Off-grid power supply and global electrification

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Introduction

The electrification of off-grid rural regions plays an essential role for a basic level of supply, in particular for economic development. Depending on the local framework conditions, different technical system concepts and business models are suitable for sustainable provision of a reliable and cost-effective supply of electricity. From small solar home systems, hybrid systems with photovoltaics, biomass, wind and hydropower, to multi-megawatt stand-alone grids which can be integrated in integrated grid structures, FVEE member institutes, together with industrial companies, develop technical solutions, test systems and components and run trials in realistic conditions.

In addition to this, new financing and business models are proposed, which are intended to create incentives for investment, and support sustainable operation and possible expansion of the systems. Advantages result from the use of different renewable energy sources, which, thanks to the suitable system technology, are often competitive with standard diesel stations or conventional grid expansion.

Solar home systems (SHS)

A simple solar home system (SHS) for basic electrification consists of the following components: a solar generator, battery and charge controller, as well as the directly connected DC consumers. An optional inverter can also be used to supply AC consumers (*Figure 1*).

Such systems are used to supply energy-saving lamps, an increasing number of LED lamps, and some radios, televisions and refrigerators. The SHS charge controller connects the solar module (15..150 Wp) to the battery and the electricity consumers. It protects the battery against overcharging and deep discharge. As storage device, lead batteries with liquid electrolyte, bound in gel or fleece in a few systems, with a storage capacity of 3 to 5 days, are used almost

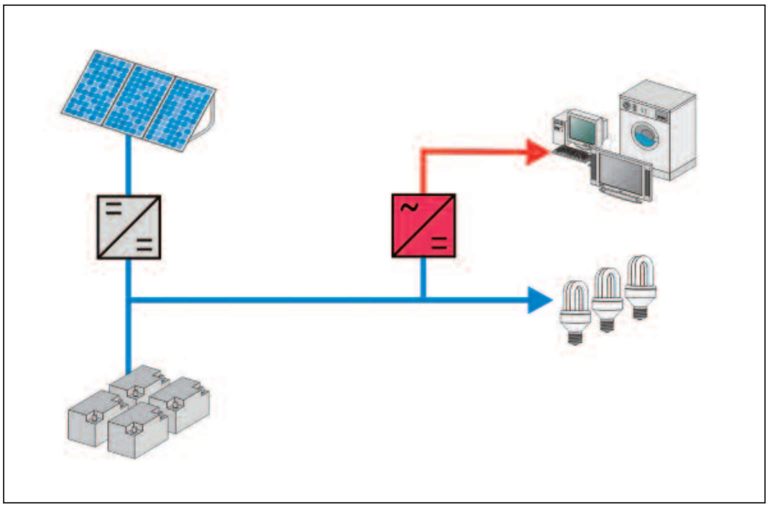

Figure 1
Block circuit diagram of a solar home system with inverter
(Source: SMA)

exclusively. All components must satisfy demanding requirements – in terms of efficiency, reliability and ease of operation. This is why Fraunhofer ISE develops and tests SHS components in the laboratory.

Worldwide, there are currently major programmes for widespread distribution of SHS, such as in Argentina, Bangladesh, Bolivia, China, India, Morocco or South Africa. The possibility of supplying remote households decentrally, simply and independently with electricity using SHS is considered a particular advantage of this technology. By contrast to central plants, these systems can be the property of the end users. However, even if the system is operated by a RESCO (Rural Energy Supply Company) and does not belong to the user, there is always a direct correlation for the user between their personal consumption and the status of the system. This reduces the coordination work compared with concepts featuring central supply.

In Ecuador for example, PV systems are subsidised by the state with the aid of a rural electrification fund (FERUM). Every year, new projects can apply for this funding. The PV systems for basic electrification consist of a 100 Wp solar generator and a 105 Ah battery for supplying DC consumers (three energy-saving lamps, one radio and a black and white television). In addition to this, PV systems with inverters in two sizes up to 200 Wp and over 200 Wp have been subsidised since 2007/2008. Now, systems with up to 800 Wp are installed at end customers' locations.

