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# Potential Autonomous Energy Systems for Rural Electrification in Ethiopia

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***Abstract-*** Autonomous hybrid energy systems use different energy sources such as solar and wind with backup units such as battery and diesel generators. They are economical options in areas remote from national grid. In this context the performance of the system to supply electric power in an efficient way of operation is important. The problem is uncertainty of renewable energy supply and load and also non-linear characteristics of components in the system. In this paper different schemes of autonomous energy system are described and a system suitable for rural electrification in Ethiopia has been recommended. The preferred system is hybrid system with AC coupling with possibility of grid integration if required.

***Index Terms-*** Autonomous, Hybrid power system; solar/wind, micro-hydro.

## I. Introduction

According to World Energy Outlook 2010 estimate, more than 76% of population of Ethiopia is living without electricity. Due to high investment costs for expanding the public grid and low power requirements, it would be uneconomical to connect remote areas to the national grid in the medium run. Under these circumstances stand-alone PV systems present a logical alternative. Stand-alone PV systems are autonomous power grids being supplied with energy from a photovoltaic generator. Examples of such systems include electricity supply systems for isolated settlements or entire villages. According to world bank (2011-2015) data, in Ethiopia only 7.6% of population living in rural area has electricity access. In such cases, stand-alone photovoltaic systems are often the most economic solution.

Various constraints have to be taken into account when planning, designing, and selecting a standalone power system. In fact, the optimum design of an electricity supply system depends primarily on the following five factors:

1) Required Connection Power
2) Energy consumption
3) Type of power consumers
4) Period of use
5) Meteorological constraints

Alongside these technical aspects, there are also cultural, social, economic, and financial factors which need to be taken into account.

## II. Components

The PV generator as the source of renewable energy is the crucial component of the stand-alone power system. Other available generators include diesel generator, water and wind turbines.
Stand-alone power systems are generally differentiated according to their type of voltage (DC or AC). In DC coupled systems, the PV generator is connected via a special DC/DC charge controller (see Fig. 1.1).

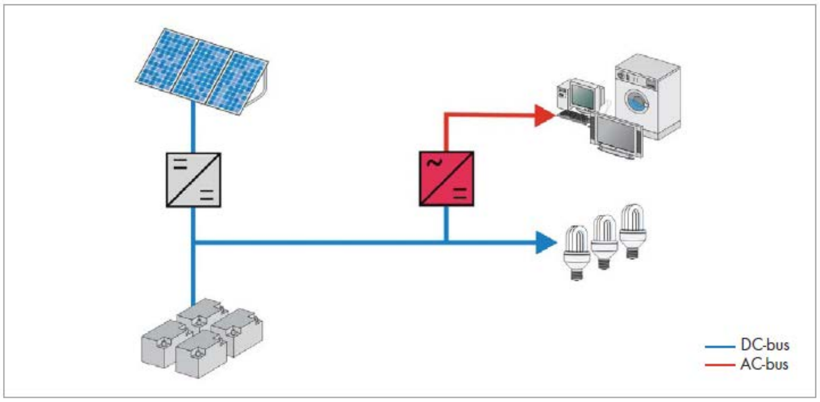


***Fig. 1.1: Solar home system capable of providing alternating current***

In AC coupled systems, a conventional PV inverter is used for feeding power into the grid (Fig. 1.3). The battery or stand-alone power inverter is the heart of the AC coupled system. It ensures that generated and load power are balanced at all times. If too much energy is generated, the inverter stores this surplus energy in the batteries. If energy demand exceeds supply, the inverter discharges energy from the batteries.
A management system that includes battery, generator, and load management is absolutely essential for the optimum operation of a stand-alone supply system. This control function is integrated into the battery inverter. It simplifies the operation of the system and keeps investment costs down.

## III. SYSTEM DESIGN

Apart from power consumers such as lamps, radios, TVs, and refrigerators, a stand-alone PV system is made up of four basic components: a power generator (e.g., PV generator), a storage battery, a charge controller, and an inverter. These components can be coupled at various system levels on the DC side, on the AC side, or in hybrid systems.

### *A. DC Coupling*

In a DC coupled system, all loads and generators are coupled exclusively at the battery voltage level (see Fig. 1.1). A DC supply on the basis of a 12-Volt battery is particularly suitable for simple system constellations. Especially when the electricity is to be used primarily for lighting, such as in a solar home system (SHS) in the power range of a few hundred Watt. During daylight hours the battery stores the energy supplied by the PV generator. This energy is then available in the evening to power the lighting system. With the help of an additional small inverter, it is also possible to operate conventional AC power consumers in the DC system.
In general, it is advantageous if AC consumers can be utilized. These are devices easily available in Ethiopian market and can be purchased at low cost.

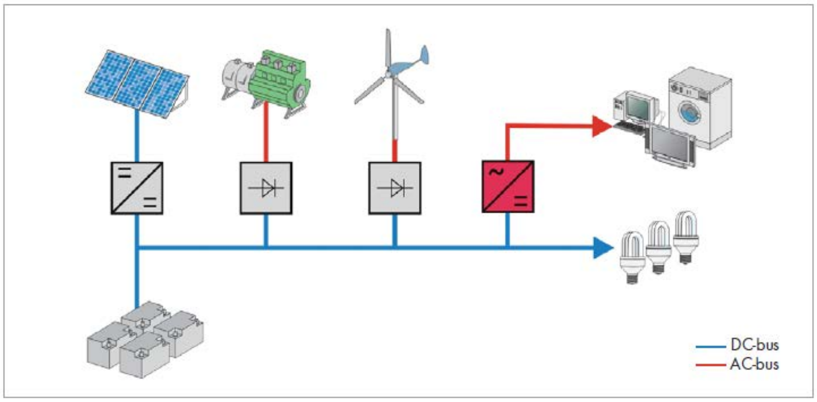


***Fig. 1.2: Hybrid system with DC coupled components***

### *B. AC-DC Systems*

Hybrid AC-DC systems are especially suitable for connecting mid-range AC power consumers with DC generators. With such systems, the battery on the DC side can be simultaneously charged via a diesel generator (see Fig. 1.2).
The demands on a hybrid system differ from those on a solar home system. Hybrid systems are used to supply remote power consumers and are able to handle higher energy requirements.

