners of that project in near future.

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