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HYPA

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EXECUTIVE SUMMARY

DELIVERABLE 1.2 - REPORT ON TECHNICAL RTD REQUIREMENTS AND NEW CONCEPTS AND INTEGRATED MODELS FOR RENEWABLE ENERGY SUPPLY

Introduction

Energy is the fuel for growth, an essential requirement for economic and social development and the driver of living standards. Increased access to electricity enhances opportunities for industrial development and improves health and education. Renewable Energies (RE) have a large potential to contribute to the strengthening and development of national sustainable energy infrastructures.

Hybrid renewable energy systems, (i.e. systems that combine more than one renewable energy technology such as photovoltaics and wind turbine), is one of the most promising applications of renewable energy technologies in remote areas, where the cost of grid extension is prohibitive and the price of fossil fuels increase drastically with the remoteness of location.

To determine inherent problems in the combination of different RE in hybrid systems, the four most widely applied technologies for electricity production (wind energy, photovoltaics, small hydro) are briefly introduced, along with a selective presentation of special issues common to the use of the above mentioned technologies and the implementation of hybrid systems, such as power conditioning, generators and energy storage.

Cost effective and standardized RE/hybrid components and systems

Numerous hybrid energy systems have been installed in many countries over the last three decades, becoming an integral part of the energy planning process.

Hybrid systems are classified according to their technical configuration. “Series” hybrid systems go well with low power applications while “switched” suit better to village grid electrification. The “parallel” configuration offers the opportunities of achieving cost reductions and improved reliability, standardisation at the component level, which is now considered to be a more satisfactory solution than standardisation at the level of the system. In particular, the modular hybrid power supply concept, by coupling all generators, storage media and loads on the AC-side, realizes simplicity in system design, expandability and security of power supply. The modular technology enables integral solutions, and establishes industrial series production at lower cost.

A new trend in hybrid systems architecture is the use of hydrogen/fuel cell subsystems, as an alternative storage mean to the classical lead-acid batteries, offering the possibility of seasonal storage.

System concepts and case studies

During recent years several large or small scale projects of hybrid systems have been realized all over the world. The majority of remote rural regions are characterized by scattered villages with population of less than 100 households per village and small energy demands (lighting, food storage and some basic utilities, generally a TV and a radio). Other cases regard isolated areas with medium to high electricity demand (e.g. touristic small islands). Hybrid mini-grids or stand-alone applications can be very suitable for these regions.

The following case studies, are selected because they represent typical hybrid system configurations, well established technologies, combination of different electricity production systems (PV, Wind, etc) and power conditioning technologies, to satisfy different loads.

- Stand-alone PV/diesel installation for electrification of a tourist resort, Greece.
- PV/diesel test facility comprising bi-directional inverter, Australia.
- PV-diesel desalination plant, Italy.
- Small autonomous hybrid PV/wind for desalination, Greece.
- PV/wind/diesel, grid assisted hybrid system for desalination, Libya.
- PV/wind/diesel off-grid system for a residence, Greece.
- PV/Thermal Solar Systems, Greece.
- PV/hydropower, with hydro storage, Greece.
- PV/diesel, modular mini grid installation, Greece.
- PV/wind/diesel modular system, Spain.
- A wind fuel cell hybrid energy system.

**Commercially available systems (standardized systems)**

The following systems comply with basic cost, robustness, standardization, requirements. Modular concept is not yet common in the market.

- Conergy ISA 3000/5000/10K/15K/30K hybrid.
- PV/wind, off-grid water pumping - The SQFlex Combi system by Grundfos.
- Distributed AC-bus system Sunny Island and Sunny Boy inverters family, by SMA Regelsysteme GmbH

**Energy efficient appliances**

In stand alone hybrid systems, a well-matched load together with a carefully selected choice of appliances can lead to significant savings in terms of reduced need for RES installation capacity and electricity storage capacity.

The bulk of the problems encountered with system operation can be traced back to inefficient appliances and processes or unmatched loads. Problems related to loads are grouped and briefly discussed, along with basic advice for troubleshooting.

Purchasing of energy-efficient appliances has a direct positive effect on the economy and the environment. On the other hand, reduced energy consumption of energy efficient appliances requires less installed RES capacity (e.g. less PV panels) and thus less investment cost.

Due to the importance of the energy efficient appliances and the related economic impact on energy bills and investment costs, the industry of electrical appliances has shown an increasing interest and a large and increasing variety of energy efficient appliances are offered by suppliers all over the world. Help on selecting efficient energy appliances is found in specialized Internet sites (selected examples are given in the report).

**R&D priority requirements**

Based on the results of the previous analyses, the currently most importance “performance gaps” of RE and hybrid systems have been identified with respect to key applications for rural electricity supply, national and regional infrastructures, sustainable tourism and commerce as well as for increased water supplies.

A number of hardware developments are required to achieve further performance improvements, including static power converters, system controllers and battery charge controllers. Most importantly power-conditioning devices need to be designed to be more efficient at the low end of their operating range. Important problems in hybrid installations are load restrictions, generator fumes and noise, maintenance and lack of technical support. Other issues such as power quality, supply reliability, insurance, or safety, are identified as less important concerns.

The provision of adequate maintenance and technical support will remain a difficult logistic problem given the remoteness of many locations. This leads to the demand of systems that are highly reliable over their entire lifetime, as well as requiring minimum maintenance, preferably by untrained operators.

Regarding energy storage, there are requirements for further improvements, i.e. more efficient and less maintenance of the lead-acid batteries while hydrogen sub-storage systems and fuel cells still have a long way to go.

The progress in the information technology allows adopting highly sophisticated management techniques and technologies to optimize the operation of hybrid energy systems. System maintenance may be also improved by applying distant operation supervision. And also fault identification can be further improved.

The next generation of decentralized power supply structures are expected to include several types of grids that operate parallel to each other and communicate with service centers for control supervision and remote maintenance purposes. These types of grids form supply structures that can be expanded step by step as the demand for electricity increases. A broad expansion of the decentralized electrification would automatically lead to the interconnection of local grids to form regional or trans-regional grids.
Major areas for R&D requirements include

- More efficient power conditioning devices need to be designed at the low end operating range
- Power conditioning devices of higher reliability and less maintenance are required (preferably to achieve more than 20 years of full operation)
- Cost reduction of hybrid system components (both for generation technologies and power conditioning devices)
- Further diversification of modular hybrid systems and standard components
- Inclusion of hydrogen/fuel cell subsystems in hybrid systems, (methods of controls, efficient and reliable operation)
- Storage systems need further improvement (in particular: efficiency, reliability and maintenance, cost reduction)
- Adaptation of battery management systems for new generation of batteries
- Introduction of new storage technologies in pilot units for large field experimentation and assessment of lifetime and cost
- Low cost support structures, for PV systems
- Low cost cabling and electrical connection components
- Development of highly sophisticated design tools (software)
- Development of diagnostic tools for early fault recognition to maximise lifetime performance
- Further improvement of the energy efficiency of appliances
- Development of greater variety of energy efficient appliances
- Development of modern decentralized power supply structures to include several types of grids
- Standards and/or guidelines for quality assurance
- Development of recycling processes
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1. INTRODUCTION

Energy is a key component of any poverty eradication and sustainable development strategy and is critical to the achievement of the Millennium Development Goals¹. Better access to sustainable energy services for the ‘energy poor’ of our planet is a prerequisite for the sufficient supply of lighting, communication systems and cooling, the development of businesses and income generation activities as well as the improvement of the public health situation. Today, it is widely accepted that Renewable Energies (RE) have a large potential to contribute to the strengthening and development of national sustainable energy infrastructures by securing better energy independence through the mobilisation of domestic RE resources, especially in rural areas.

In 2000, only one in six on this planet had access to the energy required to provide the high living standards enjoyed in developed countries. Yet these one billion people consumed over 50% of the world’s energy supply. By contrast, the one billion poorest people used only 4%. Energy is the fuel for growth, an essential requirement for economic and social development and the driver of living standards. Increased access to modern energy services such as electricity is a decisive factor in escaping the poverty trap; it vastly enhances opportunities for industrial development and improves health and education.

By 2050, world population could rise to around 9 billion (UN 2002). With no change in the global development profile, another two to three billion people would be living in poverty. The pressures of population growth and the goals to raise living standards combine to set a formidable energy challenge for the 21st century. Shifting the development profile will require considerable investment, with energy demand raising at least two or three-fold from 2000.

Present status: The pie chart below (Fig. 1) represents the main fuels in the world total primary energy supply, with a disaggregation of the share of the main renewables categories (IEA Fact Sheet²). In 2003, renewables accounted for 13.3% of the 10 579 Mtoe of World Total Primary Energy Supply (TPES)³. Combustible renewables and waste (97% of which is biomass, both commercial and non-commercial) presented almost 80% of total renewables followed by hydro (16.2%).

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¹ United Nations Millennium Declaration “We will spare no effort to free our fellow men, women and children from the abject and dehumanizing conditions of extreme poverty, to which more than a billion of them are currently subjected.” 8th plenary meeting 2000.


³ TPES is calculated using the IEA conventions (physical energy content methodology). It includes international marine bunkers and excludes electricity/heat trade. The figures include both commercial and non-commercial energy.

**Geothermal, solar, wind, tide/wave/ocean. **Includes non-renewable waste.
Renewables are the third largest contributor to global electricity production. They accounted for 18% of production in 2003, after coal (40%) and natural gas (19%), but ahead of nuclear (16%), and oil (7%), see Fig. 2. Most of the electricity generated from renewables comes from hydro power plants (90%) followed by combustible renewables and waste (6%). Although fast growing, geothermal, solar and wind still accounted for less than 4% in 2003.

**Future Global Developments:** In the Reference Scenario developed in the IEA’s World Energy Outlook 2005: Middle East and North Africa Insights (WEO 2005), which assumes continuation of present government policies and no major breakthrough in technologies, renewable-energy supply will increase by 1.8% per year from over 1 400 Mtoe in 2003 to almost 2 300 Mtoe in 2030, a rise of more than 60%, see Fig. 3.
In this scenario, the share of renewables in global energy supply will remain largely unchanged at 14%. Traditional biomass currently accounts for 7% of world energy supply, but its share will fall as developing countries shift to modern forms of energy. World hydropower production will grow by 1.8% per year but its share will remain almost stable at around 2%. Other renewables (including geothermal, solar and wind) will increase most rapidly at 6.2% per year but because they start from a very low base (0.5% share in 2003) they will still be the smallest component of renewable energy in 2030 with a share of only 1.7% of global energy demand.

Energy use and climate impacts: Over the last century the amount of carbon dioxide in our atmosphere has risen, driven in large part by our usage of fossil fuels, but also by other factors that are related to rising population and increasing consumption, such as land use change. Coincident with this rise has been an increase in the global average temperature, up by nearly a degree Celsius. If these trends continue, global temperatures could rise by a further one to four degrees by the end of the 21st century, potentially leading to disruptive climate change in many places. By starting to manage our carbon dioxide emissions now, we may be able to limit the effects of climate change to levels that we can adapt to.

Is there an acceptable limit for CO2 emissions? The yardstick typically used to approach this question is the eventual concentration of CO2 in the atmosphere, or stabilization level. Up to the time of the industrial revolution this remained at 280 ppm. The IPCC scenarios lead to CO2 concentrations continually rising during the 21st century with no stabilization below the range 700 to 1000 ppm. Such levels of CO2 are, according to the IPCC, likely to lead to very damaging impacts. A temperature rise of some 2-4°C could bring more extreme climate events, threaten sensitive eco-systems such as coral reefs and lead to rises in sea level. In the 4-6°C range we may also see structural alterations to our weather patterns, possibly led by changes in important ocean currents such as the Gulf Stream. A level of stabilization of less than 500 ppm will be very difficult to achieve, as it requires a sharp downward turn in emissions before 2020. Stabilization at a somewhat higher level would be more achievable as it allows a timeframe in which significant change in our energy infrastructure could take place. Inertia is an inherent characteristic of the climate system, with CO2 concentration, temperature and sea level continuing to rise for hundreds of years after emissions have been reduced. Thus some impacts of man-made climate change may be slow to appear.

An estimated 1.64 billion people worldwide lack access to electricity, of which approximately 80% live in rural areas of South Asia and Sub-Saharan Africa (IEA, 2002). Non-access to electricity and rural poverty are closely correlated. This is because not only is electricity a pre-requisite for ameliorating living standards, it is also an indispensable input for productive and economic activities. For vulnerable rural populations, the positive impacts of electricity inputs for basic activities such as pumping water for drinking and irrigation; lighting for extending working and learning hours; and powering small-scale rural industry are considerably greater due to a bundling of socio-economic benefits. For example, reduced labour time for obtaining electrically pumped and hygienic drinking water may potentially free up time for income generation activities by women, which may in turn be aided by electricity inputs. It also of particular importance to point out the fact that the positive contribution of electricity to the Human Development Index is strongest for the first kilowatt-hour, reflecting that the poorest are most likely to benefit from even minimal electricity inputs. This is associated to another fact that electricity supply to this category should be enhanced keeping broader development goals in mind, such as health, education, and economic productivity.

Hybrid renewable energy systems, (i.e. systems that combine more than one renewable energy technology such as photovoltaics and wind turbine), is one of the most promising applications of renewable energy technologies in remote areas, where the cost of grid extension is prohibitive and the price of fossil fuels increase drastically with the remoteness of the location. It has been demonstrated with numerous installations all over the world that hybrid energy systems can significantly reduce the total life-cycle cost of stand-alone power supplies in many situations, while at the same time providing a more reliable supply of electricity through the combination of energy.
sources. Applications of hybrid systems range from small power supplies for remote households providing electricity for lighting or water pumping and water supply to village electrification for remote communities. Mixed combinations of renewable energy systems are also possible, that is applications where different renewable energy technologies are applied in one location without the systems being necessarily interconnected in one electricity grid. Although a range of hybrid system configurations are possible what we have learned so far is that the choice must suit the community considered. Also the problem of energy storage could be addressed by the use of a hydrogen subsystem, which is an alternative to diesel generators as a backup and can help to reduce dramatically the size of the battery banks as well.

Nevertheless it is still necessary to remove the knowledge barriers against the wider implementation of hybrid renewable energy systems and to facilitate (technically and socially) the development and installation of low-cost pilot hybrid renewable energy systems in remote areas and particularly the Mediterranean area. The development and application of highly innovative hybrid RE installations based on the availability of local renewable energy sources as well as local social conditions and needs, will effect a significant contribution for creating sustainable structures with a decent living quality in the rural environments.

The RE hybrid systems are being applied with the aim to:
- deliver electricity to isolated rural populations, based on village-scale mini-grids
- desalinate sea water in order to increase drinking water supply and water availability for irrigation
- increase agricultural water pumping by solar, wind powered water pumps
- disseminate cooling systems for the food conservation in farms and fisheries powered by renewables
- address, in the grid-connected urban and tourist areas, the household and community demand for lighting, food, drugs cooling, access to communication networks by using solar home systems, small wind turbines, biogas and hydrogen sub-systems
- create joint-ventures and other manufacturing, assembly and distribution-installation capabilities in developing countries

Modern hybrid systems must be configured and sized after taking into account the local conditions of the installation place. The systems should fulfill criteria as modularity, robustness, and simplicity in use and also require very low maintenance. Additional considerations for the technologies’ selection and implementation regard the possibility of systems’ standardisation and replication. Furthermore, all local installations must serve as good practice, accelerate local skill development, and promote and encourage international partnerships amongst all relevant stakeholders, such as research, financial, and regulatory institutions, industry and service companies, in particular SMEs, local representatives and other social players.

In contrast to purely conventional power plants, renewable systems are usually designed (Kleinkauf et al. 2003) in relatively low power generation units which are built near the consumer (load or utility grid). The local availability and the wide application potentials of renewable energies give the opportunity to design decentralized power systems of modular structures which have conditions similar to the conventional energy plants, fulfill serial production conditions, are usable in different power supply fields and have specified electrical characteristics. Hybridization through combining different energy sources (i.e. renewable and conventional) in one supply system offers the best possibility to use the locally available renewable energies. The nature of hybridization is mainly based on the special features and economic potential of various energy conversion processes and on the power range. In Fig. 4, the application spectrum of various energy resources for electrification purposes throughout the total power range is described. Hybrid system technology mainly covers stand-alone systems as well as island grids of small and medium power ranges. Moreover, hybridization can be expanded to cover regional and trans-regional grids.
The benefits from the renewable energy supply to remote areas are obvious: improvement of living level, possibilities for economic and social development through the enhancement of local activities such as agriculture or small local workshops, use of environmental friendly technologies. Possibilities are also opened for a new market in the whole country namely the renewable energy market.

2. RENEWABLE ENERGY TECHNOLOGIES FOR ELECTRICITY PRODUCTION

2.1. Introduction

The four most widely applied technologies for electricity production are wind energy, photovoltaics, small hydro, and biomass combustion power technologies. The first three technologies are briefly introduced in the sections that follow and the fourth technology is out of the scope of the present report.

2.2. Wind energy systems

Introduction

Wind energy systems convert the kinetic energy of moving air into electricity or mechanical power. They can be used to provide power to central grids or isolated grids, or to serve as a remote power supply or for water pumping. Wind turbines are commercially available in a vast range of sizes. The turbines used to charge batteries and pump water off-grid tend to be small, ranging from as small as 50 W up to 10 kW. For isolated grid applications, the turbines are typically larger, ranging from about 10 to 200 kW. As of 2005, the largest turbines are installed on central grids and are generally rated between 1 and 2 MW, but prototypes designed for use in shallow waters offshore have capacities of up to 5 MW.

A good wind resource is critical to the success of a commercial wind energy project. The energy available from the wind increases in proportion to the cube of the wind speed, which typically increases with height above the ground. At minimum, the annual average wind speed for a wind energy project should exceed 4 m/s at a height of 10 m above the ground. Certain topographical features tend to accelerate the wind, and wind turbines are often located along these features.
These include the crests of long, gradual slopes (but not cliffs), passes between mountains or hills, and valleys that channel winds. In addition, areas that present few obstructions to winds, such as the sea surface adjacent to coastal regions and flat, grassy plains, may have a good wind resource. Since the early 1990s, wind energy technology has emerged as the fastest growing electricity generation technology in the world. This reflects the steady decline in the cost of wind energy production that has accompanied the maturing of the technology and industry: where a good wind resource and the central grid intersect, wind energy can be among the lowest cost provider of electricity, similar in cost to natural gas combined-cycle electricity generation.

