Advanced Active And Reactive Power Control For Mini Grids

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1. Introduction

Distributed supply based on renewable energy sources is one main element in all scenarios for the worldwide energy supply in the future. Solar energy, wind energy, bio fuel and hydro power will be basic essentials of a long-term sustainable energy supply. The integration of distributed generators into supply networks has already become a relevant issue in many countries. The costs for energy production of renewable sources will become more and more competitive to the increasing cost for fossil fuels in the next years.

Important developments have been done in the last years in field of electrical system technology for distributed generation. This evolution has brought many new possibilities using energy from local renewable resources for rural electrification, especially in the areas where an extension of the public grid is too expensive. In this areas energy production from renewable energies is economical at this stage, even without considering the ecological and social advantages.

The recent developments of the inverter technology allow to built up supply structures in stand alone grids today, that are very similar to the large interconnected public grids. The modular AC-coupled hybrid systems and mini grids have brought a completely new quality to standalone energy supply systems and has closed the gap between grid connected and the previous common off-grid systems, like solar home systems or small DC-coupled hybrid systems.

2. Features Of Modular Ac-Coupled Energy Supply Systems

In AC-coupled energy supply systems all components are connected on a standard AC low voltage grid (e.g. 230V/50Hz, 120V/60Hz). This configuration can be used in off-grid-, on-grid and mixed configuration e.g. as a utility backup system.

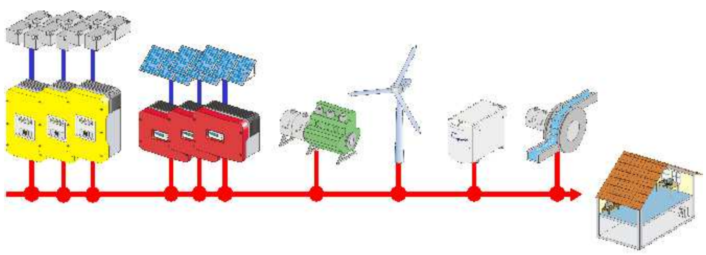

Figure 1: Parallel connected devices on an AC mini grid

The coupling of standard AC devices on a common standard AC-bus provides seveal advantages:

- Standardized components (230V/50Hz or 120V/Hz) can be used
- Cost reduction due to simplified design, installation, operation and maintenance
- Connection of off-grid systems to the utility network is possible

- Parallel operation allows unlimited extension of the system and increases reliability
- The power on AC-side sums up from all generating components; The battery inverter is not a bottle neck in the system
- Productive use due to AC network structure

3. Bi-Directional Battery Inverter

The heart of the AC-coupled supply systems is the bi-directional battery inverter which controls the voltage and frequency of the grid. In order to use all advantages of the modular AC-coupled system design new control algorithms for the inverter have been developed and successfully implemented. Comparable to the control of a pool of conventional power plants (e.g. the European electrical power supply grid UCPTE) the so-called "droop-mode-control" is based on an active power / frequency-static and a reactive power / voltage static (see figure 2). The droop mechanism is inherent in standard AC-generators as e.g. the frequency decreases while the load (active power) increases.

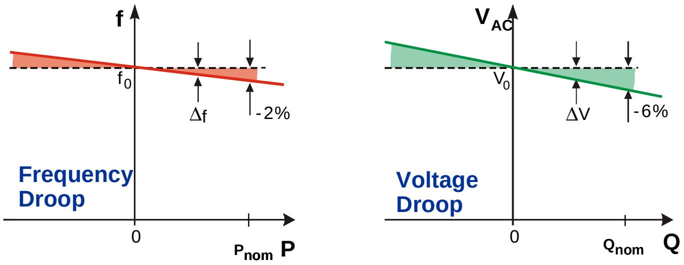

Figure 2: Active power / frequency static and reactive power / voltage static

The droop mechanism allows it to operate the inverters in parallel in an unlimited number without any high-speed communication. The inverters can be paralleled to synchronous or asynchronous gener-ators and also to the public grid. The overload capability of the whole system is really the addition from all power sources (inverters and generators) just due to the control of each device.