Funding is US$3,200 or US$3,500 per household. The size and configuration of the individual systems are specified according to the requirements of the applicants or end users. As some areas are difficult to reach, the funding also takes transport costs into account.

Standardisation of components reduces costs. The local operator model, in which technical training by RESCOS and funding play an important role, is an important success of the PV project in Ecuador. End users must make monthly payments. As part of the DOSBE EU project [1a,b], Fraunhofer ISE was involved in the development of this operator model.

Hybrid systems

Supplying electric consumers in off-grid locations is challenging if it must be guaranteed continuously all year-round. Seasonal fluctuations of the energy from the sun, wind and water in particular mean that supply solutions which rely solely on one energy source require significant investments for electricity storage.
Systems with different electricity sources are known as hybrid systems. Common combinations include PV-diesel or wind-diesel systems. Combinations of photovoltaic generators, wind turbines and diesel motors are also widespread.

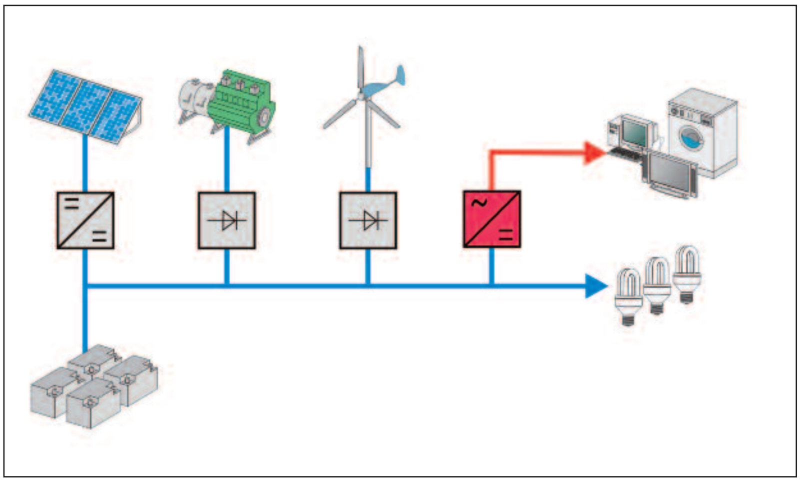

Figure 2
Hybrid system with DC-AC connection
(Source: SMA)

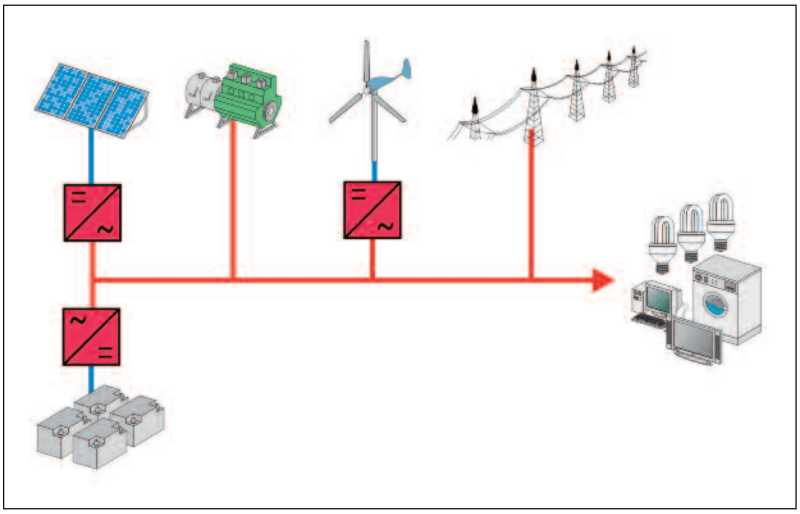

Figure 3
Hybrid system with AC connection
(Source: SMA)

Hybrid systems can be designed as DC systems, mixed DC/AC systems or pure AC systems. DC/AC systems are often used in farms or other small companies. When designing systems, planners must take into account that the inverter power must match the overall maximum consumer power. **Mixed DC/AC systems** are particularly suitable for combining medium AC loads with DC generators. At the same time, this also allows the battery on the DC side to be charged via a combustion generator (*Figure 2*).