Description of Wind Turbines
Wind turbine technology has reached a mature status during the past 15 years as a result of international commercial competition, mass production and continuing technical success in research and development (R&D). The earlier concerns that wind turbines were expensive and unreliable have largely been allayed. Wind energy project costs have declined and wind turbine technical availability is now consistently above 97%. Wind energy project plant capacity factors have also improved from 15% to over 30% today, for sites with a good wind regime.

Modern wind energy systems operate automatically. The wind turbines depend on the same aerodynamic forces created by the wings of an aeroplane to cause rotation. An anemometer that continuously measures wind speed is part of most wind turbine control systems. When the wind speed is high enough to overcome friction in the wind turbine drive train, the controls allow the rotor to rotate, thus producing a very small amount of power. This cut-in wind speed is usually a gentle breeze of about 4 m/s. Power output increases rapidly as the wind speed rises. When output reaches the maximum power the machinery was designed for, the wind turbine controls govern the output to the rated power. The wind speed at which rated power is reached is called the rated wind speed of the turbine, and is usually a strong wind of about 15 m/s. Eventually, if the wind speed increases further, the control system shuts the wind turbine down to prevent damage to the machinery. This cut-out wind speed is usually around 25 m/s.

The major components of modern wind energy systems typically consist of the following:

- Rotor, with 2 or 3 blades, which converts the energy in the wind into mechanical energy onto the rotor shaft;
- Gearbox to match the slowly turning rotor shaft to the electric generator;
- Tall tower which supports the rotor high above the ground to capture the higher wind speeds;
- Solid foundation to prevent the wind turbine from blowing over in high winds and/or icing conditions and
- Control system to start and stop the wind turbine and to monitor proper operation of the machinery.

Wind Energy Application Markets
Wind energy markets can be classified based on the end-use application of the technology. Wind energy projects are common for off-grid applications. However, the largest market potential for wind energy projects is with on-grid (or grid-connected) applications.

Off-grid applications
Historically, wind energy was most competitive in remote sites, far from the electric grid and requiring relatively small amounts of power, typically less than 10 kW. In these off-grid applications, wind energy is typically used in the charging of batteries that store the energy captured by the wind turbines and provides the user with electrical energy on demand. Water pumping, where water, rather than energy, can be stored for future use, is also a key historical application of wind energy. The key competitive area for wind energy in remote off-grid power applications is against electric grid extension, primary (disposable) batteries, diesel, gas and thermoelectric generators. Wind energy is also competitive in water pumping applications (Leng et al. 1996).
On-grid applications
In on-grid applications the wind energy system feeds electrical energy directly into the electric utility grid. Two on-grid application types can be distinguished.
1. Isolated-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 10 kW to 200 kW.
2. Central-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 200 kW to 2 MW.

Isolated-grids
Isolated-grids are common in remote areas. Electricity generation is often relatively expensive due to the high cost of transporting diesel fuel to these isolated sites. However, if the site has good local winds, a small wind energy project could be installed to help supply a portion of the electricity requirements. These wind energy projects are normally referred to as wind-diesel hybrid systems. The wind energy system’s primary role is to help reduce the amount of diesel fuel consumption.

Central-grids
Central-grid applications for wind energy projects are becoming more common. In relatively windy areas, larger scale wind turbines are clustered together to create a windfarm with capacities in the multi-megawatt range. The land within the windfarm is usually used for other purposes, such as agriculture or forestry. Another common approach for wind energy project development includes the installation of one or more of larger scale wind turbines by individuals, businesses or co-operatives. A windfarm, consists of a number of wind turbines (which are often installed in rows perpendicular to the wind direction), access roads, electrical interconnections and a substation, a monitoring and control system and a maintenance building for the larger farms. The development of a wind energy project includes the determination of the wind resource, the acquisition of all authorisations and permits, the design and specification of the civil, electrical and mechanical infrastructure, the layout of the wind turbines, the purchasing of the equipment, the construction and the commissioning of the installation. Construction involves preparing the site, grading roads, building turbine foundations, installing the electrical collection lines and transformers, erecting the turbines and construction of the substation and building.

2.3. Small hydro systems

Introduction
Small hydro systems convert the potential and kinetic energy of moving water into electricity, by using a turbine that drives a generator. As water moves from a higher to lower elevation, such as in rivers and waterfalls, it carries energy with it; this energy can be harnessed by small hydro systems. Used for over one hundred years, small hydro systems are a reliable and well-understood technology that can be used to provide power to a central grid, an isolated grid or an off-grid load, and may be either run-of-river systems or include a water storage reservoir. Most of the world’s hydroelectricity comes from large hydro projects of up to several GW that usually involve storage of vast volumes of water behind a dam. Small hydro projects, while benefiting from the knowledge and experience gleaned from the construction of their larger siblings, are much more modest in scale with installed capacities of less than 50 MW. They seldom require the construction of a large dam, except for some isolated locations where the value of the electricity is very high due to few competing power options. Small hydro projects can even be less than 1 kW in capacity for small off-grid applications.

An appreciable, constant flow of water is critical to the success of a commercial small hydro project. The energy available from a hydro turbine is proportional to the quantity of water passing through the turbine per unit of time (i.e. the flow), and the vertical difference between the turbine and the surface of the water at the water inlet (i.e. the head - in reality, this must be adjusted for various losses).

Since the majority of the cost of a small hydro project stems from up front expenses in construction and equipment purchase, a hydro project can generate large quantities of electricity with very low
operating costs and modest maintenance expenditures for 50 years or longer. In many parts of the world, the opportunities for further large hydro developments are dwindling and smaller sites are being examined as alternatives giving significant growth potential for the small hydro market (e.g. China).

There is no universally accepted definition of the term “small hydro” which, depending on local definitions can range in size from a few kilowatts to 50 megawatts or more of rated power output. Internationally, “small” hydro power plant capacities typically range in size from 1 MW to 50 MW, with projects in the 100 kW to 1 MW range sometimes referred to as “mini” hydro and projects less than 100 kW referred to as “micro” hydro. Installed capacity, however, is not always a good indicator of the size of a project. For example, a 20 MW, low-head “small” hydro plant is anything but small as low-head projects generally use much larger volumes of water, and require larger turbines as compared with high-head projects.

Description of Small Hydro Power Plants
A small hydro generating station can be described under two main headings: civil works, and electrical and mechanical equipment.

Civil works
The main civil works of a small hydro development are the diversion dam or weir, the water passages and the powerhouse. The diversion dam or weir directs the water into a canal, tunnel, penstock or turbine inlet. The water then passes through the turbine, spinning it with enough force to create electricity in a generator. The water then flows back into the river via a tailrace. Generally, small hydro projects built for application at an isolated area are run-of-river developments, meaning that water is not stored in a reservoir and is used only as it is available. The cost of large water storage dams cannot normally be justified for small waterpower projects and consequently, a low dam or diversion weir of the simplest construction is normally used. Construction can be of concrete, wood, masonry or a combination of these materials. Considerable effort continues to be spent to lower the cost of dams and weirs for small hydro projects, as the cost of this item alone frequently renders a project not financially viable.

The water passages of a small hydro project comprise the following:

- An intake which includes trash racks, a gate and an entrance to a canal, penstock or directly to the turbine depending on the type of development. The intake is generally built of reinforced concrete, the trash rack of steel, and the gate of wood or steel.
- A canal, tunnel and/or penstock, which carries the water to the powerhouse in developments where the powerhouse is located at a distance downstream from the intake. Canals are generally excavated and follow the contours of the existing terrain. Tunnels are underground and excavated by drilling and blasting or by using a tunnel-boring machine. Penstocks, which convey water under pressure, can be made of steel, iron, fibreglass, plastics, concrete or wood.
- The entrance and exit of the turbine, which include the valves and gates necessary to shut off flow to the turbine for shutdown and maintenance. These components are generally made of steel or iron. Gates downstream of the turbine, if required for maintenance, can be made of wood.
- A tailrace, which carries the water from the turbine exit back to the river. The tailrace, like the canal, is excavated.

The powerhouse contains the turbine or turbines and most of the mechanical and electrical equipment. Small hydro powerhouses are generally kept to the minimum size possible while still providing adequate foundation strength, access for maintenance, and safety. Construction is of concrete and other local building materials. Simplicity in design, with an emphasis on practical, easily constructed civil structures is of prime concern for a small hydro project in order to keep costs at a minimum.
Electrical and mechanical equipment

The primary electrical and mechanical components of a small hydro plant are the turbine(s) and generator(s).

A number of different types of turbines have been designed to cover the broad range of hydropower site conditions found around the world. Turbines used for small hydro applications are scaled-down versions of turbines used in conventional large hydro developments.

Turbines used for low to medium head applications are usually of the reaction type and include Francis and fixed and variable pitch (Kaplan) propeller turbines. The runner or turbine “wheel” of a reaction turbine is completely submerged in water. Turbines used for high-head applications are generally referred to as impulse turbines. Impulse turbines include the Pelton, Turgo and crossflow designs. The runner of an impulse turbine spins in the air and is driven by a high-speed jet of water.

Small hydro turbines can attain efficiencies of about 90%. Care must be given to selecting the preferred turbine design for each application as some turbines only operate efficiently over a limited flow range (e.g. propeller turbines with fixed blades and Francis turbines). For most run-of-river small hydro sites where flows vary considerably, turbines that operate efficiently over a wide flow range are usually preferred (e.g. Kaplan, Pelton, Turgo and crossflow designs). Alternatively, multiple turbines that operate within limited flow ranges can be used.

There are two basic types of generators used in small hydro plants - synchronous or induction (asynchronous). A synchronous generator can be operated in isolation while an induction generator must normally be operated in conjunction with other generators. Synchronous generators are used as the primary source of power produced by utilities and for isolated diesel-grid and stand-alone small hydro applications. Induction generators with capacities less than about 500 kW are generally best suited for small hydro plants providing energy to a large existing electricity grid.

Other mechanical and electrical components of a small hydro plant include:
- Speed increaser to match the ideal rotational speed of the turbine to that of the generator (if required);
- Water shut-off valve(s) for the turbine(s);
- River by-pass gate and controls (if required);
- Hydraulic control system for the turbine(s) and valve(s);
- Electrical protection and control system;
- Electrical switchgear;
- Transformers for station service and power transmission;
- Station service including lighting and heating and power to run control systems and switchgear;
- Water cooling and lubricating system (if required);
- Ventilation system;
- Backup power supply;
- Telecommunication system;
- Fire and security alarm systems (if required); and
- Utility interconnection or transmission and distribution system.

2.4. Photovoltaic systems

Photovoltaic systems convert energy from the sun directly into electricity. They are composed of photovoltaic cells, usually a thin wafer or strip of semiconductor material that generates a small current when sunlight strikes them. Multiple cells can be assembled into modules that can be wired in an array of any size. Small photovoltaic arrays are found in wristwatches and calculators; the largest arrays have capacities in excess of 5 MW. Photovoltaic systems are cost-effective in small
off-grid applications, providing power, for example, to rural homes in developing countries, off-grid cottages and motor homes in industrialised countries, and remote telecommunications, monitoring and control systems worldwide.

Water pumping is also a notable offgrid application of photovoltaic systems that are used for domestic water supplies, agriculture and, in developing countries, provision of water to villages. These power systems are relatively simple, modular, and highly reliable due to the lack of moving parts. Photovoltaic systems can be combined with fossil fuel-driven generators in applications having higher energy demands or in climates characterized by extended periods of little sunshine (e.g. winter at high latitudes) to form hybrid systems. Photovoltaic systems can also be tied to isolated or central grids via a specially configured inverter. Unfortunately, without subsidies, on-grid (central grid-tied) applications are rarely cost-effective due to the high price of photovoltaic modules, even if it has declined steadily since 1985. Due to the minimal maintenance of photovoltaic systems and the absence of real benefits of economies of scale during construction, distributed generation is the path of choice for future cost-effective on-grid applications. In distributed electricity generation, small photovoltaic systems would be widely scattered around the grid, mounted on buildings and other structures and thus not incurring the costs of land rent or purchase. Such applications have been facilitated by the development of technologies and practices for the integration of photovoltaic systems into the building envelope, which offset the cost of conventional material and/or labour costs that would have otherwise been spent.

Photovoltaic systems have seen the same explosive growth rates as wind turbines, but starting from a much smaller installed base. For example, the worldwide installed photovoltaic capacity in 2003 was around 3,000 MW, which represents less than one-tenth that of wind, but yet is growing rapidly and is significant to the photovoltaic industry.

Description of Photovoltaic Systems
The primary article of commerce in the PV market is the PV module. PV modules are rated on the basis of the power delivered under Standard Testing Conditions (STC) of 1 kW/m² of sunlight and a PV cell temperature of 25 degrees Celsius (°C). Their output measured under STC is expressed in terms of “peak Watt” or Wp nominal capacity. Note that annual industry shipments of 165 MWp indicates that PV manufacturers made modules with the ability to generate 165 MWp of electric power (nameplate capacity) under STC of 1 kW/m² of sunlight, 25°C cell temperature, and an air mass of 1.5. PV modules are integrated into systems designed for specific applications. The components added to the module constitute the “balance of system” or BOS. Balance of system components can be classified into four categories:
1. Batteries - store electricity to provide energy on demand at night or on overcast days;
2. Inverters - required to convert the DC power produced by the PV module into AC power;
3. Controllers - manage the energy storage to the battery and deliver power to the load; and
4. Structure - required to mount or install the PV modules and other components.

Not all systems will require all these components. For example in systems where no AC load is present an inverter is not required. For on-grid systems, the utility grid acts as the storage medium and batteries are not required. Batteries are typically not required for PV water pumping systems, where a water reservoir “buffers” short-term demand and supply differences. Some systems also require other components which are not strictly related to photovoltaics. Some stand-alone systems, for example, include a fossil fuel generator that provides electricity when the batteries become depleted; and water-pumping systems require a DC or AC pump.

There are various types of firms involved in the photovoltaic industry. Typical organisations include PV cell/module manufacturers, BOS manufacturers, product distributors and dealers and system integrators.

PV modules
To make modules, PV manufacturers use crystalline silicon wafers or advanced thin film technologies. In the former, single crystal silicon (single-Si), polycrystalline silicon (poly-Si) or
ribbon silicon (ribbon-Si) wafers are made into solar cells in production lines utilising processes and machinery typical of the silicon semiconductor industry. Solar cell manufacturers then assemble the cells into modules or sell them to module manufacturers for assembly. Because the first important applications of PV involved battery charging, most modules in the market are designed to deliver direct current (DC) at slightly over 12 Volts (V). A typical crystalline silicon module consists of a series circuit of 36 cells, encapsulated in a glass and plastic package for protection from the environment. This package is framed and provided with an electrical connection enclosure, or junction box. Typical conversion (solar energy to electrical energy) efficiencies for common crystalline silicon modules are in the 11 to 15% range.

There are four advanced thin film technologies. Their names are derived from the active cell materials: cadmium telluride (CdTe), copper indium diselenide (CIS), amorphous silicon (a-Si) and thin film silicon (thin film-Si). Amorphous silicon is in commercial production while the other three technologies are slowly reaching the market. Thin film modules are made directly on the substrate, without the need for the intermediate solar cell fabrication step.

Some manufacturers are developing PV modules that concentrate sunlight onto small area high efficiency PV cells using lenses. The concept here is that the lens material will be less expensive per unit area than conventional silicon modules thus resulting in a $/Wp advantage. To ensure that the concentrating lenses are always focused on the PV cells, these modules must always be directed at the sun and therefore must be used in conjunction with sun trackers. These modules are limited to areas of the world where there is a considerable amount of direct beam sunlight, such as in desert regions.

Power conditioning
Several electronic devices are used to control and modify the electrical power produced by the photovoltaic array. These include:
- Battery charge controllers - regulate the charge and discharge cycles of the battery;
- Maximum power point trackers (MPPT) - maintain the operating voltage of the array to a value that maximises array output;
- Inverters - convert the direct current (DC) output of the array or the battery into alternating current (AC). AC is required by many appliances and motors; it is also the type of power used by utility grids and therefore on grid systems always require the use of an inverter;
- Rectifiers (battery chargers) - convert the AC current produced by a generator into the DC current needed to charge the batteries.

Power conditioning units (inverters) play a key role in the energy efficiency and reliability of PV systems. The energy generated by a PV-module depends on the instant value of solar irradiation, module temperature and the operating point of the module. Therefore, the system requires a power conditioning component (Maximum Power Point Tracker) which can optimize the delivered power based on the operation conditions. DC power generated by PV-modules is inverted into alternating current (AC) of the desired voltage and frequency (e.g. 230 V and 50 Hz).

The PV plant is connected to the grid via DC/AC inverters of different technology. Basic inverter technologies available in the market today are described below:

Central inverters: In this topology (usually of power greater than 10 kW), the PV modules are arranged in many parallel strings which are connected to the single central inverter on the DC side (see Fig. 5a). These inverters are characterized by high efficiency and lowest specific costs. However, the energy yield of the PV-plant can be decreased due to possible module mismatching and partial shading conditions. Moreover, the reliability of the plant is limited due to the dependence of the power generation on one single component: The failure of the central inverter results in the shutdown of the whole plant.

String inverter- Multi-String Inverters: The PV-plant in this concept is divided into several parallel strings as shown in Fig. 5b. Each of the PV-strings is assigned to a designated inverter, the so-
called "string inverter". Consequently the string topology of the PV-plant connection reduces the parallel connection of PV-strings on the DC side by a parallel connection on the AC side. String inverters each have separate maximum power point (MPP) tracking for each PV-string. This increases the energy yield via the reduction of mismatching and partial shading losses. These superior technical characteristics lead to a reduction in the system cost and enhance its reliability. Due to these advantages, string inverters have evolved as a standard in PV-system technology for grid coupling of PV-plants, and there is a trend to increase their market share since the middle of the 1990ies.

The Multi-String inverter is a further development of the string technology with a higher nominal power since it paves the way for the application of the modular system technology principles. The Multi-String inverter omits the disadvantages and combines the advantages of both the central and the string inverters. The application area of the Multi-String inverter covers PV-plants of several kW. This Multi-String topology allows the integration of PV-strings of different technologies and of various orientations (South, West and East). This increases the modularity (i.e. flexibility and expandability) of the PV-plant and also reduces costs.

*Module integrated inverter:* One inverter is used for each module, as shown in Fig. ??c. This topology optimizes the adaptability of the inverter to the PV-characteristics, since each module has its own MPP-tracker. This concept can be implemented for PV-plants of about 50 - 400 W peak. Although the module integrated inverter optimizes the energy yield, it has a lower efficiency than a string inverter. Module integrated inverters are characterized by more extended AC side cabling, since each module of the plant has to be connected in the 230 V grid. Also, the maintenance processes are quite complicated especially for facade-integrated PV-systems.