Beside the voltage and frequency control the inverter operates the fully automatic management of the power supply system:

- Control of energy sources and loads (automatic start/stop of generators and loads)
- Protection and maintenance of components (e.g. regular battery charging)
- Minimization of losses (switching-off of parallel inverters during periods of low load)
- Supervision of all relevant system parameters

The main parameters for the operational control of the mini grid are the state of charge (SOC) of the battery storage and the actual values of energy consumption and generation. Based on these values the control functions can be realized via programmable relays and via shifting the frequency to load or unload the power sources. The automatic management and maintenance of the battery is crucial for the running costs of the system, as the battery is a main cost factor of the system and its life time can be prolonged up 100% by a efficient battery management.

The limitation of the power output of the generating components by shifting the frequency, enables to control distributed energy sources of the grid without a communication line. This control strategy can be used for all kind of controllable energy sources like PV-systems, inverter-coupled wind turbines, hydroelectric systems and different kind of fuel generators or CHP-units.

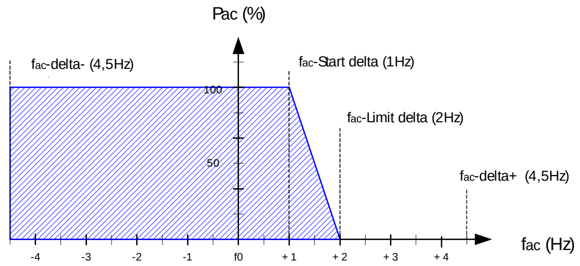

Figure 3: Frequency shift power control for limiting power output in the AC mini grid

4. Photovoltaic Inverter

Photovoltaic inverters, today produced in high numbers for grid connected systems, can also be used in AC coupled off grid systems. The following points have to be considered to achieve the best performance for the system:

- The inverter should have a very high efficiency (>95%)
- The parameters for grid supervision have to be adapted to the conditions in the mini grid
- The output power should be controllable via the frequency
- The inverter should be suitable for outdoor installation close to the PV generator

The developments and cost reductions achieved for grid connected PV-systems make use for the off grid systems as well.

4.1. Example of a realized AC-coupled PV-Hybrid System

A good example for a larger AC-coupled off grid system is the power supply of a monastery in Greece with a 31 kWp PV-generator coupled to a mini grid via 6 PV-inverters with 6 kW nominal power each. The PV-generator is connected via a three phase overhead line of approx. 800 m length, because it was not possible to install the PV-generator closer to the buildings of the monastery. The large distance between the components would not be possible in a DC coupled system, because the losses on the DC cabling would be too high considering the typical battery voltages.

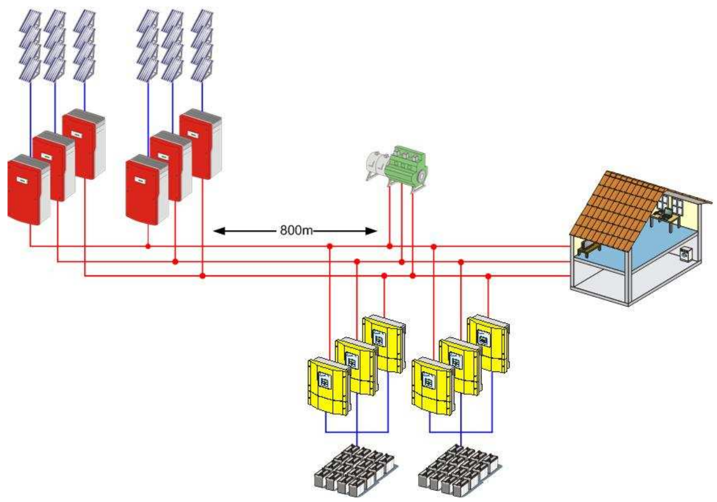

Figure 4: PV-System with 31 kWp PV-generator in a Greek monastery

A diesel genset is used as back up for the system during times of low irradiation especially in winter. Additionally it is planned to integrate a wind turbine into the systems to minimize the fuel consumption.