Pure **AC hybrid systems** can be set up flexibly with modular components (*Figure 3*). Depending on the application and the available energy sources, renewable and conventional energy carriers can be incorporated. If the power converters and combustion generators are intended for the purpose, they can also be connected to the public grid.

The system is easy to expand via additional components or electricity generators to cope with increasing energy requirements. A mass-produced modular system for AC connected hybrid systems was built and tested for the first time in the European „Hybrix" project [2] by BP-Solar, SMA and Fraunhofer IWES (*Figure 4*). It is now in use worldwide. This type of system can be used to supply all standard electric AC devices.

Figure 4
Wind-photovoltaics-diesel-hybrid system in Spain
(Source: Fraunhofer IWES)

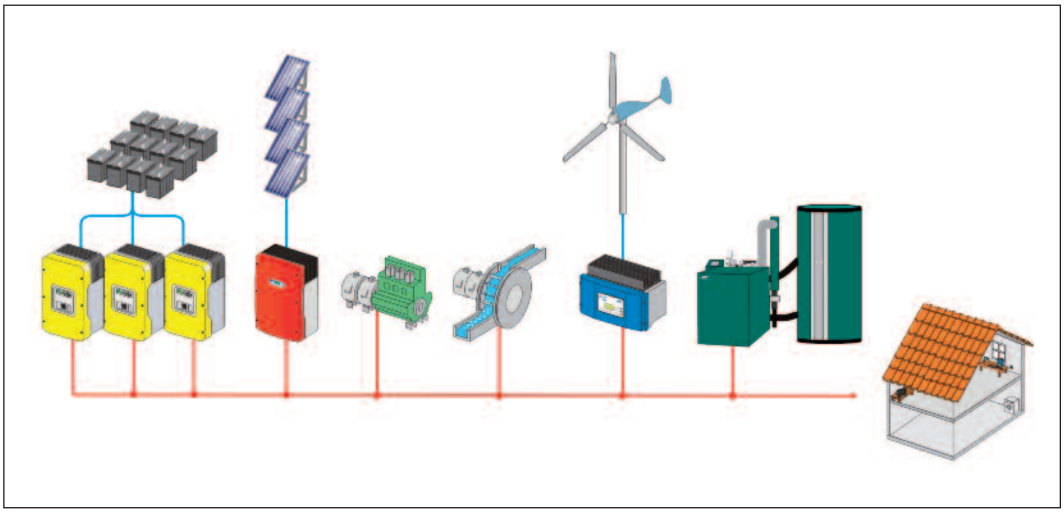

Figure 5
Modular system for AC connected hybrid systems
(Source: SMA)

From an economic perspective, stand-alone systems with battery storage in the kilowatt power range are far less expensive than systems which use diesel generators only. Even larger hybrid systems which additionally use a diesel generator to avoid long-term battery storage can be operated at lower costs than stations in which diesel motors alone are used. The reasons for this are the high maintenance work required, the short service life and the very poor partial load efficiency of diesel generators.

In power supply systems away from the integrated grids, it is primarily the expandability and the type of connection of the individual components which play an important part. The AC connection with battery inverters which can be connected in parallel (Sunny IslandTM) can connect almost any kind of power generators and all standard consumers to the hybrid system. *Figure 5* shows typical generators which can be combined easily using the SELFsync® control technology patented by Fraunhofer IWES. The system is easy to expand on the consumer side and on the generator side.

