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USE OF PHOTOVOLTAIC ENERGY STORAGE SYSTEMS IN BUILDINGS AND OTHER APPLICATIONS

Antonino Fabio Agosta[1]
[1]University of Enna "Kore" - Italy, Via G.Verdi, 23 - 97015 Modica Alta (RG), Italy
Mobile (+39) 3389459239
Corresponding Author E-mail: fabio.agosta@hotmail.com

ABSTRACT: This paper illustrates the use of storage systems with stand-alone photovoltaic systems to be used in buildings of Malta for integration of electricity and energy saving and special applications in other areas. The present energy situation suggests that the future of the domestic and industrial photovoltaic systems will include storage systems, to improve resource management of feeding renewable energy into the national grid, and increase reliability at the generation site. The paper develops around the initial stages of photovoltaic integration into the grid, when the possibility of auto consumption or net-metering was used. However, increased penetration of photovoltaic systems could now reduce the existing network load, while still not solving the main limitation of renewable sources, which is the intermittent nature of the production. Especially photovoltaics, but not only, the limitations of PV electrical generation is also subject to a certain cyclical production be it daily or seasonal, and a certain amount of "*unpredictability of production*". Such issues have a solution through energy storage. The production of electricity for other special applications would include on-site production of energy for stand-alone systems.

Keywords: Electric storage systems, self-power, stand-alone photovoltaic systems, EMS.

1 INTRODUCTION

The future of photovoltaics: energy storage systems.

With the development of photovoltaic plants and the reduction of incentives in incentive programs for the construction of these facilities, one begins to speak explicitly on the economic benefits of PV farms within cities or industries and the possibility of energy storage.

The present interest is no longer focusing on net-metering or self-consumed in situ electricity generation, but on the use of PV systems and storage as a secondary grid, where surplus electricity may be stored.

This concept of self-generation coupled with storage is most convenient for the following three reasons:

- avoids the purchase of energy from the power supply (*which means paying the energy and all the costs associated with it, service charge*);
- the storage system allows you to have a "*reserve*" of electricity for the night;
- allows a continuity of operation in case of power failure of the electricity grid;

Beyond incentives, which are short-lived, the instantaneous consumption (*which is that at the moment of production*) remains the best way to amortize the cost of the PV system in the shortest possible time.

1.1 Maximising the Instantaneous Benefits for Solar Energy Production

At night and in the short winter days the production of a photovoltaic system is low; then come into play energy storage systems come into play to extend the availability of power through energy storage. For the case of domestic and industrial plants, this is mostly achieved by the use of batteries. The future of photovoltaics is going towards increasing the use of this concept and hybridising the PV system to produce renewable energy from different sources.

The storage systems are also desired by the national electricity grid, as they help to stabilize, or "*normalize*" the energy flows entering the distribution system. When many PV systems are connected to the grid, it may be subjected to spikes and sags in voltage and frequency, especially on partly-cloudy days. Storage systems help to reduce these effects and at the same time, increase the network capacity. The future of photovoltaics therefore begins by dealing with storage systems, or better, with the cost of storage systems. The cost of the technology, the cost of "*PV kit + batteries*", is still economically not viable without incentives but it is beginning to show some drop in costs. A quality PV storage system should take into account at least two factors:

- the capacity of electricity that can stored;
- the duration and efficiency over time.

The value of the batteries can make a real difference in the amortization schedule of a photovoltaic system, thus significantly shortening recovery times.

2 STAND-ALONE PHOTOVOLTAIC POWER SYSTEM [1]

Photovoltaic systems are one of the most widely used variants of systems that use renewable energy in order to obtain electricity getting obvious advantages of both economic and environmental terms. Right now on the market we can find two types of PV systems:

- stand-alone systems (*stand alone*), which are not directly connected to the mains, but store energy in batteries or other local systems as hydrogen;

- With systems "*connected*" (*grid connect*), which do not accumulate, but exchange energy with the network through the direct link to the national distributor.

We focus on the latter to furnish a general framework that highlights the main technical characteristics, applications, advantages and disadvantages.

The stand-alone photovoltaic power system are isolated systems, autonomous, and able to provide electricity supply to isolated consumers. These electrical systems may engage in both the production with immediate use of alternating electric current, through the appropriate transformers and inverters that are sized according to the load to be supplied, as well as the storage of power for later use.

3 USING SOLAR ENERGY STORAGE SYSTEMS

The accumulation and storage of electricity are mainly used in areas, where it is not possible to provide grid-connection or it is far too expensive to do so. Often this type of installation is found in isolated chalets, country houses or shelters.