**Figure 5. Schematic diagram of three different PV plant topologies (source, [www.sma.de](http://www.sma.de))**

**Generators**

In some cases, where either large discrepancy between seasonal loads exists or where seasonal sun availability varies greatly; a system designed completely around PV components will result in the deployment of a large PV array to meet the needs of one season. Meanwhile, during other seasons, much of the energy available from the array is not used. This is similar to the problem of
meeting critical system needs with PV, where the cost generally increases rapidly as the system availability exceeds 95%. In such cases, it is often more cost effective to employ an alternate source of electricity to be available when the PV array is not meeting system needs. While it is conceivable that the back-up source for a stand-alone system may be wind or other renewable source, it is more common to employ either a gasoline, diesel or propane generator as a system back-up.

With relatively low acquisition costs of small and portable generators, it may appear that it would make better economic sense to simply use the generator without the PV array. However, life cycle cost analysis often shows the use of a mix of PV and conventional generation to be more economical than an engine-powered generator. Furthermore, the fact that PV generation is quiet and clean adds further appeal to using a maximum practical amount of PV generation in the system.

While most small electrical generators use a gasoline engine as the mechanical prime mover, methane, propane, natural gas and diesel (#2 oil) powered engines are also available. A number of factors will enter the selection process, including initial cost, power requirements, fuel availability and maintenance requirements.

While it is possible to obtain DC generators for use in battery charging applications, DC generators are generally not recommended because of maintenance requirements. AC generators are often used in PV systems to minimize maintenance costs.

Factors other than peak power output will enter the selection process if a generator is carefully chosen. Generator specifications also include rotation speed, efficiency, fuel type, altitude effects, waveform harmonic content, frequency stability, noise levels, type of starting and overload characteristics.

Electrical and mechanical losses are present in all generators. However, the greatest losses in a generator system are attributable to the prime mover engine. Since the prime mover and electrical generator will each generally have a particular load at which they will operate at maximum efficiency, manufacturers endeavour to carefully match the two components to produce maximum efficiency at somewhere between 80 and 90% of rated full load. As generator size increases, the overall maximum efficiency also increases. Whether or not to use a larger more expensive generator, operating at higher efficiency for shorter intervals, is always a challenge to the design engineer. Maximum generator size is limited in most cases by maximum allowable charging rates for the system batteries, assuming the generator is incorporated into a system with batteries. For systems with highly variable electrical loads it is particularly inefficient to incorporate a generator unless battery storage is provided to present a nearly constant load on the generator.

Generally the output waveform of an electrical generator is adequate for nearly all applications. For battery charging, almost any waveform is satisfactory, depending on whether the battery charger contains a transformer. If the charger contains a transformer, there is a remote possibility that excessive DC or harmonic content in the generator waveform may damage the transformer. If the generator is connected directly to the PV system AC loads at any time, then it is a good idea to be sure the generator output waveform is sufficiently "clean" to meet the requirements of the loads. Normally, the only loads with possible sensitivity to waveform quality will be electronic systems. Again, depending on load requirements and whether the generator is connected to AC loads with critical power frequency requirements, the frequency stability of a generator may need to be taken into account. It is generally desirable to maintain frequency fluctuations at less than ± 0.5 Hz for AC loads, but this degree of frequency stability is not necessary for many PV system loads.

Some generators are noisy and others are less noisy. Local ordinances should be checked, but normally the noise level demands of the user will be more stringent than local ordinances. National parks, for example, have relatively strict noise regulations.
2.5. Energy storage

Batteries
If an off-grid PV system must provide energy on demand rather than only when the sun is shining, a battery is required as an energy storage device. The most common battery types are lead-calcium and lead-antimony. Nickel-cadmium batteries can also be used, in particular when the battery is subject to a wide range of temperatures. Because of the variable nature of solar radiation, batteries must be able to go through many cycles of charge and discharge without damage. The amount of battery capacity that can be discharged without damaging the battery depends on the battery type. Lead-calcium batteries are suitable only in “shallow cycle” applications where less than 20% discharge occurs each cycle. Nickel-cadmium batteries and some lead-antimony batteries can be used in “deep cycle” applications where the depth of discharge can exceed 80%.

Depending on site conditions, and on the presence of a backup generator, battery banks are sized to provide a period of system autonomy ranging from a few days to a couple of weeks (in some very specific applications such as systems above the Arctic Circle). Batteries are characterised by their voltage, which for most applications is a multiple of 12 V, and their capacity, expressed in Ampere-hours (Ah). For example a 50 Ah, 48 V battery will store $50 \times 48 = 2.4$ kWh of electricity under nominal conditions. Note that optimising battery size is critical in obtaining good battery life, suitable system performance, and optimal system life-cycle costs. Unnecessary battery replacement is costly, particularly for remote applications.

Hydrogen as storage mean
Hydrogen as a storage medium in renewable energy systems has been the subject of various studies in recent years. Such a system consists of a long-term and a short-term storage system. In a battery, energy is stored for short term whereas the electrolyser, H2-tank and fuel cell combination is used for long-term energy storage to increase the reliability of supply. The same purpose can be achieved by introducing a diesel generator instead of long-term storage. The advantage of such a system is that it needs low investment cost. However, the main disadvantage is that it needs to supply fuel for the operation of the generator. The advantage of hydrogen-based long-term storage over a diesel generator is that it does not need any supply of fuel. In photovoltaic–wind–diesel hybrid systems, the surplus energy during the good season is not stored.

The varying nature of solar and wind energy causes the mismatch between supply and demand in the system. They are the diurnal mismatch and the seasonal mismatch. The mismatch between supply and demand is solved by using a buffer system. For this purpose, the lead-acid battery is widely used. To achieve the highest level of energetic reliability either the energy converter photovoltaic (PV) or Wind Energy Converter (WEC) or the battery is oversized (Samimi et al. 1997). The stand-alone WECs do not produce usable energy for a considerable duration due to high cut-in speeds, ranging from 3.5 to 4.5 m/s (Elhadidy 2002). To overcome this problem with WECs, a PV–WEC hybrid system would be a better solution because it will reduce the individual diurnal and seasonal fluctuation, which reduces the oversized battery in the stand-alone system. Due to its self-discharging property, the lead acid battery is not suitable for the seasonal mismatch. The seasonal mismatch is solved by using a diesel generator set as a backup system. It increases the reliability of energy supply. The energy flow in such a system is shown in Fig. 6.
During the good season, the load demand in the system remains insufficient to utilize the whole amount of energy converted by the energy converter (PV/WEC). Thus, during the good season of the year a large amount of energy would be wasted because of non-optimal operation of the converter. In a hybrid system, 40% of the total energy loss (Peterson et al. 1999) is due to the nonoptimal sizing of the system. However, another main disadvantage is that the diesel generator needs the fuel to be supplied for operation. Sometimes, for some of the remote applications, consumers pay high fuel costs for fuel transportation (Butler 1996). The high cost of the delivery and often dubious quality of the fuel places a premium on effective utilisation of the resources and makes the value of energy far higher. Other disadvantages can be:

- Causes emissions of greenhouse gas.
- Lower efficiency of conversion of the fuel at partial load.
- Noisy operation.

Replacing the generator by a long-term storage system, consisting of electrolyser, hydrogen tank and fuel cell combination eliminates the above-mentioned disadvantages in a generator based hybrid system. In a long-term storage system, the surplus energy during the good season is recovered by an electrolyser and hydrogen is produced, which is stored for the long-term use. When there is a shortage of energy in the battery, hydrogen is used in the fuel cell and demand is satisfied. The energy flow of such a system with long-term storage using hydrogen is shown in Fig. 7. It is clear from the Figs 6 and 7 that the unused energy in the generator based system is used in the hydrogen-based system and the fuel is produced at the site of the application thus eliminating the need for fuel transportation.

Such a system can be cost-effective where the transportation of fuel is expensive and difficult. The other advantages of such system are as follows:

- No direct greenhouse gas emissions.
- Higher efficiency of conversion of the fuel cell at partial load.
• Silent operation.

Thus, the hydrogen-based system is environmentally friendly, which is also a very important aspect that should be taken into consideration in the present course of time. In a recent paper (Ghosh et al. 2003) a comparative study of hydrogen storage and diesel generator in a renewable energy supply system was performed and the critical fuel cost was calculated which would be useful to determine the cost-effective system for a particular site. It was found that at that time (2003) hydrogen storage is not cost-effective compared to a diesel-generator-based system. In the near future however when the target cost of the electrolyser and the fuel cell is achieved, the scope of the hydrogen-based storage system will also increase and it will also be cost competitive with diesel-generator system for remote applications.

Other storage technologies
Other possible storage mechanisms include compressed air, flywheels, superconducting magnets and chemical capacitors. All of these can be shown to be useful for certain end uses, but, in general, the cost per kWh stored is quite high at present.

3. STATE OF THE ART OF HYBRID RE SYSTEMS

3.1. Introduction

More than 1.64 billion people in the world do not have access to electricity, of which approximately 80% live in rural Asia and Africa (GNESD 2004). In Southeast Asia, about 38% of the total population does not have access to electricity. The electrification level in rural areas in South East Asia is about 51%, compared to 90% in urban areas (IEA 2002) and (Shrestha et al. 2004). In some rural areas, supply of electricity is using diesel generators. Though diesel systems have their distinct advantages of electricity generation, their operational and maintenance costs are high, especially at low loads (Nayar et al. 1993, Protogeropoulos et al. 1997, Elhadidy 2002), and storage and transportation of fuel to remote location is difficult. These systems are noisy and so not conducive for residential uses. There is also the problem of oil leakage into the streams in neighboring areas.

Application of renewable energy technologies (RETs) for rural electrification is increasing in recent years, but is not very widespread (Phuangpornpitak and Kumar 2006). As an option for providing power, solar photovoltaic (PV) is gaining popularity, though its high initial cost is a major barrier for its widespread use. A photovoltaic system costs about 4000$/kW, while the cost of conventional power system such as oil, gas and coal is approximately four times lower (Hansen 1998). Thus, though PV is little far from being economic in comparison with conventional fossil fuel to provide electricity and (Infield 1994), they are used in remote areas where it is uneconomical to extend the electric grid (Hansen 1998) and (Wichert 1997). However, the market for PV is also expanding rapidly due to reduced cost of PV systems during the last decade. At the same time, a PV system alone may not easily satisfy loads on 24-h basis as the variation of solar electricity generation does not always match with the time distribution of load demand (Nayar et al. 1993), (Hansen 1998) and (Dufo-Lopez and Bernal-Agustin 2005).

The use of stand-alone wind electricity generation systems is limited in rural areas as wind resource is site dependent and depends on the season. Thus, stand alone PV or wind energy systems do not produce usable energy for a considerable portion of time during the year. PV-based hybrid system (using wind and/or diesel generator) is an option to address this barrier and supply electricity to rural areas that is far from the grid (Elhadidy 2002), (Protogeropoulos et al. 1997), (Fortunato et al. 1997), (Raja and Abro 1994), (Lipman 1994), (Lundsager and Bindner 1994) and (Woodell and Schupp 1996). PV and diesel generator have complimentary characteristics. The initial cost of PV system is high compared to diesel generator, though the maintenance requirements of PV are less. However, diesel generator can provide energy at any time, whereas energy from PV is greatly dependent on the availability of solar radiation, (Wichert
A hybrid powered mini-grid system can be generally defined as an electricity production and distribution system which supply consists of a combination of two or more types of electricity generating sources (e.g. solar photovoltaic panels, wind turbine generators, pico hydroplants, fuel gensets). Hybrid systems usually also include an energy storage.

One of the most promising applications of renewable energy technology in remote areas is the implementation of hybrid energy systems, where the cost of grid extension is prohibitive and the price for fuel increases drastically with the remoteness of the location (Wichert 1997). Numerous hybrid energy systems have been installed in many countries over the last three decades, resulting in the development of systems that can compete with conventional, fossil fuel based remote area power supplies in many applications. Hybrid energy systems are now becoming an integral part of the energy planning process to supply previously unelectrified remote areas and island communities with electricity in countries like India (White 1996), Thailand (Kruangpradit et al. 1996), Spain (Valle and Serrasolses 1994), Greece (Manolakos et al. 2004), Italy (Scrivani 2005), South Africa (Cowan 1994), or Australia (Hopkins 1992, Williams 1994).

An expanding renewable energy industry has developed reliable and cost-competitive systems for remote area power generation. Research has focused on the performance analysis of demonstration systems and the development of efficient power converters, such as bi-directional inverters, “string inverters”, battery management units, management and control units (Jordan et al. 1994), (Butler 1994) and (Nayar et al. 1993). Simulation software is available, which allow the optimum design and sizing of hybrid systems based on a life-cycle cost optimization, Rapsim2 (Cheok and Ash 1997), Hybrid2 (Baring 1996), Pvfom (Menicucci and Fernandez 1989), SOMES (Van Dijk and Alsema 1992), HOMER (www.nrel.gov/homer/default.asp), TRNSYS (www.trnsys.com), RETSCREEN (http://www.retscreen.net).

A major problem of hybrid systems is the energy storage. Batteries operating under high ambient temperatures usually need to be replaced often and this way they introduce a high maintenance system cost, along with a high environmental cost due to their toxic nature. On the other hand hydrogen seems to be the energy carrier of the future. Much research is taking place covering all aspects of hydrogen subsystems, from electrolysers and fuel cells, to metal hydride tanks and purification systems.

The current state of hybrid system technology is the result of activities in a number of research areas, such as:

- Advances in electrical power conversion through the availability of new power electronics which have led to improved efficiency, system quality and reliability
- Development of versatile hybrid energy system simulation software
- Continuing advances in the manufacturing process and efficiency of photovoltaics and wind turbines
- The development of improved system components such as bi-directional converters
- Advanced modularly expandable hybrid supply with AC-coupled components
- Development of improved, deep-cycle, lead acid batteries
- Availability of more efficient and reliable AC and DC appliances, which can recover their additional cost over their extended operational lifetime

### 3.2. Hybrid energy system configurations

Hybrid systems can be classified according to their configuration as

(a) Series hybrid energy systems
(b) Switched hybrid energy systems
(c) Parallel hybrid energy systems
In the case of series hybrid systems (a), see Fig. 8, all the electricity is passed through the battery and the AC power delivered to the load is converted from DC to regulated AC by an inverter or a motor generator. The system can be operated in manual or automatic mode, with the addition of an appropriate battery voltage sensing and start/stop control of the engine driven generator. This type of system configuration remains one of the most common installations today.

**Advantages**
- No switching of AC power between the different energy sources is required which simplifies the output interface
- The power supplied to the load is not interrupted when the diesel generator is started
- The engine-driven generator can be sized to be optimally loaded while charging the battery bank, until a battery state-of-charge of 75-85% is reached.

**Disadvantages**
- The inverter cannot operate in parallel with the engine-driven generator, therefore, the inverter must be sized to supply the peak load of the system
- The battery is cycled frequently, which shortens its lifetime
- The cycling profile requires a large battery to reduce the depth-of-discharge
- Reduced overall efficiency since all energy flows through the battery and the inverter
- Inverter failure results in complete loss of power to the load

The switched configuration shown in Fig. 9 remains one of the most common installations today (Kremer et al. 2000) and (Taylor et al. 2001). It allows operation with either the engine-driven alternator or the inverter as the AC source, yet no parallel operation of the main generation sources is possible. The battery can be charged by the diesel generator and the renewable energy source. The load can be supplied directly by the engine-driven generator, which results in reduced cycling of the battery. It can be operated in manual mode, although the increased complexity of the system makes it highly desirable to include an automatic controller, which can be implemented with the addition of appropriate battery voltage sensing and start/stop control of the engine-driven alternator.
Advantages
- Both energy sources can power the load directly

Disadvantages
- Power to the load is interrupted momentarily when the AC power sources are transferred
- The engine-driven alternator and inverter have to be designed to cope with the peak load
- No optimised allocation of fuel-based and renewable resources is possible

In Fig. 10 is shown a typical hybrid village power system of the switched type that includes PV, wind turbine and generator. The system can satisfy both DC and AC loads.
Figure 10. Typical hybrid system of switched type that includes PV, wind turbine and generator (Taylor 2001)

The parallel configuration (c) shown in Fig. 11 allows all energy sources to supply the load separately at low or medium load demand, as well as supplying peak loads from combined sources by synchronising the inverter with the alternator output waveform. The bi-directional inverter(s) can charge the battery (rectifier) when excess energy is available from the engine-driven generator, as well as act as DC-AC converter (inverter) under normal operation. These systems require highly sophisticated control systems.

Figure 11. Parallel PV-diesel hybrid system
The parallel configuration offers a number of advantages over other system topologies (Nayar et al. 1993):

*Advantages*
- The system load can be met in an optimal way
- Diesel efficiency can be maximised
- Diesel maintenance can be minimised
- A reduction in the rated capacities of the diesel generator, battery bank, inverter, and renewable resources is feasible, while also meeting the peak loads
- In case other renewable sources are present (such as wind) the diesel generator could be eliminated

The above objectives can only be met if the interactive operation of the individual components is controlled by an intelligent energy management system. The parallel configuration offers the opportunities of achieving cost reductions and improved reliability, standardisation at the component level which is now considered to be a more satisfactory solution than standardisation at the level of the system. The implementation of the parallel configuration will promote the series production of subsystem units for use as flexible system components (Kleinkauf, Sachau 1994).

All the above configurations (a) to (c) own advantages and disadvantages and every configuration suits to different conditions and requirements of the certain application. Configuration (a) goes well with low power applications while configuration (b) suits better to village grid electrification.

3.3. The modular hybrid system concept

3.3.1. Fundamentals of modular supply plants

The modular hybrid power supply concept described in (Kleinkauf, Sachau 1994), proposes the coupling of all generators, storage media and loads on the AC-side which come out with numerous advantages, as for example: simplicity in system design, expandability and security of power. Moreover, the AC-side structure provides standardization, quality assurance and serial production which also results in a considerable potential of cost reduction.

Decentralized power generation plants can be integrated into the supply structure in different ways according to the design criteria. Implementing the suitable engineering concepts is indispensable to guarantee cost-effective design and to ensure the expandability and compatibility of power supply units.