Stand-alone grids and micro-grids

Stand-alone grids can be used for several remote houses or loads outside the integrated grid. Grid interconnection levels the load profile and increases the supply security. Stand-alone grids can be fed from a central power plant, a hybrid system or multiple decentralised electricity sources. In the integrated grid, the number of consumer-related independent generation systems, e.g. photovoltaic systems and combined heat and power plants, has increased significantly in recent decades. This technology can also be used for stand-alone grids. However, high decentralised power inputs may not endanger the stability of the grid.

Feed-in tariffs could be used to create incentives for investments and for sustainable operation of the remote generators in the stand-alone grid. In this way, grid participants with more financial clout could help to finance the overall system and would thus also ensure that it runs smoothly.

In principle, a collectively supported feed-in tariff could be used for such systems, similar to the German Renewable Energy Sources Act (EEG). The WG 4 – Rural Electrification working group of the European PV technology platform developed a proposal for this [3]. The technical feasibility of such stand-alone systems was demonstrated on the Greek island of Kythnos (*Figure 6*). This is similar to independent generation in the integrated grid, but research is still required for organisational implementation.

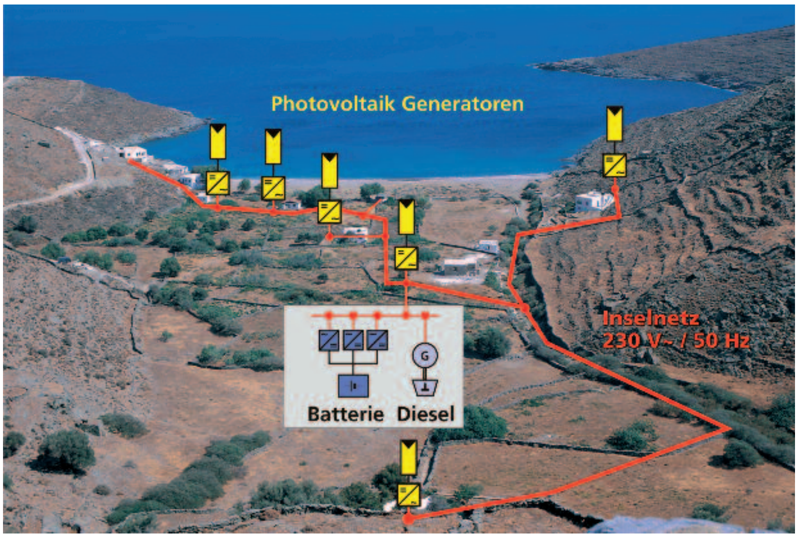

Figure 6
Stand-alone grid with distributed feed from PV systems
Source: Fraunhofer IWES

Stand-alone grids can be connected to one another or to the integrated grid using suitable, i.e. grid compatible control technology. This allows so-called micro-grids to be formed temporarily, which can then continue to operate without problems even if the main grid fails (*Figure 7*).

It was proven [5] that a variation of the grid frequency – imperceptible to the user – is suitable to derate excess solar power fairly (*Figure 8*).

A continuous decentralised derating of PV systems becomes necessary when the batteries are fully charged and electricity is in relatively low demand. It is crucial that the PV systems installed in houses are derated in a fair manner. This is achieved automatically by increasing the grid frequency. *Figure 9* demonstrates this for houses on the island of Kythnos.