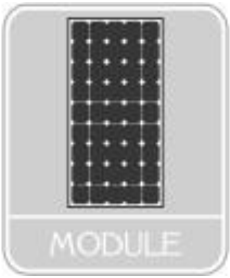
Small stand-alone installations are used in mobile homes, boats, ships, charging stations for electric equipment, but also on road signs and visual lamps or any other electrical load current dimensions in terms of power.

From the grid point of view, energy storage goes beyond the generation of renewable energy to cover the "*traditional*" energy chain of national distribution. They can be used as local stored capacity on distribution networks or even become autonomous power grids "*closed*", or an stand-alone system.

4 THE COMPONENTS OF PHOTOVOLTAIC STAND-ALONE SYSTEM OR "*STAND ALONE*" [1]

Looking purely from the technical aspect, a photovoltaic stand-alone system consists of the following main elements:

- The photovoltaic field, which through the use of photovoltaic modules is able to trap, collect solar energy and transform it into electrical energy. They are made from modules, which are connected in parallel and series to form larger units called arrays, to produce electric power that meets almost any electric need.



- The charge controller, which has the function to filter the collected energy from the photovoltaic field making it compatible with the standards of the plant. A voltage regulator or charge controller is an essential part of nearly all power systems that charge batteries, whether the power source is photovoltaic, or utility grid. Its purpose is to keep the batteries properly fed and safe for the long term. The basic functions of a controller are quite simple. Charge controllers block reverse current and prevent battery from getting overcharged. Some controllers also prevent battery over-discharge, protect from electrical overload, and/or display battery status and the flow of power.

- The Battery Storage which is any system of chemical accumulation of electricity, designated to collect and then store as long as possible the energy produced, transformed by the photovoltaic field and filtered by the regulator. Normally, it consists of one or more rechargeable batteries connected in series or in parallel. A storage medium, battery bank, which is involved in the system to make the energy available at night or at days of autonomy (*sometimes called no-sun-days or dark days*), when the sun is not providing enough radiation. The standard batteries that are used in solar system are lead-acid batteries because of their high performance, long life time and cost effectiveness. It is recommended though to buy high quality batteries, which are able to withstand extreme temperatures and low discharges. Good deep-cycle batteries can be expected to last for 5 to 15 years, and sometimes more, while cheaper batteries can give trouble in half that time.

- The inverter, which will convert the electrical dc voltage to alternating voltage (*if necessary, depending on the type of use*), is used to power any user electric and electronic products. An inverter is a device that changes a low dc-voltage into usable ac- voltage. It is one of the solar energy system's main elements, as the solar panels generate dc-voltage. Inverters are classified according to their output wave format, output power and installation type. The inverter is also called power conditioner because it changes the form of the electric power. There are two types of output wave format: modified sine-wave (*MSW*) and pure sine-wave. The MSW inverters are economical and efficient, while the sine wave inverters are usually more sophisticated, with high-end performance and can operate virtually any type of load. There are also two types of inverters for installation, stand-alone installation and grid-connected installation.

All the above components are connected as described in the block diagram (Figure 1) and schematic diagram (Figure 2) below:

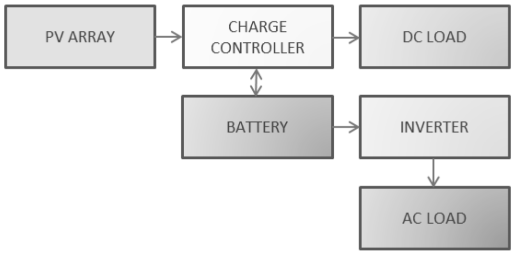


Figure 1: Stand-alone photovoltaic system: block diagram

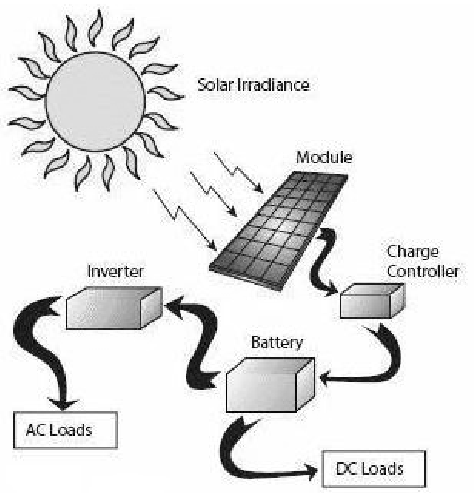


Figure 2: Stand-alone photovoltaic system: schematic diagram

4. ADVANTAGES AND DISADVANTAGES OF STAND-ALONE SYSTEMS

The major advantage of stand-alone systems is to be autonomous and independent of the electrical networks: for example for remote cabins, where it is often more economical to install a solar plant with storage systems than extend the connection of the electricity grid. Even for campers, for example, instead of charging the batteries with the classical systems (*diesel generators*), it is far more economical to use small solar systems.