The components of such modular supply systems are developed using the most innovative technologies for energy storage, power conditioning and communication. The components are combined into supply systems which fulfill the expandability, compatibility and flexibility requirements. The advantages of modularization of power supply units appear mainly in the kW range (e.g. the development of autonomous supply stations and isolated grids up to weak interconnected grids) and can be extended up to the MW power scale (Kleinkauf et al. 2003).

Despite new possibilities and increasing flexibility in power conditioning via power electronics the conventional sinusoidal single- or three-phase alternating current (AC) of almost constant amplitude and frequency is not changed. The sinusoidal AC standards have many positive characteristics (Kleinkauf et al. 2000) such as: easiness in transformation with different voltage levels, electro-dynamically non-distracted curve-form, and symmetrical three-phase alternating voltage of a temporally constant power flow. These features make them suitable for energy transformation for medium and high powers, as well as for the supply of rotating machines. Hence the conventional AC standards are adopted by renewable modular hybrid systems. Based on the power to be transferred and the distance, different voltage levels are used. DC systems, however, are only used for power supply on very low power levels or for the transfer of extremely high power (in the GW range).
3.3.2. AC-compatible supply structures

Hybrid systems fed with renewable energies have a complex structure due to their multiple converters and because of the fluctuation in the raw resources (e.g. solar irradiation and wind speed). In order to combine them into island grids or connect them to utility grids, the electrical characteristics of the generators and storage have to be considered. Accordingly, the component functions in the modular hybrid system technology are divided into three main categories: grid-forming, grid-supporting and grid-feeding units (Engler et al. 1997). This classification makes the whole supply system able to integrate units which deliver controllable and non-controllable active and reactive power and guarantee a balanced and flexible grid. An important aspect for island supply systems is how easily they can be expanded by additional generators and/or connected to other grids. That can be achieved by applying reactive and active power for voltage and frequency control respectively, similarly to the primary control of utility grids. Moreover, special control algorithms for parallel operation of components have to be implemented.

![Diagram of modularly expandable hybrid supply with AC-coupled components](image_url)

**Figure 12. Modularly expandable hybrid supply with AC-coupled components**

The systems' construction technique decisively influences the flexibility, functioning, quality and economic performance of stand-alone hybrid plants. The configuration shown in Fig. 12, should cope with different problems and varied requirements of the electrification. It should be

- generally adapted to satisfy diverse load-specific requirements,
- modularly expanded as a single or three-phase PV-hybrid system to cover increasing energy and power needs and
- easily connected to a conventional grid, if available.

The whole executive control level of the plant is implemented in a decentralized way and only superimposed tasks have to be co-ordinated centrally. The control which is integrated in the power units covers the specific functions of supervision, control and monitoring, like grid-formation, MPP tracking and battery charge control and allows the safe parallel operation of the components.

Based on the standardization of system design, the global market-oriented modularization degree and a small set of expandable inverters, the modular technology enable integral solutions, thus paving the way for establishing industrial series production.
3.4. Hybrid systems comprising fuel cell subsystems

In this type of hybrid system, the genset may be replaced by a fuel cell system. It can be used as a back-up generator and also minimize the size of batteries. Some principle differences between a genset and a fuel cell (FC) affect the design, sizing and the operating strategy of such a hybrid system.

- Unlike a Diesel engine the efficiency of a FC decreases with power output for a given capacity. Consequently, the system performance, but also the initial cost is raised with an increasing FC capacity. According to the load profile, the most feasible FC capacity can be determined, whereas a genset should be operating at rated power as much as possible. In particular, when loading lead acid batteries, the characteristics of a fuel cell match better with the load than those of a genset.

- A genset will provide rated power to the load in a few seconds after start up. A FC-system needs more time to provide rated power and the output should only be increased slowly after start up. The increasing operating temperature which occurs during operation does improve the efficiency of a FC significantly.

- For low power applications in the range of an average load around 100 W or less, DC-systems are most likely. Instead of the rectifier and charge controller required for a typical genset equipped with an induction or synchronous generator, only a charge controller is necessary for the FC operating as a back-up generator. This charge controller must of course be designed adequately in order to allow power control of the FC.

- For applications in the several kW power range, AC systems are necessary. In order to connect a FC to such a system either a customised DC-DC-converter for direct connection with the battery bench or a separate inverter is required. In a PV-Diesel-hybrid system, the genset will form the grid when operating. The battery is then charged directly via a charge controller or through a bi-directional inverter with charge control capabilities. In case of the FC as back-up generator, a second stand alone inverter is required for the FC or the battery inverter is used for the FC operation.

One significant advantage of a FC as back-up generator over a Diesel or Petrol genset is the high conversion efficiency of the FC. Whereas a 1 kW Petrol genset achieves total efficiencies between 5 % and 10 %, a similar FC-system can achieve up to 50 % efficiency when operated with H₂ and O₂. Even at less favourite conditions, e.g. comparison of a larger Diesel genset (e.g. 50 kW) with an equivalent FC-system supplied by a fossil fuel that needs to be processed before utilised in the stack, the performance of the FC exceeds the genset performance by 10 to 15 %.

Another advantage of a FC-system is expected to come up in the future, when mass production and technical improvements lead to lower investment cost and expanded life time. Due to much lower maintenance cost, FCs are expected to generate electricity at lower cost than conventional gensets even at higher initial investment cost. Assuming state of the art FC technology manufactured in industrial series production and achieving lifetimes in the range of several ten thousand hours, the electricity cost could fall below 50 c€/kWh, which is significantly lower than the electricity cost of state-of the art gensets.

Except the use of hydrogen, the available fuels for remote FC systems are depending on the type of cell used. Liquid anhydrous Ammonia is a very good storage medium for hydrogen. For AFCs Ammonia can be used after cracking into hydrogen and nitrogen. Since AFCs are insensitive to small amounts of NH₃ they allow for an efficient cracking process.

Hydrogen production by reforming of alcohol such as methanol or hydrocarbons leads to higher CO₂ concentrations as can be handled by AFCs. These fuels are easier to use in e.g. PEM FCs. Liquid hydrogen as a clean fuel is recommended only for remote sites or applications with particular environmental conditions. A general disadvantage is that the energy necessary for the liquefaction reduces the overall system efficiency.
The PV/electrolyser/FC system and hybrid system typologies

For the power supply of remote applications photovoltaic energy conversion has become a very important energy source. In order to achieve very small loss of load probabilities with a PV generator, the system must be designed for the worst case of climate and load condition, which can occur. Consequently, only a small proportion of the theoretical electricity production of the PV generator is actually used in the system. For sites with a strong seasonal variation of climatic conditions and for a load profile which is not ‘in phase’ with the production, the ratio between the amount of energy utilised in the system compared to the maximum amount of electricity that could be produced like in case of a grid connected PV-generator can be as low as 10%.

In addition, there is only one generator to provide electricity. In case of a malfunction, there is no emergency or back-up generator available. For many applications, a loss of load is not acceptable. In remote power applications, it is obviously very attractive to realise seasonal energy storage and to install a 2nd source of energy, as it is the case for the proposed hybrid system. Excess energy is stored in the form of compressed hydrogen via conversion through the electrolyser (EL). The FC is used to produce electricity if the load exceeds the electricity production from the PV generator. It can also function as an emergency generator, if the PV system fails.

Assuming a total efficiency of the storage system in the range of 50% and a suitable storage volume, the PV generator capacity can be reduced significantly. This compensates partially the extra cost for the hydrogen system (EL, storage, FC). Based on the site specific climate, the load profile and the component characteristics the installed capacities of the components and the storage volume can be optimised e.g. by means of simulation.

In the past, a number of hybrid systems have been realised using hydrogen for seasonal energy storage. Different system typologies have been used to connect the components electrically. Most common is the DC-connection of PV generator, EL and FC with or even without DC-DC-conversion. A typical system layout is shown in the following Fig. 13. Technically it is possible to store not only the hydrogen but also the oxygen. Due to safety problems and extra cost, the oxygen is normally vented and the FC is operated with air.

Assuming a total efficiency of the storage system in the range of 50% and a suitable storage volume, the PV generator capacity can be reduced significantly. This compensates partially the extra cost for the hydrogen system (EL, storage, FC). Based on the site specific climate, the load profile and the component characteristics the installed capacities of the components and the storage volume can be optimised e.g. by means of simulation.

In general, the advantages of the AC supply emerge as the required power increases. Power conditioning, transmission and consumer device technologies are technically and economically more effective. Standard motors, static inverters and transformers of high efficiency are widely available. In principle, single phase AC technology can be applied for supplying single consumers covering power ranges from a few 100 W up to around 10kW. A typical configuration for an AC system is shown in Fig. 14.

Recent developments allow coupling all components of a PV hybrid system on the AC-side in a standardised way, as shown in Fig. 14. This way adding or taking away of single components becomes possible without any change in the overall plant control resulting in a modular system for general applications.
Within the last seven years many efforts have been made in the development of low temperature fuel cells (Jossen et al. 2004). As a result fuel cells are now available as prototypes and first production models appear on the market. The most popular low temperature fuel cell is the proton-exchange membrane fuel cell (PEMFC) and this paper will concentrate on this fuel cell type. The PEMFC has not only advantages in comparison with batteries, but also some disadvantages, as lower efficiency in case of very low power, start-up delay, and up to now comparable high costs and low lifetime. Hybrid systems, based on a PEMFC and a lead–acid battery can combine the advantages of both technologies and avoid the disadvantages. Table 1 shows the advantages and disadvantages of batteries and fuel cells (IEA 2004). The table shows that both systems complement one another.

Table 1: Comparison between fuel cell and battery

<table>
<thead>
<tr>
<th>Energy content</th>
<th>Defined by the storage unit</th>
<th>Specific energy: 25–200 Wh kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power capability</td>
<td>Defined by the fuel cell stack</td>
<td>Coupled with the battery size</td>
</tr>
<tr>
<td>Efficiency &lt;10% rated load</td>
<td>Worse (caused by periphery)</td>
<td>Discharge within a few minutes possible</td>
</tr>
<tr>
<td>Efficiency 50% rated load</td>
<td>Medium</td>
<td>Approx: 1–10% per month</td>
</tr>
<tr>
<td>Efficiency Rated load</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Start-up characteristic</td>
<td>At RT about 50% of rated power</td>
<td>Immediately full power possible</td>
</tr>
<tr>
<td>Electrical rechargeable</td>
<td>Not possible (only in combination with an electrolyzer)</td>
<td>Possible</td>
</tr>
<tr>
<td>Charge time</td>
<td>Fuel refill/exchange is very fast</td>
<td>Charge time: 15 min–10 h</td>
</tr>
<tr>
<td>System technology</td>
<td>Complex</td>
<td>Simple</td>
</tr>
<tr>
<td>Costs</td>
<td>Up to very expensive, in general</td>
<td>In comparison to fuel cells low costs</td>
</tr>
<tr>
<td></td>
<td>Power is expensive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Periphery is expensive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy is less expensive</td>
<td></td>
</tr>
</tbody>
</table>

4. SYSTEMS CONCEPTS AND CASE STUDIES

4.1. Simulation, design and optimization tools for hybrid systems

There are some many programs available that simulate renewable energy systems both freely and commercially available. Among them some have the ability to simulate hybrid systems; the most
popular of which are: HYBRID2, developed by the NREL (National Renewable Energy Laboratory, USA), TRNSYS originally developed by the University of Wisconsin (USA), HOMER (Hybrid Optimisation Model for Electric renewables), developed by NREL, and RETScreen. Some other software packages are also mentioned such as SOMES, RAPSIM2 and HOGA.

**SOMES v.3.2**
SOMES, or Simulation and Optimisation Model for renewable Energy Systems, was developed in the Department of Science, Technology and Society at Utrecht University in the Netherlands. Its development began in 1986, ver. 3.0 was published as package in 1993 and ver. 3.2 became available in 1996 (Van Dijk 1996). SOMES can simulate both battery and grid-connected energy systems incorporating PV, wind and diesel generators. It has models for inverters, different control strategies and economic analysis functions. Performance is determined using an hour-by-hour simulation.

**HYBRID2**
The Hybrid2 code can model many combinations of wind turbines, photovoltaic arrays, diesel generators, power converters, and battery storage in AC, DC, or two-bus systems. Hybrid2 also allows for more than 100 different dispatch configurations with multiple diesel generators, renewable sources, a synchronous condenser, and battery storage. The model has an easy-to-use graphical interface, an in-depth library to facilitate system design, and a detailed glossary of frequently used terms to assist users who are not familiar with hybrid power system terminology. The software also includes an energy audit tool to assist in determining the load for an unelectrified community as well as a method to enter such data into the model.

Time-series data for wind, solar insulation, and temperature can be entered into the software and a data processor is available to fill holes that may occur in the data. The code also includes a comprehensive economics package that incorporates system operation and maintenance costs, equipment overhaul costs, installation costs, taxes, and the system salvage value. Outputs include, where applicable, useful wind and solar energy, diesel energy, diesel operating hours and start/stops, diesel fuel use, storage system energy losses, and battery life. Economic module outputs include, but are not limited to, life-cycle costing, project cash flow, and investment payback. To ensure code accuracy, Hybrid2 software has been compared to a number of operational hybrid power systems and has been tested independently.

**RAPSIM2**
RAPSIM2 (Remote Area Power SIMulator) was developed by Murdoch University Energy Research Institute (MUERI) Australia. It was originally produced to evaluate diesel/battery systems, but it contains also renewable energy components, such as PV and wind generators. It also incorporates other RAPS components and can simulate systems using different control strategies. It performs life-cycle costing. Version 2.0 was released in 1997 (Mueri 1997)

**TRNSYS**
TRNSYS was initially developed to simulate thermal systems but it has incorporated PV systems to simulate hybrid systems such as those proposed here, however it cannot optimize them. Since the original release many others have contributed to the TRNSYS software and the most recent release is the 16th version. TRNSYS can be used to simulate and design hybrid systems (Program manual, University of Wisconsin– Madison, 2000). TRNSYS has a modular structure; it recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS library includes many of the components commonly found in electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. The modular nature of TRNSYS gives the program tremendous flexibility, and facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. TRNSYS is well suited to detailed analyses of any system whose behavior is dependent on the passage of time.
HOMER
The National Renewable Energy Laboratory (NREL) has developed HOMER, an optimization model that considers hourly and seasonal variations in loads and resources, simple performance characterizations for each component, equipment costs, reliability requirements, and other site-specific information. HOMER ranks the configurations by life-cycle cost and can automatically perform sensitivity analyses on any subset of its inputs. It is intended for prefeasibility analysis when the interest spans a broad range of inputs, either because the input data is uncertain or because the analysis covers a large area with differing conditions. In addition to performing optimized configurations, HOMER provides hourly energy flows through each component, the impact of several simple load management strategies, and economic information such as the cost of energy and net cost of the system.

NREL researchers have used HOMER in several analyses for the Philippines, Indonesia, China, Russia, Argentina, Chile, Brazil, Mexico, South Africa, and for market analyses for domestic renewable energy suppliers and technology developers. It also has been used for market assessment and screening to initialize detailed site-specific Hybrid2 analyses. HOMER is intended for use by renewable energy or rural electrification professionals. If hourly load data is not available, it can be synthesized using typical days for each month, with a user-specified level of additional variability. Hourly solar and wind resource data can also be synthesized from monthly averages if measured hourly data is not available. A grid extension module has been added, allowing a cost comparison between stand-alone hybrid power systems and the traditional extension of the electrical grid. The output capabilities of HOMER are significant. Any of the annual outputs (including the optimal system type) can be plotted versus one or two sensitivity variables. HOMER reports both optimal and near-optimal solutions. Sample files have been created that compile the results of more than a million annual simulations into a sensitivity analysis that shows the optimal design over a wide range of load, resource, and economic parameters.

In Fig. 15 are shown several hybrid system configurations that can be simulated and optimized by HOMER (Lambert et al. 2006).
Figure 15. Schematic diagrams of some micropower system types that HOMER models: (a) a diesel system serving an ac electric load; (b) a PV–battery system serving a dc electric load; (c) a hybrid hydro–wind–diesel system with battery backup and an ac–dc converter; (d) a wind–diesel system serving electric and thermal loads with two generators, a battery bank, a boiler, and a dump load that helps supply the thermal load by passing excess wind turbine power through a resistive heater; (e) a PV–hydrogen system in which an electrolyser converts excess PV power into hydrogen, which a hydrogen tank stores for use in a fuel cell during times of insufficient PV power; (f) a wind-powered system using both batteries and hydrogen for backup, where the hydrogen fuels an internal combustion engine generator; (g) a grid-connected PV system; (h) a grid-connected combined heat and power (CHP) system in which a microturbine produces both electricity and heat; (i) a grid-connected CHP system in which a fuel cell provides electricity and heat.

**RETScreen**

**RETScreen® International** is a standardised and integrated renewable energy project analysis software. This tool provides a common platform for both decision-support and capacity-building purposes. RETScreen can be used worldwide to evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for various renewable energy technologies (RETs). RETScreen is made available free-of-charge by the Government of Canada through Natural Resources Canada’s CANMET Energy Diversification Research Laboratory (CEDRL). The user is encouraged to properly register at the RETScreen website so that CEDRL can report on the global use of RETScreen.

RETScreen can be used worldwide to easily evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various RETs.

**HOGA**

HOGA is another software program that optimises hybrid PV-Diesel systems using Genetic Algorithms. The program calculates the optimal configuration of the system. This optimal configuration is described very precisely: the number of PV panels and the type of PV panels, the

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4 [http://retscreen.gc.ca](http://retscreen.gc.ca) or [http://www.retscreen.net](http://www.retscreen.net)
number of batteries and the type of battery, the inverter power, the Diesel generator power, the optimal control strategy of the system with its parameters, the Total Net Present Value 1 of the system and the different relative costs such as the fuel cost, and finally, the number of running hours for the Diesel generator per year. The program also optimises the dispatch strategy, as does HOMER, but it also optimizes the state-of-charge (SOC) set point, that is an important variable (Lopez, Agustin 2005).

4.2. Presentation of hybrid systems concepts and case studies

4.2.1 Introduction

During the recent years several large-scale grid extension programs have been realized in rural areas in the North African and other Mediterranean countries. However, the majority of remote rural regions, are characterized by, scattered villages, population of less than 100 households per village and small energy demands (lighting and some basic utilities, generally a TV and a radio). Therefore it is economically not feasible to extend the grid to such dispersed areas. Renewable energy systems provide an adequate alternative solution since they may be easily adapted to such boundary conditions. Furthermore, these regions are known for their abundant solar radiation which makes these regions very attractive for decentralized PV energy generation and use. Hybrid renewable energy-based mini-grids (PV and wind) are very suitable for these regions will contribute to infrastructure development and provide a locomotive for sustainable development.