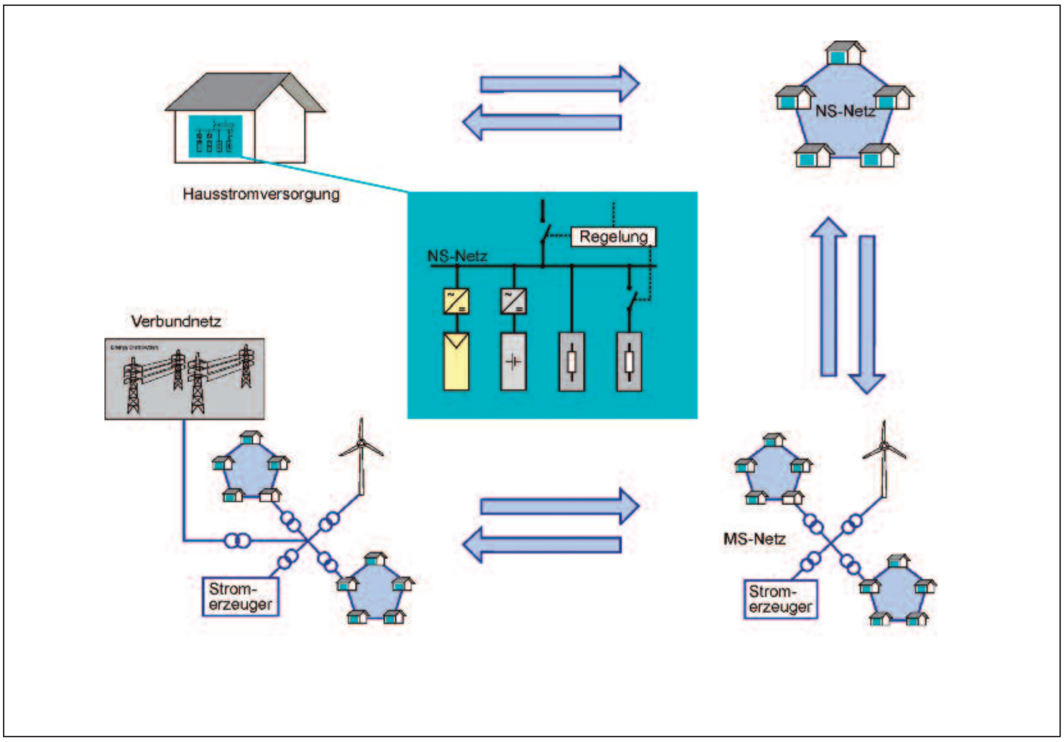

Figure 7
Bidirectional transitions from the domestic supply via stand-alone grids to the integrated grid [4]