Accordingly, such AC-DC systems are typically used in remote areas. The designer of an AC-DC system should take into account that the inverter capacity must correspond to the required energy consumption. Even when more energy is available from PV and wind sources, the inverter will limit the capacity supplied on the AC side.

*C. AC Coupling*

The connection of all power consumers and generators on the AC side (see Fig. 1.3) offers a decisive advantage: it enables systems to be built up or expanded with standardized components on a flexible, modular basis. Renewable and conventional power sources can be combined, depending on the application and the available energy carrier. This is a particular advantage in situations where the grid structure is weak. The connected energy sources charge the batteries and supply energy when it is needed. If inverters are intended for that purpose, a connection to the public grid is possible. The system can easily be expanded by adding further generators, thus enabling it to handle a rising energy demand. Additionally connected AC sources result in a real increase in capacity on the AC side. AC coupled systems can be used to supply all power consumers. Hence, they are ideally suited for applications like rural villages of Ethiopia.

In the medium power range (2-100 kW); the structure of such supply systems does not require any additional control or monitoring unit. Battery inverters such automatically check the availability of the grid and the system components.
This simplifies the operation of the system and keeps investment costs down.
From an economic perspective, stand-alone power systems with a storage battery in the kW power range are considerably more cost-effective than systems which use diesel generators only. Even larger hybrid systems which use a diesel generator to avoid long-term battery storage can be operated at lower cost than stations working exclusively with diesel units. This can be attributed to the high cost of maintenance, short service life, and very poor partial load efficiency of diesel generators.

Expandability and the type of connection of the individual components play a key role in off-grid power supply systems. The AC coupling enables power generators of all kinds as well as standard power consumers to be connected to the stand-alone power grid. The system is easy to expand both on the consumer and on the supply side.

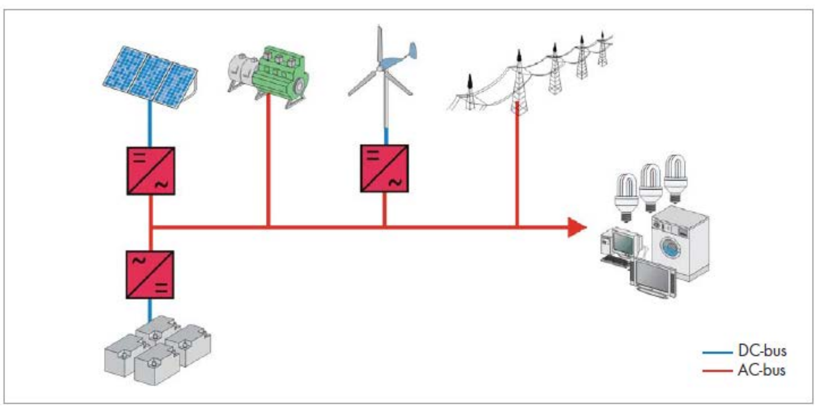


***Fig. 1.3: Hybrid system with AC coupled components***

## IV. FUNCTIONALITY

Stand-alone power inverters are connected to a battery bank and form the AC grid of the stand-alone power system. At the same time, they control the voltage and frequency on the AC side. Generators as well as power consumers are connected directly to the AC grid. Whenever there is a surplus of energy (e.g., when solar irradiation is high and consumption low), the stand-alone power inverter draws energy from the AC grid and uses it to charge the batteries. When there is an energy shortage (little or no solar irradiation and high consumption), the inverter uses the batteries to supply the grid.
Various power generators can be connected to the stand-alone power grid: PV plants, wind turbines, micro-hydro power stations, and diesel generators.
The latter can step in when the battery charge is low and there is not enough solar irradiation available for recharging.

## V. EXPANDING AND CONNECTING OF STANDALONE POWER SYSTEMS

Stand-alone power grids can be gradually expanded into large-scale systems as a result of the parallel connectability of all energy suppliers and consumers. They are particularly well suited for the supply of grid-isolated areas such as remote villages. Fig. 1.4 shows the layout and the expansion possibilities for an AC coupled village power supply.

The autonomous energy system can easily be expanded by further power generators when the power demand rises. One further advantage of the stand-alone power system: Thanks to the storage batteries, energy not needed during the day will be available at night, e.g., for street lighting.


***Fig. 1.4: Expansion options of an AC coupled hybrid system for a village electricity supply***

Legend Fig. 1.4

1) : PV generator
2) : PV inverter
3) : Battery inverter
4) : Storage battery
5) : Generator
6) : Wind turbine

## VI. CONCLUSION AND REMARKS

Autonomous Energy systems are recognized as a variable alternative to grid-electricity for rural village power supplies.

A hybrid energy system using AC Coupling which combines PV-arrays and other energy sources (micro-hydro, wind and diesel generators) with lead-acid batteries for energy storage can offer a more cost effective and more reliable type of system. However, hybrid system with diesel generator depends the user on transportation and storage of fossil fuel and higher maintenance.

Therefore, the authors recommend hybrid system with wind and/or hydro turbines for rural electrification in Ethiopia.

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