4.2.2 PV-diesel

4.2.2.1 Stand-alone PV/diesel installation for electrification of a tourist resort, Greece.

The electrification of a bungalow complex in the tourist resort at Elounda, Crete, was examined by Bakosa and Soursos (2002). The ecological character of this tourist facility is due to the replacement of the old diesel engines by a stand-alone PV system to cover the electrical demand. From the technical point-of-view, an optimal PV system design is feasible as the peak demand in the tourist period in Greece coincides with the maximum solar-insolation period.

The stand-alone PV system at Elounda is presented in Fig. 16. The photovoltaic station consists of 112 monocristalline panels rated 57 Wp each, giving 6.4 kW total nominal power. The system was designed for an extended summer operation and the PV modules are inclined to 30° angle. The DC bus of the system is 48 V and the 220 V AC side is divided into two parts, each supported by a single-phase inverter. The inverters are rated at 5 and 6 kVA and they were manufactured in Greece. Two inverters were installed in order to share the high start-up inductive loads and to increase system reliability. Additionally, in the case of malfunction of one inverter, the second can support all the electrical load of the tourist facility. Two battery banks are connected in parallel. The 2 V battery cells are lead-acid, vented, tubular type and have 680 Ah nominal capacity. The total storage capacity is 65.3 kWh. Maintenance of the battery cells is limited to only periodical electrolyte density measurement and water-level check.
The electrical loads include indoor and outdoor lighting, eleven small refrigerators (one for each bungalow), three professional middle-size refrigerators, one professional freezer, one water-pressure pump, one microwave oven, one waste-water treatment unit, indoor and outdoor insect repellent devices and other ordinary household electrical appliances, e.g. TV sets, hair dryers, etc.

The daily electrical demand in a typical summer day of each device is shown in the above table.

The maximum daily energy requirement in July and August is around 40 kWh, averaging at 35 kWh over the extended summer tourist-period. The summer daily-load could be lessened by more than 10%, i.e. 4 kWh, if the existing incandescent indoor and outdoor lamps are replaced by fluorescent "energy-saving" lamps. In long overcast winter periods and for extreme load consumption e.g. July and August, one of the old diesel generators is used for battery charging and grid support.

The photovoltaic system at Elounda was the first autonomous PV installation in Greece for the electrification of a tourist resort. It was installed in June 1996 and since then operates satisfactorily. The electrical demand was previously covered by two diesel generators, which consumed approximately 18 tn of light diesel-fuel between May and September in a typical tourist season. The expenses for fuel and regular engine maintenance exceeded 13 kEURO in the 1995 tourist season. The Greek government approved 30% funding for the PV stand-alone system at Elounda, under Law 1892/90 which supports incentives for the realisation of productive investments. The rest (70%) was provided by the bungalow-complex owner.

4.2.2.2 PV/diesel test facility comprising bi-directional inverter, Australia

To quantify the potential for performance improvements of photovoltaic-diesel (PV- diesel) hybrid energy systems, a test facility has been installed at the Centre for Renewable Energy Systems Technology in Australia (Wicherta et al. 2001). The research facility is part of the cooperative program to develop improved power conditioning systems for the provision of electricity in remote areas (ACRE Project 4.1). A customised control interface has been developed using the control and data acquisition software, LabVIEW.
Fig. 17 shows a parallel PV-diesel hybrid energy system using a bi-directional inverter. The power conversion device can charge the battery bank (rectifier) when excess energy is available from the engine-driven generator, as well as act as a DC/AC converter (inverter) under normal operation. A detailed review of different topologies of stand-alone renewable energy systems and their operational characteristics has been presented in (Wichert 1997).

Fig. 18 presents an overview of the developed test facility for PV-diesel hybrid energy systems. The individual system components and their operational characteristics are outlined in the following paragraph.

The photovoltaic array consists of two series strings of 8 x 80 Wp BP280 monocrystalline PV modules, generating a maximum of 1.28 kWp under peak irradiance. The modules are connected directly to the DC bus, which has a nominal voltage of 110 VDC. A solar controller is integrated with the bidirectional inverter to limit the PV array current when the load demand is low and the batteries are fully charged. For an ideal summer day in Perth, the PV array will generate up to 8 kWh of electrical energy.
The battery bank consists of a series string of 18 x 6 V SunGel 200 gel-type VRLA batteries from Battery Energy. Individual batteries are rated at C120 = 200 Ah and C10 = 125 Ah. Selecting the 10 h rating as representative for the typical operation of batteries in hybrid energy systems, the available storage capacity is given as \( E_{BB} = 13.5 \text{ kWh} \). Assuming a typical minimum state-of-charge (SOC) of 40% and a subsequent recharge of the battery bank to 90% SOC, the useable storage capacity is limited to \( E_{BB} = 6.75 \text{ kWh} \). For the selected load profile, the battery bank provides approximately one day of storage.

The genset is a Honda GD410 (Pmech = 5 kW) diesel engine driving a Sincro 6 kVA alternator. As is typical for small generator sets, the voltage regulation is poor with a variation from 250 VAC under no load to 220 VAC at a full load of 4 kVA electrical power output. The total harmonic distortion of the alternator waveform is within acceptable limits with a THD below 8% over the full operating range. Automatic starting and stopping of the diesel generator is controlled by the AES Static Power Pack inverter, which supervises the start sequence and synchronises the inverter with the generator output waveform before the diesel genset is brought on line.

A controllable load bank (CLB) has been built, which can be switched to provide the required load demand. For the AC loads, resistive heating elements have been used, which can be selected via digital inputs or manual switches. A total electrical power demand of 9.75 kW can be applied to the system, with a resolution of 20 W for the smallest resistive load. Additional AC loads, such as, a refrigerator, incandescent lights, a personal computer or inductive motor loads can be connected for test purposes.

The 5 kVA bi-directional inverter from Advanced Energy Systems converts electrical power from DC to AC, as well as charging the battery bank from the diesel generator, therefore rectifying the diesel AC power to the DC battery charge voltage. Typically, the microcontroller-based inverter control unit implements a fixed setpoint control strategy, which automatically starts the diesel at high load levels or at a low battery SOC. Once started, the diesel generator operates until the battery bank is returned to a high SOC and the load has dropped below a minimum level, implementing a standard diesel dispatch strategy for the autonomous operation of a PV-diesel hybrid energy system. Apart from the operational control of the diesel generator, the important features of the StaticPower Pack inverter can be summarized as:

- Temperature compensated two-step battery charging
- Continuous supervision of system operation, fault indication and fault response
- Automatic control of system power
- Integrated solar controller to prevent overcharging of the battery bank from the photovoltaic array
- Comprehensive data acquisition of system performance and remote monitoring capability

To apply a novel, predictive control strategy to the operation of a PV-diesel hybrid energy system, the graphical control environment, LabVIEW was selected. The software tool facilitates communication between the PC based control environment and the Static Power Pack inverter, both, for the acquisition of system performance data and for sending commands to start and stop the diesel generator. All supervisory control functions are retained as part of the normal operation of the Static Power Pack. The only operational interaction with the test system from LabVIEW is the start/stop control of the diesel generator within the limits of the typical, fixed setpoint control strategy. Weather data is collected using a DataTaker DT50 from Data Electronics, which sends a string of data every 5 min via the RS232 serial interface. Fig. 18 shows the developed graphical user interface, which displays the actual performance of the test system.

4.2.2.3 PV-diesel desalination plant, Italy

In Ginostra a PV-Diesel Hybrid system for the generation of electricity was installed in the winter of 2003–2004 and is operating since February of 2004 (Scrivani 2005). In Table 2 the most important parameters of the system are reported. The PV installed power will be expanded to 125 kWp because of the installation of the desalination system.
The hybrid system is actually divided in two subsystems: the first being composed by the PV panels, the power electronics, the control hardware and the batteries, see Fig. 19. The second subsystem is the diesel generator set (genset). The first subsystem has been installed in a very remote part of the island on the south-eastern flank of the volcano. This choice was dictated by necessity of having a free southern horizon and by the environmental laws protecting the area. The second subsystem had to be separated and placed within the village, in the vicinity of the port.

Table 2. Batteries and power electronics

<table>
<thead>
<tr>
<th>Sub-system</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV panels (installed kWp) (after the expansion)</td>
<td>104 kWp (125 kWp)</td>
</tr>
<tr>
<td>Diesel genset (rated power)</td>
<td>160 kVA</td>
</tr>
<tr>
<td>Inverters-rectifiers (rated power)</td>
<td>3 × 50 kW</td>
</tr>
<tr>
<td>Valve regulated lead acid batteries</td>
<td>1236 kWh (about 3 d demand in the peak summer season)</td>
</tr>
<tr>
<td>(energy stored in the series of 200 cells with C10 = 3090 Ah)</td>
<td></td>
</tr>
</tbody>
</table>

The complete energy storage in Ginostra is a series of 200 cells each of 2 V nominal voltage and 3090 Ah nominal capacity. The batteries are Exide A602/3000, of the lead acid valve-regulated (VRLA) type with gel electrolyte. They mainly differ from the usual lead acid batteries in two aspects. First of all, they don’t need periodical maintenance interventions to restore the water in the electrolyte and, on the other hand, they can reach a much lower SOC when discharging. In fact they can theoretically reach as low as 0% of SOC without hampering their longevity. The initial cost of this kind of lead acid batteries is much higher than the costs of the ones usually used in hybrid systems but this fact is compensated by the much lower operating costs of the systems due to the batteries being virtually maintenance free. The electronic device driving the batteries is a parallel of three 50 kW inverters, developed ad hoc for the Ginostra plant. The third inverter is redundant and guarantees that service is not interrupted in case of failure of one of the other two.

The Energy Management of the power plant is based on the control of the battery level through some setpoints on the voltage of the battery (that is 400 V nominal at full charge). When the lower voltage setpoint (380 V) is reached the diesel generator is started in order to completely recharge the batteries. The diesel intervention threshold corresponds in this case to 15.53% of the SOC assuming a discharge current equal to I10.

In order to prevent overcharging of the batteries in hours of high solar radiation and low electrical demand, and considering the direct DC coupling of PV and batteries, the 104 kWp panels have been divided into three 34 kWp so that the energy coming from the panels can be modulated with the battery state of charge to prevent the battery from overcharging when the SOC is nearly 100%. This modulation is implemented through three electro mechanical switches actuated by the PLC control unit. So there are three operational modes in the system:
• normal mode: when only the PV panels are generating the power that charges the batteries, being the latter who provide the power to the load via the power electronics (Battery voltage between 380 and 420 V),
• mixed mode: when both the PV panels and the diesel generator are recharging the batteries (the charging voltage is 440 V), being again the latter to feed power to the final user (after a level of 390 V is reached),
• emergency mode: the diesel only is feeding the power to the load, this mode can be started only manually and is triggered when a failure on the battery or the inverters is signalled to the control unit.

The desalination system has to fulfill completely the water demand of the inhabitants of the village and to operate as storage for the excess energy produced by the PV panels in the days of low demand in the months spanning from October to May when the population is far smaller than during summer. An estimate of the daily water demand is calculated by applying a quantity of 150 litres per capita to the population data. These calculations lead to a yearly demand of around 6300 m$^3$ with a peak of 50.55 m$^3$ daily demand during July and August. In the worst case of a water shortage, the plant must be able to supply in 24 hours the maximum demand above mentioned multiplied by a caution coefficient that rounds 1.5. In the specific case a plant with nominal output flow of 2.82 m$^3$/h has been selected, the maximum daily production being 67.68 m$^3$/d, the caution factor being 1.34.

For this scale of desalination system a reverse osmosis (RO) type had been selected since it allows output flows of the order of the required one together with a specific energy consumption of around 5 kWh/m$^3$ with an energy recovery system. For the Ginostra plant an ERT system with Pelton turbine has been selected in order to limit the capital cost of the plant (ENEA 2003). The block diagram of the desalination system with the energy recovery turbine is shown in Fig. 20 in a scheme by the manufacturer of hydraulics systems Grundfos.

![Figure 20. Reverse osmosis desalination plant with energy recovery turbine.](image)

An energy management and DSM technique (taking into consideration the loads, the batteries and the water storage) was used during a simulation of the operation of the system, in order to optimise the production of water and thus the exploitation of the PV excess energy.

During summer the electricity and water demand is very high, and the PV produced energy is only sufficient to supply the primary load. The effect of the energy management is the minimization of the water production during these months, when an intensive use of the stored water is made. The diesel hours are consequently much lower since a greater amount of the water is produced in autumn winter and spring, when a large amount of PV excess energy is available. The energy management also maximizes the use of the PV excess energy during the months when the electrical demand is lower. In fact the amount of diesel produced energy during these months is
less than a half smaller when the proposed DSM technique is adopted. Finally, the overall annual use of the genset is lowered by a 20% when the energy management algorithm is working.

4.2.3 PV-Wind

4.2.3.2 Small autonomous hybrid PV/wind for desalination, Greece

The system is installed at the Agricultural University of Athens (Mohamed and Papadakis 2004). The wind-PV system consists of 18 Arco solar (Shell SM50-H) solar modules, with total rated peak power of 846 W and a Whisper 1 kW wind generator. The hybrid configuration gives the system the possibility to operate at night and generally at low solar radiation in winter which as a result lower battery bank which is the most problematic part in the stand alone systems. The technical characteristics of the system components are shown in Table 3 while the system diagram is shown in Fig. 21. The system was designed with TRNSYS software where new subroutines were developed for the reverse osmosis sub-system components.

Table 3: Specifications of the installed hybrid wind PV system

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PV module</strong></td>
<td>Arco solar</td>
<td><strong>Charge controller</strong></td>
<td>Tarom 235</td>
</tr>
<tr>
<td>Peak power</td>
<td>47 W</td>
<td>System voltage</td>
<td>24 V</td>
</tr>
<tr>
<td>Peak power voltage</td>
<td>14.2 V</td>
<td>Nominal load current</td>
<td>35 A</td>
</tr>
<tr>
<td>Open circuit voltage</td>
<td>22 V</td>
<td>Nominal discharge current</td>
<td>35 A</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>3.49 A</td>
<td>Max. current for 10s</td>
<td>45 A</td>
</tr>
<tr>
<td>Normal operating cell</td>
<td>45 °C</td>
<td>Surge current for 0.5s</td>
<td>58 A</td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No of modules in series</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No of modules in parallel</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Battery bank</strong></td>
<td>FIAMM TMHD 425/3</td>
<td><strong>Wind generator</strong></td>
<td>Whisper H-80</td>
</tr>
<tr>
<td>Capacity at C5</td>
<td>315 Ah</td>
<td>Rotor diameter</td>
<td>3 m</td>
</tr>
<tr>
<td>Max. discharge current</td>
<td>63 A</td>
<td>Start up wind speed</td>
<td>3.1 m/s</td>
</tr>
<tr>
<td>Max. charging current</td>
<td>50 A</td>
<td>Peak power</td>
<td>1000 W</td>
</tr>
<tr>
<td>Number of cells in series</td>
<td>12</td>
<td>Voltage</td>
<td>24 V</td>
</tr>
<tr>
<td>No of cells in parallel</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell voltage</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total battery voltage</td>
<td>24 V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The reverse osmosis (RO) unit
The RO unit consists of two 25-40 inch spiral wound sea water Filmtec membranes with total potable water production capacity of 100 l/h at 25 °C. Feed water (NaCl solution of 35000 ppm) is transferred from the mixing tank to the Clark pump which is the energy recovery unit and the substitution of the high pressure pump in the commercially available units, this transfer is done by a rotary vane pump powered by a permanent magnet brushless DC motor of maximum power 510 W which is the only power load of the system (see Table 4).

Table 4: Pump and motor specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Characteristic Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DC motor</strong></td>
<td>Drive systems LV74.9</td>
</tr>
<tr>
<td>Rated power</td>
<td>510 W</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>24 V</td>
</tr>
<tr>
<td>Maximum current</td>
<td>25 A</td>
</tr>
<tr>
<td>Rated RPM</td>
<td>1500</td>
</tr>
<tr>
<td><strong>Rotary vane pump</strong></td>
<td>Fluid-o-tech PO700</td>
</tr>
<tr>
<td>Maximum pressure</td>
<td>16 bar</td>
</tr>
<tr>
<td>Flow rate at 1450 rpm</td>
<td>800 l/h</td>
</tr>
</tbody>
</table>

4.2.4 PV-Wind-Diesel

4.2.4.1 PV/wind/diesel, grid assisted hybrid system for desalination, Libya

GECOL (General Electricity Company of Libya) and a consulting consortium of experts are managing the implementation of an experimental research facility for Sea Water Reverse Osmosis desalination powered from Renewable Energy Sources (SWRO+RES) at Libya’s coast of the Mediterranean Sea, (Sultan et al. 2005). The nominal production of the plant will be 300 m$^3$/d for the supply of a village with potable water. Both wind energy conversion (WEC) and photovoltaic
power generation (PV) will be integrated into a grid connected power supply for a Reverse Osmosis (RO) desalination plant with power recovery by pressure exchange. The facility design is flexible for the integration of Diesel generator and electrochemical storage as power supply alternatives as well as brackish water reverse osmosis (BWRO). The wide range of feasible plant configurations will allow for extension of the scope of research to off-grid stand alone performance analysis of such hybrid systems.

The expected nominal power load for the operation of the RO desalination system is 60 kW (net power after recovery), the solar PV system is designed for 50 kWp, and the WEC for 275 kW nominal output. The WEC configuration aims at more than 80% reduction of the annual grid power consumption. This is predicted to increase the Levelised Water Cost (LWC) by not more than 45% compared to the grid-power-only solution with its very low electricity cost of 0.032 €/kWh.

The coastal village Ras Ejder is located on the border between Libya and Tunisia at 33° North and 11.5° East. The average salinity of sea water here is 42000 ppm TDS. With annual irradiance of 1829 kWh/m² on a flat surface tilted 25° from horizontal to South the site has good solar resources for photovoltaic power generation. With an annual average of 4.4 m/s wind velocity at 10 m height the site is not very advantageous for wind energy conversion to power.

The following basic subsystem sizes were chosen:
- SWRO-desalination system with 2 beach wells and 2 streams for up to 150 m³/day each product water with less than 500 ppm TDS. Water Recovery 35%
- Stationary full load operation during 24 h per day, requiring 60 kW nominal AC power. Energy recovery by pressure exchanger. Total specific power consumption 4.3 kWh/m³.
- PV field for generation of 50 kWp such that one of the RO streams may be operated on clear days during summer for 6 h per day from PV output alone.
- Commercially available WEC for the generation of nominally 275 kW. A special wind turbine design dedicated to rough stand alone situations on islands and remote rural places was selected. The wind turbine type allows lifting and lowering of mast and nacelle with equipment permanently available on site, not requiring a special large capacity crane.