5. Wind Turbines

Two types of wind turbines can generally used in AC-coupled mini grids:

- Stall wind turbine with induction generator
- Wind turbine with PME generator and inverter for grid connection

A stall wind turbine with induction generator can easily be connected onto a AC mini grid, if the following points are considered:

- The inrush current has to be adequate to the capability of the mini grid, therefore a soft start should be integrated
- The power output of this type of wind turbine cannot be controlled. In small mini grids other measures e.g. a controllable load have to integrated to avoid an excess of power in the system.

Wind turbine with PME-generators are coupled to the AC-grid by inverters that are very similar to the PV-inverters described before. The following additional points have to be considered for this application:

- A rectifier and possibly an additional over voltage protection or a step-up converter is needed on the input of the inverter
- The inverter must have the function to reduce the power output with increasing frequency
- A special control characteristic for wind turbines (turbine mode) has to be used (different from PV-characteristic)
- It must be insured that no over speed occurs or over voltage is produced by the wind turbine if the inverter is unloaded or disconnected from the grid

5.1. Example of a realized AC coupled off grid system with wind turbines connected via inverter

Figure 5 shows the block diagram of a mini grid used as power supply system for guest lodges in South Africa, consisting of a PV-system of 3,6 kWp, two inverter coupled wind turbines of 2,5 kW each and diesel genset.

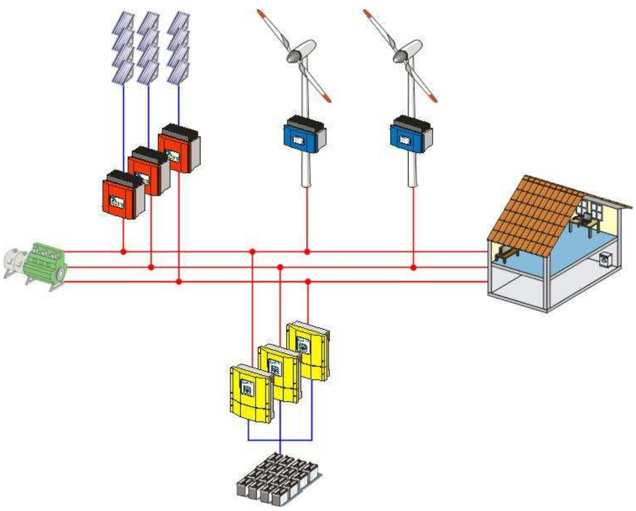

Figure 5: Energy supply system in South Africa with two wind turbines with PME generator and inverter

6. Bio Fuel Generator

Bio fuel generators can be integrated to AC-mini grid in the same way as conventional fuel generators or CHP units. The principal configurations are:

- Grid forming generators (synchronous generator or PME generator inverter coupled)
- Grid parallel units (mostly CHP units with induction generator or PME generator inverter coupled)

For villages electrification it will usually be advantageous to use grid forming units with synchronous generator. This is the most common technique for stand-alone applications and makes it possible to operate the generator completely independent and redundant to the other components.

The generator can be operated fully automatically controlled by the battery inverter. In this case it will be started depending on the state of charge of the battery and in case of too high consumer power. If the generator is paralleled to the battery inverter in droop mode the available power is the sum of both devices. That makes it possible to cover peak loads or to start up large devices like big pumps, motors etc. The automatic generator control integrated to the battery inverter should also consider the requirements of the generator like minimal runtime, warm up and cool down time. Additionally it is possible to operate the generator manually, if an automatic control is not possible.

6.1. Example of a realized system with a jatropha plant oil generator

Several projects have been realized with vegetable oil generators in Tanzania, Ghana and Indonesia. Figure 6 shows the block diagram of a power supply system consisting of 10 kWp photovoltaic generator and a generator operated with jatropha oil at a training centre in Tanzania. The jatropha plants are grown and processed directly on-site. Independence from fossil fuel achieved through vegetable oil.