In the event of a power failure to the grid network, these systems have the advantage of being able to continue to produce and accumulate power.

On the other hand, the biggest disadvantage of solar islands lies in the fact that it is not linked to any general power grid. For this, the risk is that one has to be dependent on the accumulation systems, to ensure a steady and stable supply over time. Other critical points are related to battery life, to their efficiency and, not least, to their costs. Also, batteries have their own efficiencies, and hence not all the power generated from the sun can be accumulated in the batteries.

5 THE STORAGE SYSTEMS: BATTERIES

A first battery system is that of traditional lead-acid batteries. However, technology today is considering greater use of lithium batteries. Lithium batteries are electrochemical storage systems, similar to batteries of any kind of modern electric vehicle. The technological advantages of this system are obvious, higher duration, better storage capacity and more efficient conversion. The limits are economic costs.

Despite these temporary limits and critical points, the technology is making great strides overcoming some of the most significant technological limitations: performance increase with new materials and extended life operation.

In the coming years there will be, from this point of view, significant technological improvements. The economies of scale that will come also will result in the further reduction of costs.

6 STORING ENERGY FOR OWN CONSUMPTION: A SOLUTION

We describe a storage system, aimed at domestic installations, capable of ensuring domestic energy independence through the use of a dedicated electrical panel and through the accretion in the current self-produced batteries. We propose this system only by way of example to see if and how much energy need to be stored.

A 3 kWp PV system should include a storage system with up to 24 kWh (Figure 3).

With the energy accumulation system the goal is to reach the transition stand-alone power supply: reducing the withdrawal from the network the user can maximize the effectiveness of the system cancelling, or almost, energy expenditure family. This could be a self-sustained system, thus reaching independence from the grid.

The principle is simple: store solar energy at any time of day, to be able to consume energy at any time of the day or night.

One may reach a good level of autonomy, when the storage capacity exceeds 70% of total household consumption.

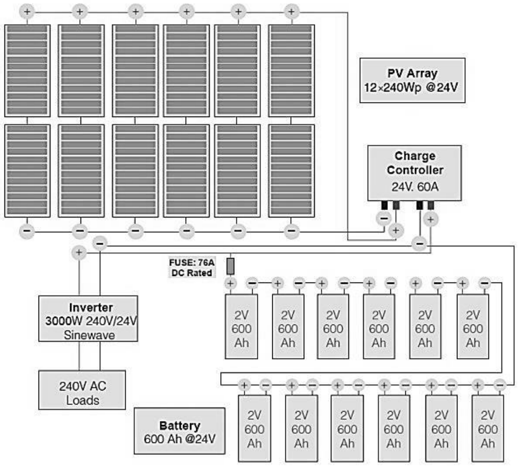


Figure 3: Scheme Stand-Alone PV System

7 EVOLUTION OF THE STORAGE SYSTEM: EMS (ENERGY MANAGER SYSTEM) [2]

A change in the traditional storage system allows to obtain and use a mix of grid connect and stand-alone systems, in order to implement significant energy savings in homes and in industry.

From a general point of view of a storage system managed with logic EMS (Figure 4), one can connect to other types renewable energy plants that can be integrated to perform the charging of the batteries.

For example in the specific case of a system for home users the batteries have a good durability and a good resistance to cycles of loading and unloading and can increase the maximum available power by 2.6 kW.

This type of solution is indicated particularly suitable for users with an annual consumption of 3,500 kWh and, when it arrives "*at the end of life*", presents favourable conditions for the replacement of the battery with its recycling process.

The system must be constituted by a pack lead batteries (*type battery with industrial-type cells PzS*) from 24 kWh gross, 12 kWh net, and from an electric panel with appropriate electronic equipment and control logic (*micro controller and PLC*).

The storage capacity of 24 kWh of electricity corresponds to the average daily energy needs of a family of 4 persons: about 6 kWh gross per person/day.