Costs data for the systems analyzed are shown in Table 5.

<table>
<thead>
<tr>
<th>SWRO300</th>
<th>invest (€)</th>
<th>replace (PW) (in 20a life) (€)</th>
<th>out_m_f (€/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Pressure vessels+20 membranes</td>
<td>20,000</td>
<td>24,417</td>
<td>3200</td>
</tr>
<tr>
<td>2 hp pumps+motors</td>
<td>56,806</td>
<td>16,144</td>
<td>2627</td>
</tr>
<tr>
<td>Pre treatment</td>
<td>33,462</td>
<td>9510</td>
<td>1673</td>
</tr>
<tr>
<td>Post treatment</td>
<td>10,613</td>
<td>3016</td>
<td>531</td>
</tr>
<tr>
<td>Feed tank</td>
<td>7949</td>
<td>2259</td>
<td>397</td>
</tr>
<tr>
<td>Product tank</td>
<td>33,965</td>
<td>9653</td>
<td>1698</td>
</tr>
<tr>
<td>2 Beach wells+motors</td>
<td>63,450</td>
<td>18,032</td>
<td>3080</td>
</tr>
<tr>
<td>Feed pump+motor</td>
<td>3417</td>
<td>971</td>
<td>157</td>
</tr>
<tr>
<td>2 Pressure exchanger</td>
<td>17,419</td>
<td>4951</td>
<td>348</td>
</tr>
<tr>
<td>2 Booster pumps+motors</td>
<td>10,418</td>
<td>2961</td>
<td>496</td>
</tr>
<tr>
<td>Brine disposal</td>
<td>4509</td>
<td>128</td>
<td>90</td>
</tr>
<tr>
<td>hp piping+pv-racks</td>
<td>14,698</td>
<td>42</td>
<td>8</td>
</tr>
<tr>
<td>lp piping and headers</td>
<td>3106</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>SWRO total</td>
<td>28,3677</td>
<td>92,102</td>
<td>14,299</td>
</tr>
</tbody>
</table>

The following eight plant configurations (see Table 7) were analyzed, 5 with connection to national grid, 3 for integration with local grid based on Diesel generator.
Table 6. Analysed specification of plant configurations

<table>
<thead>
<tr>
<th>Configurations for connection to National Power Grid (NG)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWRO300_NG</td>
<td>Reference SWRO system for 300 m³/d powered from national grid only</td>
</tr>
<tr>
<td>SWRO300_PV50_NG</td>
<td>Integration of 50 kW\text{peak} PV power generation into power supply from national grid</td>
</tr>
<tr>
<td>SWRO300_PV200_NG</td>
<td>Integration of 200 kW\text{peak} PV power generation into power supply from national grid</td>
</tr>
<tr>
<td>SWRO300_WE275_NG</td>
<td>Integration of nominal 275 kW WEC into power supply from national grid</td>
</tr>
<tr>
<td>SWRO300_WE275_PV50_NG</td>
<td>Integration of nominal 275 kW WEC and 50 kW\text{peak} PV power generation into power supply from national grid</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Configurations for integration with Local Power Grid (LG) based on Diesel Generator Set</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWRO300_DG200_LG150</td>
<td>Reference SWRO system for 300 m³/d powered from 200 kW DieselGenSet supplying up to 150 kW into local grid</td>
</tr>
<tr>
<td>SWRO300_PV50_DG200_LG150</td>
<td>Integration of 50 kW\text{peak} PV power generation into power supply from 200 kW DieselGenSet supplying up to 150 kW into local grid</td>
</tr>
<tr>
<td>SWRO300_WE275_DG200_LG150</td>
<td>Integration of nominal 275 kW WEC power generation into power supply from 200 kW DieselGenSet supplying up to 150 kW into local grid</td>
</tr>
</tbody>
</table>

Integration of photovoltaic power generation from solar energy into the local cogeneration of water and power is shown in Fig. 22.

![Figure 22. Diesel and PV Power for SWRO and Local Grid.](image)

If a wind turbine is integrated with the cogeneration of water and power the inclusion of an ACCU for few minutes of full load capacity is compulsory to protect the Diesel engine from the possible very fast transients of power supply from the WEC into the AC busbar, (see Fig. 23).
The total project cost is calculated as the present value of the project at start, and includes all cost items expected during the assumed plant life. Levelised production cost is separately evaluated for electricity and potable water. In this context the power generation is seen as a local de-centralized small scale power plant and the Levelised Electricity Cost (LEC) calculation excludes the cost components of the SWRO. The Levelised Water Cost (LWC) includes all cost components of the project. For the eight plant configurations (5 with connection to national grid, 3 for integration with local grid based on Diesel generator) the key results are included in Table 7 for comparison. The following assumptions were made:

- 20 years life of plant
- 6% discount rate
- 0.032 €/kWh electricity price for supply from national grid
- 0.50 €/kg price for Diesel fuel on site (including cost for transport of small quantities)
- 60,000 €/a cost for permanent staff running the 300 m³/d-SWRO-system
- 10,000 €/a cost for permanent staff running the 50 kW-PV-system
- 20,000 €/a cost for permanent staff running the 200 kW-PV-system
- 20,000 €/a cost for permanent staff running the 275 kW-WEC-system
- 20,000 €/a cost for permanent staff running the 200 kW-Diesel Generator

The assumption of the very low electricity consumer price is based on the fact that grid access is already available on the site of the facility. The results are summarized in Table 7.

Table 7  RE Fractions and cost results

<table>
<thead>
<tr>
<th>SWRO300</th>
<th>f' RE (SWRO only)</th>
<th>Invest k€</th>
<th>spec Invest €/(m³/d)</th>
<th>LEC_hybrid €/kWh</th>
<th>LEC_lw €/kWh</th>
<th>LWC €/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWRO300_NG (reference NG)</td>
<td>0%</td>
<td>449</td>
<td>1494</td>
<td>0.06</td>
<td>n/a</td>
<td>1.41</td>
</tr>
<tr>
<td>SWRO300_PV50_NG</td>
<td>13%</td>
<td>799</td>
<td>2662</td>
<td>0.16</td>
<td>0.81</td>
<td>1.89</td>
</tr>
<tr>
<td>SWRO300_PV200_NG</td>
<td>42%</td>
<td>1582</td>
<td>5269</td>
<td>0.25</td>
<td>0.74</td>
<td>2.76</td>
</tr>
<tr>
<td>SWRO300_WE275_NG</td>
<td>87%</td>
<td>1000</td>
<td>3330</td>
<td>0.20</td>
<td>0.21</td>
<td>2.04</td>
</tr>
<tr>
<td>SWRO300_WE275_PV50_NG</td>
<td>93%</td>
<td>1351</td>
<td>4499</td>
<td>0.28</td>
<td>0.29</td>
<td>2.43</td>
</tr>
<tr>
<td>SWRO300_WE275_PV200_NG</td>
<td>12%</td>
<td>507</td>
<td>1688</td>
<td>0.19</td>
<td>n/a</td>
<td>2.06</td>
</tr>
<tr>
<td>SWRO300_WE275_PV150_NG</td>
<td>87%</td>
<td>1154</td>
<td>3843</td>
<td>0.25</td>
<td>0.26</td>
<td>2.31</td>
</tr>
</tbody>
</table>

4.2.4.2 PV/wind/diesel off-grid system for a residence, Greece

Conergy has installed at Grammatiko village (near Athens) a hybrid system to supply electricity to a private residential building for lighting, water pumping, water treatment, and refrigeration. The installation was completed in spring 2006 and consists of PV generator of 12 kWp, small wind turbine (Inventus 6) of nominal power of 6 kW (3-phase 400 V), a diesel generator of 60 kVA and a battery bank of 2400 Ah at 240 V.
4.2.5 PV-Thermal

4.2.5.1 Hybrid PV/Thermal Solar Systems

Most of the absorbed solar radiation by solar cells is not converted to electricity and increases their temperature, reducing their electrical efficiency. The PV temperature can be lowered by heat extraction with a proper natural or forced fluid circulation. An interesting alternative to plain PV modules is to use hybrid PV/Thermal (PV/T) systems, which consist of PV modules coupled to heat extraction devices, providing electricity and heat simultaneously (Tripanagnostopoulos et al. 2002). PV cooling has been applied to residential buildings. The total energy output (electrical plus...
thermal) of the hybrid PV/T systems depends on the solar energy input, the ambient temperature, the wind speed, the operating temperature of the system parts and the heat extraction mode. The electrical output is of priority and the operating conditions of the system thermal unit must be adapted accordingly.

Hybrid PV/Thermal solar systems were experimentally studied in outdoor conditions regarding their thermal and electrical performance. Design principles of PV/T systems and the constructed models were described. Water was used and air to extract heat from the PV module rear surface and to keep the electrical efficiency of it at a satisfactory level by the reduction of its operating temperature.

The results from the steady state tests of all models of the studied hybrid PV/T systems show the following:

1. Heat extraction by water circulation through the used heat exchanger is more efficient than that of the simple mode of air circulation, especially during summer when water temperature from mains is lower than ambient air temperature.
2. Higher value of electrical efficiency is achieved by hybrid PV/T systems for higher value of thermal efficiency.
3. The PV/T systems with additional glazing give higher values of thermal efficiency up to about 30%, but the increase of optical losses reduces by about 16% their electrical efficiency to that of the basic PV/T systems.
4. The addition of a glazing in PV/T systems could be considered effective in case of using these systems with priority in thermal output.
5. The use of booster diffuse reflector increases both electrical and thermal PV/T system output.
6. The PV/T systems with the booster diffuse reflectors operating with concentration factor C51.35 can achieve electrical output increase by about 16% to the basic PV/T systems, giving also a remarkable thermal output.
7. The use of both additional glazing and booster diffuse reflector in PV/T systems results to a significant increase of thermal output by 45% and almost 100% compared to that of the corresponding basic PV/T systems using water and air, respectively.
8. The negative effect of PV electrical efficiency drop by the additional glazing is balanced by the positive effect of the additional solar input from the diffuse reflector, keeping the electrical efficiency of these systems at a satisfactory level.
9. Booster diffuse reflectors of aluminium sheet can increase the incoming solar radiation on PV module plane up to 50%, resulting to an electrical output increase 25 to 35% for PV operating temperature 40 to 70°C, correspondingly.
10. The use of the booster diffuse reflector is limited in the forming angle between it and the PV module plane, with angle of about 90° being more effective in the achieved concentration and smooth distribution of the additional solar radiation on PV module plane.

It was also estimated that the combined PV/T systems give better annual benefits, considering their higher performance from spring to fall.

The results also showed that PV/T systems of the basic type, like the used experimental models PV/WATER and PV/AIR, present a low increase in electrical efficiency but a high rise in their total efficiency, because of the simultaneous operation of these systems as thermal collectors. Considering cost per energy gain, the additional thermal unit of PV/T systems is more expensive than the achieved increase in electrical efficiency by PV cooling and only thermal output is the main gain in simple type PV/T systems. The study suggested the use of booster diffuse reflectors in PV/T system installations, which can increase significantly the thermal and the electrical output, overcoming the additional cost of reflectors. Therefore, the application of low cost booster diffuse reflectors, mainly in horizontal installations, can be considered a promising improvement for the achievement of cost effective hybrid PV/T systems, aiming to their commercial fabrication and practical use in buildings for water preheating and space heating, in swimming pools for water heating and also for use in industry.
4.2.6 PV/hydropower, with hydro storage, Greece

The following case study (Manolakos et al. 2004) regards the implementation of a stand-alone photovoltaic system in which battery storage is partially replaced by a micro-hydraulic system. The system was installed on Donoussa island in the Aegean Sea, Greece to cover basic electricity needs of the remote village of Merssini (13 houses). Lighting, TV set and refrigerator were considered basic electricity needs for each house. The photovoltaic array consisted of 300 photovoltaic modules of 60 Wp each, for a combined 18 kWp total installed power.

The micro-hydraulic subsystem consisted of a water pump of 6 kVA and a water turbine coupled with a DC generator of 7.5 kW and two identical water reservoirs of 150 m³ capacity each. During the day, the load is satisfied directly from the photovoltaic generator through an inverter (UPS unit of 25 kVA, 380 V-3 phases alternative current), while any energy surplus is directed to the pump for pumping water from the low level reservoir (at about 100 m altitude from sea level), to the high level reservoir (at about 200 m altitude from sea level). During the night, water is passed through the turbine to the low level reservoir providing energy to the load. There is also a battery bank of 186 cells of 2 V nominal voltage in series, with a total capacity of 100 Ah. The batteries cover primarily load peaks.

Fig. 25 illustrates the flow diagram of the hybrid PV installation.

![Figure 25. Schematic diagram of the PV-Hydro system installed at Donoussa island](image)

In the following the most important conclusions are given. The installed stand-alone plant at Donoussa island had the PV field as the sole energy source. The micro-hydraulic subsystem was used for energy storage. The intermittent nature of solar radiation does not guarantee the uninterrupted power supply. Thus, in long periods of cloudy weather conditions, especially in winter season, the system could be led to energy deficit state restricting the system reliability. The use of a micro-hydraulic system as a part of the storage system has advantages and disadvantages.

The following are included in the advantages:
1. No standby losses.
2. Reliability in power production, simple construction and low maintenance cost.
3. Except the use of the micro-hydraulic as energy storage, some other benefits rise from its implementation. In this present case, the pumped water is used both for irrigation and household water supply.
4. No specialised staff is required for the system maintenance. For systems installed in isolated area this factor is very important.
5. In general hydraulic plants are environmentally friendly while the batteries have toxic wastes.

The disadvantages could be described as follows:

1. In small-scale applications, the efficiency is low and a considerable amount of energy may be lost. The efficiency of a larger system will be considerably higher.
2. The initial installation cost of the water storage system is high compared to the battery cost.
3. Civil works are required for installing a micro-hydraulic system. The size of the system defines the extent of these works.

The most significant experienced gained was the observed relatively low efficiency of the micro-hydraulic subsystem. This fact makes the use of such systems not competitive to the batteries in case that the water is not used for other purpose too. Stand-alone systems are usually installed in isolated areas where the grid expansion is technically or economically not feasible. The investment cost of the installed stand-alone system is considerably high. The expenditure rises due to the high cost of civil works (water reservoirs) and also due to lack of accessibility (need for road construction) and to high cost of materials transportation. On the other hand, the economical and social impacts derived from the installation of such stand-alone systems are of great importance (both electricity and water supply) because economical and social development is associated to the infrastructure. Under such circumstances the high investment cost is of minor importance.

4.2.7 Mini grid modular hybrid systems

4.2.7.1 PV/diesel, modular mini grid installation, Greece

Since April 2001, 3 demonstration systems are running successfully on the Greek island of Kythnos (Strauss et al. 2000, Strauss et al. 2003). The high modularity of the technology allows to easily building a single phase or a three-phase system. Several battery inverters can operate in parallel on one phase in order to increase the peak power of the power plant. The research lead by ISET (Germany) on the AC bus technology focuses on power sharing between distributed generators without communication (Engler et al. 2001).
4.2.7.2 PV/wind/diesel modular system, Spain

The three phase parallel operation was also applied at the pilot installation “HYBRIX” at San Agustin, Spain. The system is part of the “Iberdrola Test and Demonstration Centre”. It consists of 3 x 3 Sunny Island battery inverters, 3 lead acid batteries (2x2200 Ah, 1x800 Ah, 60 V), 15 Sunny Boy PV string inverters (27 kW), a 10 kW Vergnet wind energy converter (WEC) and a 20 kVA diesel genset. During the test phase the system was connected to a set of loads allowing the automatic application of a given load profile.
4.2.8 RE with hydrogen/fuel cell subsystems

4.2.8.1 A wind fuel cell hybrid energy system, Canada

In Iqbal (2003) a hybrid energy system is described, consisting of a 5 kW wind turbine and a fuel cell system. Such a system is expected to be a more efficient, zero emission alternative to wind diesel system.

The proposed system consists of a 5 kW, DC generator stall controlled wind turbine, a proton exchange membrane (PEM) fuel cell stack, a wind mast, a dump load, two independent controllers, an electrolyzer and a data acquisition system. A PC can be used as a controller and data acquisition system. Fig. 28 shows the details of system interconnections and some required instrumentation. The following parameters of the hybrid energy system are recorded: a) Wind turbine speed, b) wind turbine current, c) wind turbine voltage, d) fuel cell voltage e) fuel cell current, f) fuel cell temperature, g) fuel cell pressure, h) fuel flow rate, i) wind speed, j) wind direction and k) load current. PID type wind turbine controllers run the turbine in variable speed mode while adjusting the generator field voltage.
The fuel cell system consists of a fuel cell stack and an electrolyzer. Fuel cell stack consists of a proton exchange membrane (polymer) electrolyte fuel cells connected in series. The output current can vary between 0 and 50 A. The fuel cell delivers the current difference between the load current and the wind turbine current. If the output voltage of the fuel cell stack drops below 380 V its controller is switched on. A PID type fuel cell controller adjusts the fuel inlet and oxygen pressure to maintain a constant stack output voltage. This controller action compensates the drop in the fuel cell stack voltage caused by the load current variations. The sampling time of this controller is selected as 10 msec. If the wind turbine generates more current than required by the load then excess current is diverted towards an electrolyzer. The electrolyzer-produced hydrogen is stored in a tank for later use in the fuel cell stack.

5. COMMERCIALLY AVAILABLE SYSTEMS (STANDARDIZED SYSTEMS)

5.1. Introduction

Three standardized systems offered by the following companies namely Grundfos (PV-wind water pumping system), SMA Regelsysteme GmbH (inverters) and Conergy, have been found in the market.

Two modular hybrid system architectures have been identified, having the objective to design an expandable, low cost but standard quality mini-grid kit with multiple renewable and non renewable energy power generators. Low cost expandability of the power plant capacity is a prerequisite to make a multi-user mini-grid sustainable. It allows to easily upgrading the system in case of an increase of the load.