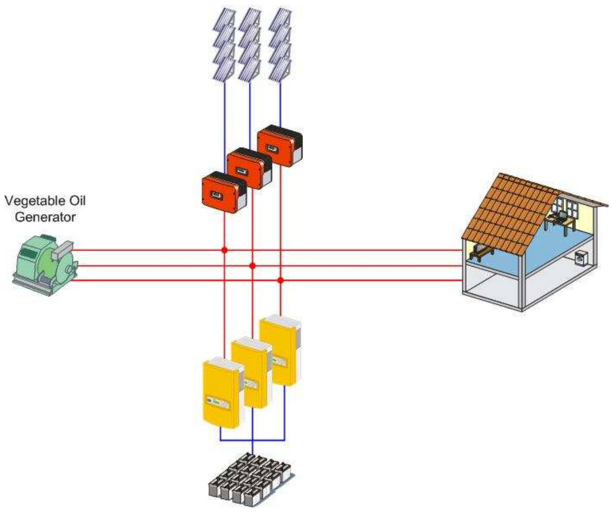

Figure 6: Energy supply system with PV generator and vegetable oil generator at a training centre in Tanzania

7. Hydro-Electric Plants

The following three types of hydro-electric plants can be integrated into AC-coupled Mini grids:

- Frequency and voltage controlled systems with synchronous generator
- Systems for grid connection with induction generator (similar to stall wind turbines; they should have a soft start).
- Inverter coupled systems with PME generator

The principles for the integration of the hydroelectric plants is very similar to the integration of wind turbines as described before.

7.1. Example of a realized off grid system with a hydroelectric plant

Several standalone small hydro systems with synchronous generator have been improved by parallel battery inverter systems in droop mode in the last years. Figure 7 shows the configuration on an alpine lodge with a 10 kW hydro plant, a CHP unit of 10 kW and a 13,5 kW battery inverter system. The battery inverter is operating in droop mode and supports the very unstable control of the small hydro plant. The CHP unit is used for producing heat and to charge the battery if the energy from the hydro plant is not sufficient.

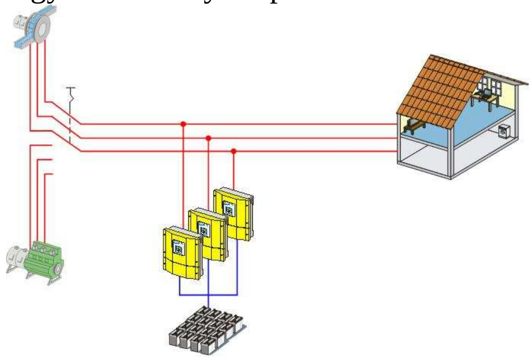

Figure 7: Power supply system with hydro electric plant on alpine hut

8. Back Up Systems

The backup system is the synthesis of grid connected and off grid systems. AC-coupled systems can operate in parallel to the public grid and can also operate off grid in case of a failure in the supply network. Especially in regions with unstable or weak grids this configuration can be of high value. If the grid is available the generation system supplies the local consumers, additionally excess energy can be fed into the grid in order to support the public utility. In case of a grid failure the system disconnects from the grid and changes to off-grid mode to maintain the local supply. Very important is, that the system detects failures on the grid and disconnects immediately. The limits for grid voltage and grid-frequency have to be adapted to the local requirements and additionally a detection for unintended islanding should be integrated. All this can be realized by the battery inverter.

9. Conclusions And Outlook

Modular AC coupled mini grids and hybrid systems have proven their efficiency in very different applications and with all kind of renewable energy sources. It is the ideal way to build up distributed energy supply systems for grid connected, off grid and back up applications and is therefore the appropriate technology for rural electrification and remote areas with renewable energy sources. The innovations and developments from the very fast growing market for grid connected PV-technology can be applied in systems in a power range from 3 kW to 100 kW or even more that can easily be designed, installed and operated with standard components. The control principles are compatible to that of conventional power plants and therefore it is easy to integrate these systems into public networks. The manager of the AC-coupled mini grids is the battery inverter that utilizes voltage and frequency control and the operational control of the energy supply system. The droop control in combination with the power control of the generators via frequency shift makes it possible to built up distributed system without a fast communication system.

Rising cost for fossil fuels and further cost reductions and developments in the field of renewable energies, especially photovoltaic, will make AC-coupled energy supply systems based on renewable source one main element for rural electrification in the near future.

10. References

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