The adaptability to integrate with existing photovoltaic systems has further advantages for those who already have a photovoltaic system in operation, but want to increase the share of consumption, which is the factor of greatest savings to further reduce electricity bills.

The system, in addition to having a system of energy storage with recyclable batteries, also has an electrical panel complete with inverter and charge controller.

The communication unit EMS (*Energy Manager System*), located in the control cabinet, will have to operate in such a way as to optimize energy flows deciding to:

- store the energy in batteries;
- used directly on the user allowing optimised consumption;
- connect to the network if you are connected to the power supply system.

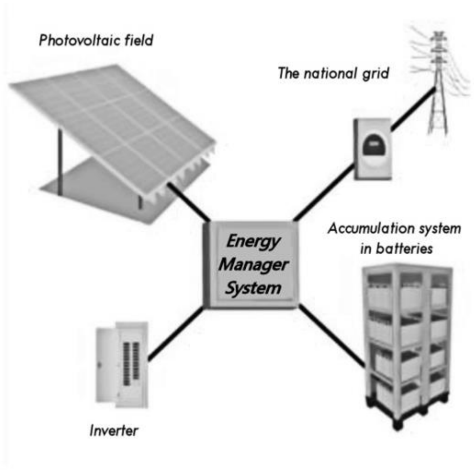


Figure 4: EMS System

Description of operations that an *Energy Management System* can perform:

1. solar energy is converted into electrical energy and accumulated in the batteries;
2. share of electricity produced by photovoltaic panels is used directly to electrical loads;
3. in the case when the electrical loads are minimal and the batteries are charged, the surplus electricity is fed into the electricity network.

8 OTHER APPLICATIONS

8.1 The hypothesis of hydrogen as further energy accumulation system.

Another technology which is spoken by the accumulation of energy produced from renewable sources is hydrogen.

The question here is slightly more complex: hydrogen is a clean fuel that needs energy to be produced. Hydrogen thus becomes a reservoir of energy storage and is a readily usable fuel.

The limit of this other technology is the conversion efficiency and safety, given the high flammability of the component.

8.2 PV Water-Pumping [3]

PV pumping systems are often attractive options for small-scale community water supply, household water supply, agriculture and livestock needs (*PV is usually not an attractive option for medium and large-scale irrigation*).

This section gives an overview of solar water-pumping system planning processes. Water pumping has a long history; so many methods have been developed to pump water with a minimum of effort.

These have utilised a variety of power sources, namely human energy, animal power, hydro power, wind, solar and fossil fuels for small generators.

The relative merits of these are laid out in Table 1 below.

Table 1: Comparison of pumping techniques

	Advantages	Disadvantages
Hand pumps	• local manufacture is possible • easy to maintain • low capital cost • no fuel costs	• loss of human productivity • often an inefficient use of boreholes • only low flow rates are achievable
Animal driven pumps	• more powerful than humans • lower wages than human power • dung may be used for cooking fuel	• animals require feeding all year round • often diverted to other activities at crucial irrigation periods
Hydraulic pumps (e.g. rams)	• unattended operation • easy to maintain • low cost • long life • high reliability	• require specific site conditions • low output
Wind pumps	• unattended operation • easy maintenance • long life • suited to local manufacture • no fuel requirements	• water storage is required for low wind periods • high system design and project planning needs • not easy to install
Solar PV	• unattended operation • low maintenance • easy installation • long life	• high capital costs • water storage is required for cloudy periods • repairs often require skilled technicians
Diesel and gasoline pumps	• quick and easy to install • low capital costs • widely used • can be portable	• fuel supplies erratic and expensive • high maintenance costs • short life expectancy • noise and fume pollution

Solar pumps are used principally for three applications:

- village water supply
- livestock watering
- irrigation

A solar pump for village water supply is shown schematically in Figure 5.

With village water supply, a constant water demand throughout the year occurs, although there is need to store water for periods of low insolation. In environments where rainy seasons occur, rainwater harvesting can offset the reduced output of the solar pump during this period.

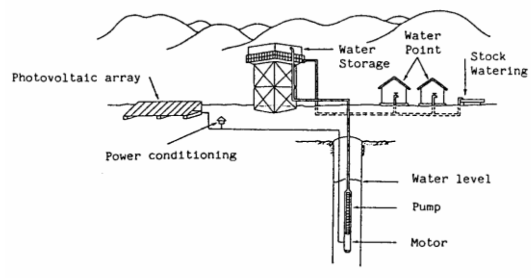


Figure 5: Village water supply

A solar irrigation system (Figure 6) needs to take account of the fact that demand for irrigation water will vary throughout the year.