5.2. Conergy ISA 3000/5000/10K/15K/30K hybrid

Conergy ISA hybrid standalone inverters enable power to be supplied to remote areas that are not connected to the public electricity grid. The inverter controls the battery charging, which is done primarily using solar generators, and convert the battery electricity into grid-compatible AC power for supplying electricity, (see Fig. 29). A diesel generator can be integrated within the power management system, which can take over the electricity generation without interrupting the power supply if needed (hybrid system). All Conergy ISA hybrid standalone inverters have an internal MPPT (Maximum Power Point Tracking) charge controller. This controls the charging and power management and may provide up to 20 % more energy output.
Conergy ISA hybrid inverters use charge controllers with processor-controlled MPPT. This technology provides the battery always with the maximum power available. The integrated DC/DC regulator charges the battery at its voltage level.

*Figure 29 Typical system layout*
Battery and power management
The integrated MPPT charge controller regulates the battery and power management. The battery’s state of charge is constantly monitored by a current-compensating voltage meter that also compensates for the battery temperature. If there is insufficient solar energy, the process controller switches on a diesel generator that supplies the consumers with AC power without any
interruption. The diesel generator simultaneously charges the batteries via the intermediate inverter, which in this case operates as a rectifier.

Technical data of the inverters

<table>
<thead>
<tr>
<th>Technical data Conergy ISA hybrid:</th>
<th>Conergy ISA 3000 hybrid</th>
<th>Conergy ISA 6000 hybrid</th>
<th>Conergy ISA 10K hybrid</th>
<th>Conergy ISA 15K hybrid</th>
<th>Conergy ISA 30K hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous output power 40 °C</td>
<td>3,000 VA</td>
<td>5,000 VA</td>
<td>10,000 VA</td>
<td>15,000 VA</td>
<td>30,000 VA</td>
</tr>
<tr>
<td>Peak output power 40 °C (10 sec)</td>
<td>4,500 VA</td>
<td>7,500 VA</td>
<td>15,000 VA</td>
<td>22,500 VA</td>
<td>45,000 VA</td>
</tr>
<tr>
<td>Output voltage</td>
<td>230 V&lt;sub&gt;AC&lt;/sub&gt;</td>
<td>230 V&lt;sub&gt;AC&lt;/sub&gt;</td>
<td>230 V&lt;sub&gt;AC&lt;/sub&gt;</td>
<td>230/400 V&lt;sub&gt;AC&lt;/sub&gt;</td>
<td>230/400 V&lt;sub&gt;AC&lt;/sub&gt;</td>
</tr>
<tr>
<td>Output frequency</td>
<td>50 Hz</td>
<td>50 Hz</td>
<td>50 Hz</td>
<td>50 Hz</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Output voltage wave</td>
<td>True sine wave</td>
<td>True sine wave</td>
<td>True sine wave</td>
<td>True sine wave</td>
<td>True sine wave</td>
</tr>
<tr>
<td>Inverter efficiency</td>
<td>90–92 % (15–100 % output power)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient temperature range</td>
<td>0–40 °C/40–60 °C, with derating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation mode</td>
<td>MPP tracking (microprocessor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Solar generator voltage range (V<sub>in</sub>−V<sub>in</sub>max) | 58–150 V<sub>DC</sub> | 145–350 V<sub>DC</sub> | 145–350 V<sub>DC</sub> | 145–350 V<sub>DC</sub> | 290–770 V<sub>DC</sub>

Max. continuous charging current from solar and diesel generator | 63 A | 42 A | 83 A | 83 A | 83 A

Max. output diesel generator | 6,000 VA | 10,000 VA | 20,000 VA | 30,000 VA | 60,000 VA

Battery voltage (rated) | 48 V | 120 V | 120 V | 120 V | 240 V

Dimensions (W x H x D, mm) | 354 x 587 x 657 | 354 x 587 x 657 | 454 x 750 x 821 | 610 x 1,800 x 800 | 610 x 1,800 x 800

Reliability

The components used in Conergy ISA hybrid inverters are designed for maximum reliability in order to easily withstand continuous heavy loads over many years. This is indicated by:

- Electrolytic capacitors with a service life of up to 30,000 hours under full load
- Output stages with five-fold voltage resistance
- An operating temperature range between 0 and +60 °C
- High-quality ball-bearing fans

5.3 Hybrid renewable energy systems for off-grid water supply - The SQFlex Combi system by Grundfos

The Danish pump manufacturer Grundfos has developed a water-supply solution for remote locations that incorporates a hybrid system, (http://net.grundfos.com/doc/webnet/sqflex/frames_flash_mx.htm). The new system is called SQFlex (see Fig. 31) and comprises a submersible pump, either a helical rotor pump (3") for high heads and small flows or a centrifugal pump (4") for low heads and large flows, a selection of control panels ranging from a simple on/off switch to a more advanced version which can be used in level-control systems, a switch box, and one or more energy supply sources: solar modules and/or a wind turbine, supplemented by a generator and/or batteries if necessary. The hybrid version is known as SQFlex Combi and combines a wind turbine with solar modules, which will be appropriate for those who need stable water supply regardless of weather conditions and seasonal cycles. The system can also be expanded to include a water reservoir, which is, of course, the most efficient solution for fully utilising solar and wind energy, as opposed to storing surplus energy in batteries. A special level switch cuts out the pump when the reservoir is full.
The solar modules used in the SQFlex system are amorphous silicon, thin-film modules developed especially for the SQFlex pump. These solar modules are high-voltage, with a nominal voltage around 140 V. They provide good performance-power outputs during hot spells, and are especially effective in diffuse lighting or moderately cloudy conditions. The modules are fitted with plugs and sockets for easy installation and connection of several modules. The exact number of solar modules needed at a specific site is determined by means of a sizing tool, which is available for WinCAPS or as a paper version.

The wind turbine used was developed especially for water pumping systems. It is a high-voltage turbine, which makes it easy to combine with the high-voltage solar modules. The turbine can generate up to 1 kW. The system includes a variety of control boxes, ranging from a simple on/off switch to the so-called CU 200, a control unit that communicates with the pump via 2-way power line communication. This CU 200 unit uses continuous communication to indicate any malfunctions on the front panel. The current pump status is also indicated on the panel, including information on the current power consumption. If a levels switch within a water reservoir is activated, the unit will also report information from there via a LED on the front panel.

The use of new and cheaper technologies mean that such a system is now far more viable in financial terms than ever before: it is estimated that even the hybrid solution, which naturally requires a higher initial investment due to the need for a wind turbine and solar modules, will reach breakeven within a period of 4-6 years. This makes renewable energy even more competitive to those who still rely on polluting energy sources such as diesel generators, as renewables can now provide the same level of stability at the same - or even lower - cost. Naturally, a renewable-energy system also does away with the need for transport of fuel, where supply lines can sometimes be erratic or even break down altogether. This brings us to another area where the competitiveness of renewable energy is also on the rise: Simplicity, reliable water supply in rural areas requires more than renewable energy systems that adapt themselves to seasonal cycles. Easy installation and maintenance is also of paramount importance. Acquiring spare parts may be difficult or even impossible, and skilled technicians are often few and far between in remote areas. Special conditions apply in developing countries, where issues concerning installation and maintenance
are particularly important. History shows us that development projects are at risk of foundering after the initial start-up if the technology used is too complex to be operated by unskilled operators.

Grundfos has addressed this problem by making things as simple as possible, the objective being that everybody should be able to use the products. New technology has been used to eliminate familiar problems. A new motor has been developed especially for the SQFlex range, ensuring that a single motor handles all applications. This motor, designed according to the permanent-magnet principle with a built-in electronic unit, has several unique features aiming at greater flexibility. For example, problems regarding positive/negative poles have been eliminated - regardless of how you plug in the SQFlex, the pump will always turn the right way. This prevents a traditionally very common installation problem from ever becoming an issue. Voltage issues can also cause difficulties during installation and sizing. Grundfos has solved this by developing a motor that operates at any voltage between 30 and 300V DC or 90 to 240V AC, which once again makes installation and sizing especially easy and eliminates the risk of mistakes. The pump will be cut out if the voltage should fall outside the permissible voltage range, and will automatically start again when the voltage is once again within the permissible range. The built-in electronic unit also indirectly boosts the competitiveness of renewable energy solutions, e.g. by means of the Maximum Power Point Tracking function (MPPT). Even though installation will almost always be carried out by “official” technicians, levels of training and literacy vary greatly from country to country. In a nutshell, this means that manufacturers cannot always trust that their equipment is installed and used the way it was intended. Grundfos has taken this into account by creating a system where minimal skill is required for installation, and no special tools are required.

The system uses a “plug’n’play” approach with simple cable connection points and these cables also take subsequent potential problems into account: plugs are sealed and loose cables are tucked away in cable guards between the individual solar modules to avoid attacks from birds and insects. Going beyond the installation phase, user interfaces are available in different versions, including a very simple panel that includes nothing but an on/off switch. Small pitfalls are sometimes forgotten, but may have significant repercussions. One such issue would be instruction manuals, which are often bewilderingly complex to any audience and may not even be available in the native languages of developing countries. Grundfos has addressed this problem by issuing instruction manuals that contain no words whatsoever, relying instead on pictures and pictograms to get the message across. A more conventional version of the manual is also available to those who prefer it.

5.4. The distributed AC-bus system Sunny Island and Sunny Boy family from the company SMA Regelsysteme GmbH

Distributed systems are feeding the user grid from multiple points and all the generators are coupled directly via the distribution grid. Distributing the generators along the grid is the technology normally used only with the bigger power systems while it takes the grid control more sophisticated (local robust generator controls or fast communication between each generators and a supervisory control are necessary). Especially, the parallel operation of multiple grid forming generators requires new devices for synchronisation, load sharing, etc. Advantages of the distributed systems are a theoretically unlimited expandability, the reduction of distribution line costs, decentralised location for the RE generators allowing e. g. PV integration in building roofs.

In Fig. 32 is shown the structure of a modular distributed AC bus system.
The Sunny family of products from SMA Regelsysteme GmbH comprises several modular components:

- Sunny Island: a single phase 3.3 kW bi-directional battery inverter able to work as an AC grid-forming unit. This component includes all the mini-grid supervisory controls. 3 Sunny Island can be connected in parallel to build a 3-phase grid if needed.
- Sunny Boy: a family of single phase current source PV inverters ranging from 450W to 2200W
- Sunny Boy Control for data acquisition
- Windy Boy: a family of inverters to be used with wind converters of small power up to about 5.5 kW.

This new AC coupled technology for hybrid systems has been jointly developed between the Kassel University (Germany) and SMA and has been described in many papers (see for example Burger et al. 2000).

The decentral energy supply systems based on renewable energies supplied by SMS consist of modular elements and provide a wide range of possible combinations. Decentral hybrid energy supply systems can be easily designed by means of modular AC supply units (see Figs 33 and 34). The necessary components (PV, wind and hydro generators, batteries etc.) can be integrated in modular form and combined with standard components such as Sunny Island, Sunny Boy, Windy Boy and Sunny Boy control.
Figure 33. Hybrid modular single phase AC system consisting of PV, wind, genset and a Combined Heat and Power unit, (source: www.sma.de)

Figure 34. Hybrid modular three phase AC system consisting of PV, genset, a Combined Heat and Power unit with the possibility to connect to the grid, (source: www.sma.de)
6. R&D REQUIREMENTS

6.1. Identification of areas for R&D

At present hybrid systems range from small, “do it yourself” systems (which may satisfy both the electrical load and the technical curiosity of users) to highly sophisticated, professional systems installed to provide remote communities with reliable, grid quality electricity. Further improvements will allow the extension of markets for this emerging technology, both in industrialized and less developed countries.

In the following paragraphs we intend to give emphasis to the identification of R&D requirements for hybrid system components other than the electricity production technologies (e.g. PV, wind converters etc.) since these components (power conditioning devices such as inverters, controllers, etc.) play a major role in structuring the hybrid systems.

At the system level, the research should be aimed towards cost reduction, reliability and utility. The proposed work considers new configurations of systems to add value to the electricity generated, including, for example, the concept of including storage in grid-connected systems with inverters that are able to operate in island mode to increase the reliability of supply. A number of hardware developments are required to achieve further performance improvements, including static power converters, system controllers and battery charge controllers. Most importantly power conditioning devices need to be designed to be more efficient at the low end of their operating range. Inverter operation has to be improved for low load demand, which accounts for a significant percentage of the total energy conversion in most hybrid energy systems. For example inverters are required with efficiency of more than 95% from 1% to 200% loading.

Reliability of system components has to remain the highest priority for new hardware developments regardless of the performance improvements achieved by modern power electronic converters. It is well known and generally widely recognized that most important problems in hybrid installations are load restrictions, generator fumes and noise, maintenance and lack of technical support. This is also confirmed from a survey at Kythnos island, Greece (Gaidouromandra village mini grid hybrid installation). Other issues such as power quality, supply reliability, insurance, or safety, are identified as less important concerns. While the technical issues can be addressed by the development of advanced hybrid energy system technology, it must be emphasized that the provision of adequate maintenance and technical support will remain a difficult logistic problem given the remoteness of many locations. This leads to the demand of systems that are highly reliable over their entire lifetime, as well as requiring minimum maintenance, preferably by untrained operators. This can be achieved by:

- Maintenance-free energy storage systems
- Fully automatic energy management systems
- High percentage of energy demand supplied by renewable energy sources
- Improved reliability of power conditioning devices

Lead-acid batteries are still regarded as the most economic form of energy storage for the next decade, despite their less ideal operating conditions. Progress has been reported on the development of new chemical storage systems, such as hydrogen storage, vanadium-redox and zinc-bromide batteries, but it remains difficult to assess if it will be economic within the next decade to integrate these storage systems in small to medium size energy systems.

Three specific topics relating to the use of storage in hybrid systems were identified:

- Firstly, whilst battery management (BMS) systems have been developed for other applications of new battery technologies such as Li-ion and Ni-MH, there is a need to adapt the BMS systems for hybrid applications. The BMS improves battery life, provides information on the state of charge and state of health of the battery and allows communication between the battery and the system supervisor.
Secondly, it is recommended that new battery technologies developed for other applications (e.g. automotive, consumer market) and with the potential to reduce life cycle costs in hybrid applications are field tested in pilot units to give a clear assessment of lifetime (target of 30 years), performance, added value and cost (a target of less than 3 Eurocents per kWh of energy throughput may be set).

Thirdly, it is necessary to consider innovative approaches to the storage of small amounts of electricity (1-10 kWh) for short-term storage purposes. Issues to be addressed include materials and processes for cost reduction, lifetime, flexibility in operation, modularity and compliance with requirements on recycling, emissions etc.

The progress in the information technology allows adopting highly sophisticated management techniques and technologies to optimize the operation of hybrid energy systems. In particular the performance of modular hybrid energy systems can be improved through the implementation of advanced control methods in a centralized system controller. Optimum resource allocation, based on load demand and renewable resource forecast, promises to significantly reduce the total operating cost of the system. The application of modern control methods to supervise the operation of modular hybrid energy systems allows the utilization of the renewable resource to be optimized, while also reducing the fuel consumption of any combustion engine-driven generator. System maintenance may be also improved by applying distant operation supervision. And also fault identification can be further improved. High priority topics in this area include:

- management of island mini-grids with a high share of RE generators
- cost effective instruments for surveillance (e.g. via satellite) of large numbers of distributed RE systems
- development of efficient incentive management for RE hybrid systems
- billing and metering for off-grid hybrid systems.

Future hybrid energy systems may replace the combustion engine-driven generator with fuel cells, which offer a number of advantages (e.g. Ghosh et al. 2003):

- High efficiency of energy conversion particularly at part load operation
- Little or no noxious emissions, depending on the fuel cell type
- Silent operation
- Modular construction
- Ability to utilize many fuels.

Such systems may combine fuel cells with hydrogen storage systems, which allow the inclusion of seasonal storage, potentially making the system completely independent from the supply of fuel. In the longer term, renewable energy could provide communities with hydrogen fuel for cars, space and water heating, cooking, refrigeration, and reliable supply of electricity during periods of low renewable energy input.

Although many software design tools have been developed from companies and research organizations sophisticated design tools are still necessary for better hybrid system designs that also take into account the type of loads and appliances to be used along with the energy production system.

6.2. Hybrid power systems – The next generation requirements

Modern decentralized power supply structures and components should be developed, tested and demonstrated to include several types of grids that operate parallel to each other and communicate with service centers for control supervision and remote maintenance purposes. Fig. 35 shows how decentralized hybrid power systems will evolve to include:

- Local (e.g. supply of single loads via stand-alone systems)
- Regional (e.g. supply of amenities, businesses etc. via island grids) and
- Trans-regional (coupling to utility grids)
These types of grids form supply structures that can be expanded step by step as the demand for electricity increases. A broad expansion of the decentralized electrification would automatically lead to the interconnection of local grids to form regional or trans-regional grids.

In such decentralized structures, communication is a key issue for reliability and cost-effective maintenance. In addition to the powerline coupling of the different system components and plants, another communication structure for control and supervision purposes is an essential feature for decentralized power supply structures. Similar to the management of the centralized power systems has to be managed. Each structure has to be equipped with the suitable communication technology, as shown by the dotted line in Fig. 35.

Such decentralized power structures are anticipated to represent the future trend towards sustainable energy generation and to be the most effective model for remote and rural areas. Moreover, the trend towards decentralized power structures is also starting now in industrialized countries. However in order to achieve the goals set for the decentralized power structures, system technologies will have to achieve price reduction for electronic components such as charge regulators, converters etc, within the next decade.

6.3. Standardization testing and assessment – Quality assurance – Recycling and Life Cycle Analysis

Standardization testing and assessment
Both European, national and especially local authorities and utilities require that RE systems meet agreed standards. In a number of cases either existing standards or differences in local standards (inverter requirements/settings) or the lack of standards hinder the development of the RE market. Therefore it is important that new and revised standards are drafted such that the interests of the RE community are assured.

Adopted or new performance, energy rating, qualification and safety standards are required in particular for the certification of modules inverters. The specific properties of RE systems need to
be taken into account in standards regarding the grid and in standards regarding the connection of
decentralized power systems to the grid.

Sometimes guidelines can be more appropriate than standards. Guidelines are required in the
cases of, among others, quality assurance, specification of materials, Balance Of System (BOS) components, system design, system installation, systems tests and monitoring/evaluation (specifications of both hardware and data formats).

Standards and/or guidelines are required for the whole value chain. The development of new and adapted standards and guidelines implies in many cases that dedicated research and development is required.

**Quality assurance**

Quality assurance is an important tool assuring the effective functioning of both individual components in a RE system and of the RE system as a whole. Standards and guidelines are an important basis for quality assurance. In-line production control procedures and guidelines also need to be developed. At the system level monitoring techniques need to be developed for early fault detection.