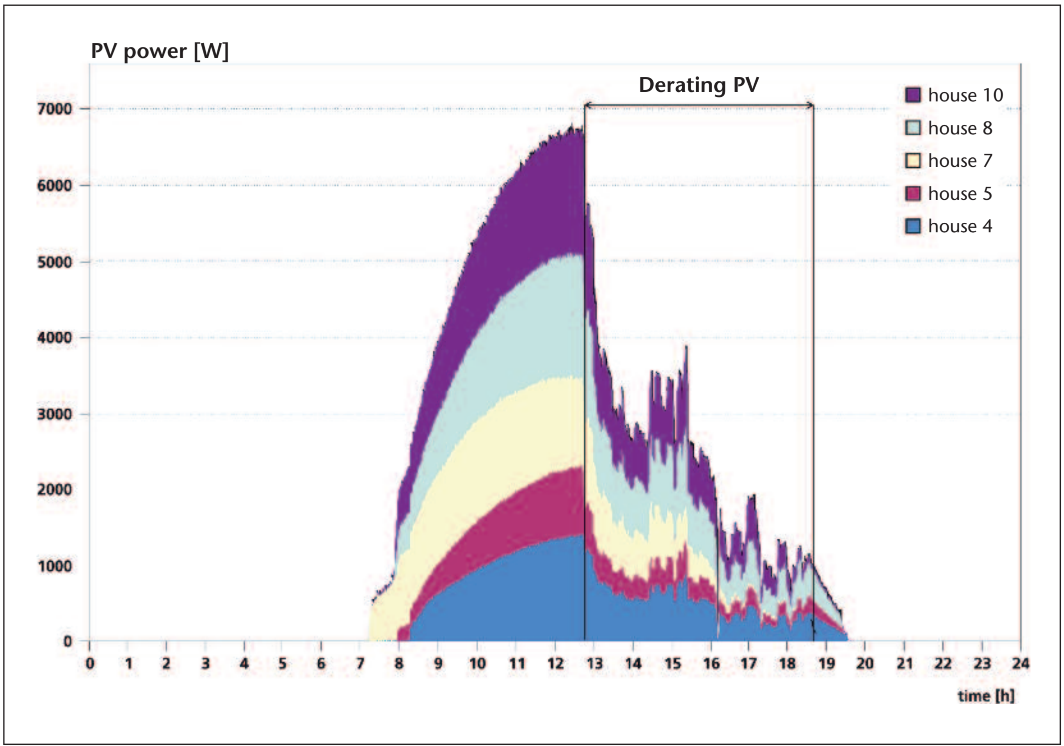

Figure 8
Derating the decentralised feeding PV generators. The power inputs of the PV generators before and during the derating. [5]

Financing and business models

The best-known financing model for SHS world-wide is via micro-loans, which also enables poor rural population strata to purchase small systems. Financial scope for paying down the loan is provided by the dropped costs for kerosene. In its basic form, this business model works without government subsidies. It is widely recognised as being highly successful and is increasingly supported by development institutions.

The Grameen Shakti Bank in Bangladesh is an internationally recognised pioneer. It offers the customer not only financing but also guarantees professional installation and maintenance by certified and specially trained contractors. To date, Grameen Shakti has financed more than 200,000 systems.

Common business models for solar home systems also include leases (e.g. SolarLuz), the „Fee for Service Model" (e.g. the Moroccan PERG-Programme, based on a Public Private Partnership) and subsidies for the acquisition costs [6].

Given the very low income levels, mini-grids in rural areas of developing countries are generally not economically self-supporting. A common form of financing that allows independent electricity generators to make profit is a subsidy on the investment combined with tariffs covering operating costs for end customers [7].

This model, for example, is often used by African "Rural Electrification Agencies". In practice, however, it has often been shown that the users' low capacity or willingness to pay causes the cash flow of these projects to remain below expectations.
The moment the batteries need replacing is therefore generally regarded as critical to the sustainability of this financing model.

Following the feed-in tariff, the Joint Research Centre of the European Commission (JRC) developed a tariff concept tailored to mini-grids in cooperation with the EU PV technology platform named Regulated Purchase Tariff (RPT), which is a strong incentive for independent electricity producers to continuously operate the system while giving financial leeway for required repairs and replacements of system components. Depending on the actual electricity generation, compensation guaranteed by the government will be granted, which will ensure the sustained operation of the system in combination with the user fees. This model has yet to be tested in practice. The RPT corresponds to the development policies of output based aid, which is becoming increasingly important.

Summary

In order to electrify off-grid regions, systems in the range of under 50 watts to systems of several megawatts were developed that are fed with renewable energy.

Very small systems which are privately owned by the electricity consumers are already operated sustainably worldwide. There are also appropriate financing and operator models.

An even greater challenge are the so-called mini-grids that can be successfully operated as stand-alone grids but which impose significantly higher requirements to the organisational framework. The advantage of grid interconnection is both the equalisation of generation and load and the higher energy yield as less power has to be stored or derated.
The goal is to build power supply grids for densely populated areas which offer a secure supply and a high grid quality and can possibly later operate in an integrated grid. The challenge now is to develop financing and support models and to provide incentives for investors and the sustainable operation of the power supply systems that can be used in the respective regional socio-cultural environments. The "Renewable Energy Regulated Purchase Tariff" [3] is a viable model especially for stand-alone grids which, however, still needs to be tested in practice.

The development of grid-compatible stand-alone systems, which has been promoted in Germany since the nineties, has also allowed for a technological edge for the next generation in grid technology of integrated grids. The systematic introduction of modern information and communication technology at the distribution grid level, promoted under the slogan "Smart Grids", also benefits from this preliminary work. An example is the so-called micro-grid that can work as a distribution grid in an integrated grid and, in the case of a blackout, can ensure supply as a stand-alone system.

Acknowledgement

The research upon which this article is based would not have been possible without the support of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the European Commission.

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