Peak demand during the irrigation seasons is often more than twice the average demand. This means that solar pumps for irrigation are under-utilised for most of the year. Attention should be paid to the system of water distribution and application to the crops. The system should minimise water losses, without imposing significant additional head on the pumping system and be of low cost.

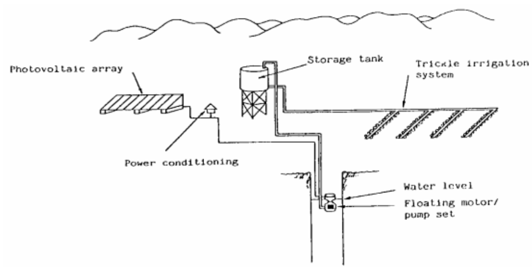


Figure 6: Solar irrigation system

Pumping systems coupled to a storage system would allow the use of water for the uses described above even at night.

8.3 PV street lighting Solar LED [4]

Another important application of stand-alone systems is Solar LED street lighting for public areas (Figure 7).

The main advantages are as follows:

1. zero electricity costs
2. maximum safety from electric shock
3. rehabilitation of old poles and recycling of underground cables
4. zero maintenance electric lines
5. zero problems with black-out
6. low maintenance
7. very low cost of installation
8. excavations with zero problems relating to traffic
9. high economic returns and zero CO_2 emissions
10. reconfiguring the positioning of the poles at any time

These particular PV stand-alone systems are used in the lighting of parking lots, streets, public gardens, parks, bike paths and in all those places, where there is no economic advantage to install systems from the network of the traditional type.

In particular, it is advantageous in environmental contexts where, for landscape constraints, environmental, security, rights of way or by the presence of railway crossings and highways, is extremely expensive to construct ducts for interconnection to the distribution network.

Figure 7: Solar LED

Description of the Components

- Solar panel. Standard size 40W, with monocrystalline cells, with daily production capacity of 200Wh.

- Charge regulator and twilight. The charging of the battery by the solar panel must be controlled and adjusted continuously, in order to avoid excessive loads and therefore overheating of the elements and electrolyte. The regulator also has the function of blocking of the charge, if the voltage of the panel is not able to charge the battery, thereby avoiding the reverse path of landfill battery. A second important function of this address is the function of twilight precision, using the photovoltaics panel. In fact, as the sun goes down, the panel reduces its production in proportion to the value of illuminance, to zero during the night. An internal controller compares the production until it reaches a minimum threshold set, then automatically switches the lights on. Similarly during sunrise, the electronic checks the value of illuminance, and then automatically switches off the lamp. The electronics also have the function of controller of the minimum state of charge of the battery, that in the event set value is reached, detaches the load, while maintaining an active stand-by all electronics.

- Led illuminator - The LED light operates at low voltage (*12V*), which offers maximum security against accidental shock from high voltage, and comes complete with power supply. It is mounted in a suitable container to semi-spherical dome for protection against atmospheric agents, and thanks to the fact that the LED has a very long life (*100,000 hours*), it does not require scheduled maintenance or replacement of internal components. The semi-sphere is mounted on a cantilever arm of 800 mm from the support pole at a height of 4 meters above the ground. The lamp is composed of a matrix to a circular shape of a diameter of 175 mm, of 400 LEDs of white color. The luminous flux is 1,600 lumens (*corresponding to 2 incandescent lamps of 100W*) with a consumption of 12Wh. At a height of 4 meters, the area illuminated corresponds to an area of about 20 square meters, equivalent to a circle of 5 m. The value is 75 lux on the ground. Global consumption overnight (*12h*) is 145Wh.

- Battery storage and storage. The battery used is of the type compact electrolyte gel and sealed with integrated elements and double electric insulation. The battery has a capacity of 50 A/h life at full charge cycles. This battery has an average life of more than 600 complete cycles of charge and discharge. Being in the gel electrolyte sealed, requires no maintenance and/or additions of electrolyte.

- Support. The whole system is designed to be supported on a single support pole. This is fixed to the ground on a concrete anchoring base.

9 CONCLUSIONS

The integrated use of an stand-alone photovoltaic systems, with and without EMS system, allows the production of electrical energy and its storage for later use, even when the solar energy is minimal or at night. The optimum design and construction are very important goals to be achieved in order to obtain high efficiency by the use of solar energy for both applications in homes, in industry and in other uses described in this paper. In the near future, these systems will spread widely and will be the technical basis for micro-grids.

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