**Recycling and life cycle assessment**

Regarding recycling, attention has been paid mainly to recycling of crystalline silicon solar modules so far, in the EU PV programs. Methods for recycling of thin-film modules and BOS components (in the case where no recycling procedures exist) need to be addressed as well.

Life Cycle Analysis (LCA) studies have become an important tool to evaluate the environmental profile of the various renewable energy sources. In order to assure the position of RE systems with respect to other sources, reliable LCA data are required. From these data properties like the CO$_2$ emission per kWh of electricity produced and the energy payback time can be calculated. In addition the results of LCA data can be used in the design phase of new processes and equipment for cell and module production lines.

Especially for BOS components LCA studies are required to obtain the overall environmental profile. This technique can also be useful in informing the direction of research for cells and modules with the lowest environmental impact. LCA studies for thin-film modules and emerging cell technologies should be carried out within the PV program. LCA data of BOS components like batteries and inverters should come from the battery and the inverter industry as far as possible, but are crucial to obtain the overall profile.

### 6.4. Conclusions

Major areas for R&D requirements include:

- More efficient power conditioning devices need to be designed at the low end operating range
- Power conditioning devices of higher reliability and less maintenance are required (preferably to achieve more than 20 years of full operation)
- Cost reduction of hybrid system components (both for generation technologies and power conditioning devices)
- Further diversification of modular hybrid systems and standard components
- Inclusion of hydrogen/fuel cell subsystems in hybrid systems, (methods of controls, efficient and reliable operation)
- Storage systems need further improvement (in particular: efficiency, reliability and maintenance, cost reduction)
- Adaptation of battery management systems for new generation of batteries
- Introduction of new storage technologies in pilot units for large field experimentation and assessment of lifetime and cost
• Low cost support structures, for PV systems
• Low cost cabling and electrical connection components
• Development of highly sophisticated design tools (software)
• Development of diagnostic tools for early fault recognition to maximise lifetime performance
• Further improvement of the energy efficiency of appliances
• Development of greater variety of energy efficient appliances
• Development of modern decentralized power supply structures to include several types of grids
• Standards and/or guidelines for quality assurance
• Development of recycling processes
• LCA studies on BOS components

7. ENERGY EFFICIENT APPLIANCES

7.1. Introduction

In stand alone hybrid systems, a well-matched load together with a carefully selected choice of appliances can lead to significant savings in terms of reduced need for RES installation capacity and electricity storage capacity.

In fact the bulk of the problems encountered with system operation can be traced back to inefficient appliances and processes or unmatched loads (Report IEA PVPS T3-09: 2002).

7.2. Load related problems

PV system components have high reliability and are currently meeting or exceeding high quality standards. Nevertheless, rural electrification projects frequently do not perform as expected and more often than not, long-term service sustainability is not achieved. It is commonly found that the lack of performance is attributable to non-technical factors (Serrano et al, 2000).

However, there are also technical breakdowns of systems and the frequency of their occurrence has to be reduced to improve the acceptability of this technology. The wide range of problems identified have been classified in eight groups:

*For all systems (AC and DC supply systems):*

**Wrong selection:** some loads are non-adapted for stand-alone hybrid systems. For example, generally it is not appropriate to use RES produced electricity to produce heat. These thermal appliances can have dramatic consequences for the system:

• High consumption will cause a system cutout.
• Permanent low SOC of batteries and deep discharge can damage batteries.
• For a diesel hybrid (genset) system, increased running hours of the genset causing increased operation costs. The appliances that convert electric to thermal energy can be replaced, using gas, liquid fuel, solar-thermal collectors or firewood where appropriate.
• If electrical to thermal energy conversion is difficult to avoid – e.g. autoclave sterilizers use only high efficiency appliances and make sure that user is aware of the energy consumption of their operation.

**Housewiring:** substandard or inadequate wiring and protection devices will also cause poor system response. Wiring is an important issue to guarantee correct performance when using appliances.

• If section of wires is undersized or selection of fuses is incorrect, high current through these can cause a fire (by resistive heating).
• Undervoltage may detrimentally affect the performance of some appliances. Current limiters and switches must be installed to avoid high currents and drains.
Low efficiency: low electrical efficiency loads lead to over energy consumption. On the market there are electric appliances that provide an identical service, but with different efficiency. Generally speaking, inefficient appliances are cheaper to buy. Often the user will be poorly advised and will select the appliance according to price rather than efficiency considerations. If the system was sized for efficient loads and, inefficient devices are used, insufficient energy is available, resulting in:

- Frequent cut-offs.
- Frequent low SOC of batteries resulting in low life.
- System undersized.
- User unsatisfied and may even by-pass the controller.
- If diesel genset runs periodically, operating costs can increase dramatically due to increase in demand/ or increased demand.

It is usually cheaper to invest in efficient appliances than to invest in generation capacity to meet the incremental demand from inefficient appliances. In addition, almost all high-efficiency appliances have longer operation lifetime than conventional ones, resulting in self-saving of its own extra costs. Some users of remote systems can have problems in purchasing efficient appliances. A solution would be to make provision for the purchase of these appliances in the project. In the cases where the appliances already exist, it is advised to measure the actual consumption before sizing. The advantage of replacement with efficient appliances can be calculated. Raise the awareness of the end-user through training and dissemination.

Stand-by loads: stand-by mode of some loads waste energy. When these appliances are left on stand-by for hours or even days, their cumulative effect can become a significant part of system consumption. This may be reflected as low charge of the batteries and earlier cutoff of the system.

Start-up: current spikes during the start-up of some loads can create temporal overload of the system. Some appliances consume high electric power (several times its rated power) at start-up. In case of AC current, the inverters should resist peaks of power several times higher than its rated power value, during the short start-up periods. The following could be done to overcome the problems.

- The loads affected should have a starter, which could “soften” the start-up.
- The problem would be solved using loads according to the availability of power, always considering energy-availability (e.g. water pump with less kW but operating during longer time).
- In case of simultaneous start-up of the appliances, the peak power would be the sum of each one. Progressive start-up of the loads connected should be done, controlled by the inverter or another device.
- The last solution would be to use an alternative power source for problematic loads (e.g. a diesel generator).
- Specify the inverter continuous watts and surge watts by estimating the surge requirements correctly.
- Use a linear current booster or use permanent magnets in pumping systems to assist start-up.
- A starter used for a water pump could be a device, which produces a frequency variation of the output inverter AC signal, to improve the start-up of the water pump.

Only for AC:

Reactive power: when appliances with capacitive or inductive loads are used, real circulating current differs from the consumed. All the non-ohmic loads consume reactive power. So, the phase between voltage and current is not zero. The current to be delivered by the inverter is much higher than the real consumption, resulting in a possible overcharging of the system. Current through the cables is higher than necessary, resulting in the need to increase the wire section to reduce voltage drops. This will add to the cost of cabling. Measures to be taken are:

- Reduce the need for inductive loads like conventional ballasts, etc.
• Use of synchronous motors instead of induction motors in the relevant appliances.

Install capacitors at the inductive load or the distribution panel to provide the required amount of capacitive reactance.

**Harmonic distortion:** some electronic appliances with non-linear loads can create waveform deformation of the inverter output signal. Some non-linear electric loads are generating signal distortion on the power line.

• This causes voltage deformation in the output signal of the inverter, which may occasion problems with the other loads.
• Harmonics can shorten the life of the appliances by voltage stress and increased heating of electrical insulation.
• Some devices need to sense ‘zero-crossings’ to control internal switching and could malfunction as the ‘zero-crossings’ may appear to shift because of harmonics.
• Use of output filtering or use of inverters with high switching frequency in situations where harmonics are expected.

**Mismatch between load and inverter size:** Low overall efficiency can result from oversized inverters operating at low power for long periods. Low overall efficiency can result from oversized inverters operating at low power for long periods.

The energy consumed is higher than the expected one, resulting in:

• Cutout of the system or permanent low SOC of batteries
• High non-useful energy consumption.

Use of a specific dedicated inverter for the application, or a modular inverter with working points of good performance ranging from low to its maximum power.

Problems that we consider trivial in grid-connected systems (wrong selection, etc) can be critical in a Stand-Alone hybrid system. Buying appropriate appliances can solve some of these problems.

For the consumption issue, there are in the market high efficiency lamps, freezers, and other appliances, with consumption rates several times lower than the conventional ones. Even though, it’s also very important to raise the users’ awareness on efficiency.

Relating to the reactive power, there are e.g. fluorescent lights with electronic ballast which allow a phase to phase voltage-current consumption.

Other problems like harmonic distortion, stand-by loads, and start-up currents can’t be easily solved, because these are basically technical problems that are always present in some of the shelf appliances.

Furthermore, the market is not yet large enough to manufacture adequate appliances – without these problems, at reasonable prices. In these cases, the best solution is to modify the design of the system (mainly batteries and inverters) to account for the losses introduced by appliances. Housewiring carried out by an accredited electrician can avoid unnecessary troubles to the user when using appliances.

Since installation requirements are considered as an integral part of the implementation of projects, it’s advisable to have identification and a choice for loads from stand-by. To summarize, a good social approach and technical design of the systems are crucial to succeed in achieving an adequate electric supply and satisfaction of the users.

**7.3. The Importance of energy-efficient appliances**
Household energy bills can be sharply reduced by using high-efficiency appliances and space conditioning equipment. While these may be more expensive to buy than comparable models with lower or average efficiency, the reduced energy bills will put that money back, long before the product wears out.

Purchasing of energy-efficient appliances has a positive effect on the economy and the environment. The more efficient use of oil, gas, and electricity improves economic competitiveness, and reduces the environmental pollution associated with energy production and use. In fact, choosing energy-efficient appliances reduces immediately household contribution to global climate change. Carbon dioxide (CO$_2$) is the primary gas affecting global warming and virtually all energy-using equipment results in CO$_2$ emissions either directly or indirectly. Even by replacing a 20-year-old refrigerator with a new, energy-efficient model, not only about 800 kWh per year will be saved, but a household CO$_2$ contribution will be reduced by about one ton per year.

On the other hand, reduced energy consumption of energy efficient appliances require less installed RES capacity (e.g. less PV panels) and thus less investment cost. An energy efficient refrigerator typically reduces refrigerator energy consumption by a factor of five compared to the typical household refrigerator currently in use. The accompanying cost of the solar power system is similarly reduced. For example a DC refrigerator model consumes 15 KWH per month, or an average of 42 amp hours per day. Producing the 110 KWH needed to run the typical refrigerator on a solar power system would require an investment of around $12,000 in hardware, batteries, and inverter. The DC refrigerator model will reduce this cost by a factor of at least six because of its increased efficiency and the elimination of inverter losses. Inverters convert DC battery power to 120V AC at an energy loss of about 10%.

7.4. Commercially available efficient appliances

Due to the importance of the energy efficient appliances and the related economic impact on energy bills and investment costs, the industry of electrical appliances has shown an increasing interest and a large variety of energy efficient appliances are in the market. In order to facilitate the designers and the final consumers, a number of specialized organizations (either public, non-profit or private) offer, in their internet sites, tips and information for the selection of energy efficient appliances to fit in each specific installation.

For reference only, the Group for Energy Efficient Appliances (GEEA, www.gealabel.org) is briefly presented.

Initiated by government agencies and institutions from Denmark, the Netherlands, Sweden, Switzerland and the European Energy Network (EnR), a workshop was organised in March 1996, where it was decided to formulate a Memorandum of Understanding as a basis for collaboration to harmonise ongoing and/or planned voluntary informative activities in the field of home electronics and office equipment.

In this respect a uniform communication and cooperation between public and private energy agencies or organisations, relevant parties, such as manufacturers, importers and the European Commission are of prime importance.

Since May 2000, the Group for Efficient Appliances has been incorporated as a Foundation (GEA Foundation) under Dutch law. Please note - from June 2001, the name has been "Group for Energy Efficient Appliances (GEEA)". This incorporation was a necessary step in order for the group to formally function as a legal body when cooperating with other organisations and institutions.

**Members**

- Switzerland: The Swiss Federal Office of Energy (SFOE)
- Denmark: The Danish Energy Authority (DEA)
- Sweden: The Swedish National Energy Administration (STEM)
The GEEA works closely together with partners from Industry: EICTA - European Information, Communications and Consumer Electronics Technology Industry Association.

**Goal**

The goal is to effectively contribute to the establishment of a uniform European-wide scheme on voluntary informative activities. In several countries different voluntary informative activities have already been implemented or are planned for TVs and VCRs. For this reason we decided to start harmonising work in the field of TVs and VCRs. We based our working methods and philosophy on the Swiss E2000 scheme, which has been working very successfully since its implementation in 1994.

Each GEEA Member implements informative campaigns according to the characteristics of its consumer market. To allow the consumer to make an informed choice a recognisable label has been launched.

![Figure 36. Label indicating high energy efficiency](image)

This label indicates that the appliance has a high energy-efficiency profile only reached by approximately 25% of the most efficient models on the market (note: in case of Energy Saving Devices, this percentage can increase to 100%). It is not intended to have compulsory use of the label; not for GEEA Members or Industry. It acts as an additional tool to help us reach our goal: efficient use of energy. In the GEEA Information Wizard, that helps somebody to find GEEA labeled devices, there are now 15 active categories with 2329 registered most energy efficient devices.

Important information are also presented in the site of American Council for the Energy-Efficient Economy (www.aceee.org), mainly on energy policies, tax credit and incentives in United States. There is also a friendly consumer guide to home energy savings, presenting lists of energy-efficient appliances (bearing Energy Star label) for food storage, cooking, cooling and heating systems etc.

### 8. NEW CONCEPTS AND INTEGRATED MODELS FOR RENEWABLE ENERGY SUPPLY

#### 8.1. Introduction

Using models for renewable energy supply tend to serve energy as well as development needs. At first the target was to integrate renewable energy systems in development as part of the energy policy and planning. The new concepts require renewable energy systems integration into development planning and strategy, as well as environmental planning.

In that way models for RES become a critical part in the chain of development in an area boosting sectors on top of energy like abandoned agricultural practices, tourism quality etc, and giving solution to various environmental problems like water deficit, air pollution, etc.
New concepts and integrated models for renewable energy supply are those systems that try to examine and introduce, if possible, renewable energy in the early stages of a complete planning process in space and time. Complete planning requires parallel development approaches per sector, identification of possible synergies between sectors, forecasting and then backcasting, and all these on a macro horizon scale. Complete planning is about efficient planning, resources saving and preventive policy.

Renewable energy systems seem ideal tools in such a frame. They can fit in most sectors and they serve extremely well the principles of sustainability. Their implementation fields can vary from energy to architectural solutions.

The development of new concepts and integrated models in the fields of power generation, heating and cooling, agriculture, transport, etc. will significantly improve opportunities for the market penetration of RE and hybrid systems in Europe as well as in MPC.

8.2. Basic principles

There are some basic principles governing the new concepts in renewable energy systems. These are briefly presented below:

- Use of RE Systems integrated in development
  If not part of a development strategy RES would probably face lack of political will and conflicts with local people. Integration increases profits from such systems and strengthen possibilities for success.

- RE Systems as paths to sustainability
  Sustainability combines balance in time and space, environmental protection, precaution and prevention, better quality of life. Renewable energy systems appliances could present the ideal paths towards such a target.

- Integration of RE systems in planning
  Correction activities with RE systems could only have limited results. Restrictions in time and sources, and weakness in appearing as a permanent solution could turn a lack of planning problem into RE defamation. On the other hand, integration of RE systems in early stages of planning could take full advantage of their potential benefits.

- Integration of RES in economic -every day- sectors aiming to improve the quality of the sector, e.g. rural electrification, tourism, agriculture, waste management.
  Every day life is the constant judge of appliances and presents a huge proportion of needs. Even small scale applications could assist renewables to become not only environment friendly but also user friendly. Some sectoral examples of such interventions are:

  - RES for Rural electrification
    - Public buildings and services, lighting – heating - cooling (schools, hospitals, bus stations etc)
    - Cover of house demand in remote areas

  - RES in Tourism
    - Use of RES to cover peak demands and satisfy fluctuations.
    - RES as additional value to the tourism product quality.
    - Attraction of special tourist categories in relation to responsible tourism.
    - Use of RES to strengthen traditional activities related to tourism.

  - RES in Agriculture
    - Use of RE Systems to provide water suitable for irrigation (e.g. desalination).
    - Cover water needs in dry regions. Improve cultivation possibilities (strengthen competitiveness).
• Use of RES to cover farm needs in energy.
• Manage RES as agricultural products (e.g. biomass plantations).

♦ Waste management for RES
• Use sewage or solid waste as RES products.
• Avoid illegal dumping and health risk problems.
• Improve quality of life in rural areas.
• Use RES bio-products from waste management.
• Use RES to power waste management units (energy needs of plants and installations).

Serve Multiple Purposes Principle
That means exploit RES not only in terms of energy efficiency and capacity, but also in order to satisfy other societal needs. A brief description in bullets would be:

• Take best advantage of RES installations (e.g. wind power for electrification and energy storage as hydrogen production, then use of hydrogen for transportation).
• Positively affect more than one sector.
• Small scale –every day- applications for combined purposes like energy and education, or energy and aesthetical reasons or architecture.

The above principles and concepts are depicted in Fig. 37.
Figure 37. Schematic representation of new concepts for renewable energy supply
REFERENCES
37. Leng et al, 1996.
43. Mueri, RAPSIM – Remote Area Power SIMulator Ver. 2.0, 1997, Perth: Murdoch University


51. Scriveri A. Energy management and DSM techniques for a PV-diesel powered sea water reverse osmosis desalination plant in Ginostra, Sicily, Desalination 183, 2005, 63–72

52. Serrano J. et al., User training in PV rural electrification programs, 16th E.P.S.E.C.E., Glasgow, May 2000


57. Sultan E, Kershman A, Rheinlander J, Neumann C T, Goebel O. Hybrid wind/PV and conventional power for desalination in Libya—GECOL’s facility for medium and small scale research at Ras, Desalination 183, 2005, 1–12

58. Taylor R. Challenges and Opportunities for Renewable Hybrid Systems in Developing Countries. Proceedings, Workshop on Photovoltaic Hybrid Systems Montreal, Canada September 10, 2001


60. TRNSYS, a transient system simulation program manual, solar energy laboratory, University of Wisconsin – Madison, February 2000, USA


63. Van Dijk V. Hybrid photovoltaic solar energy systems, design, operation, modelling and optimisation of the Utrecht PBB system, 1996, PhD. University of Utrecht.


