Application note:
Implementation of a Demonstrator

Summary

The change from fossil to renewable energy sources will change electric grids to become more decentral (distributed generation) and flexible (Smart Grid). New solutions must guarantee reliable and economical operation of this fundamental, yet increasingly complex infrastructure. Easy Smart Grid focusses on energy management in micro grids. These are parts of larger grids (areas), island grids, or blocks of a future "cellular" grid. On the basis of successful R&D work we demonstrate in a concrete example how consumers can react to changing availability of renewables.

1. Challenge

We wish to influence a large number of consumers in a micro grid such that their flexibility helps to optimally use renewable energy from PV or Wind. Today electric grids are managed centrally and can economically apply demand side management (DSM) from about 500 kW. Our objective is to scale by a factor of 1000 with our decentral management scheme. To achieve this, the existing effort (and cost) must be reduced by thousand, to economically integrate a large number of consumers in the range of 0.5-5 kW (electric cars, heat pumps, white goods). Research already completed has confirmed the feasibility (value created by DSM, stability of decentral automation, comparable performance of decentral and central energy management). For further information on those, please contact us.

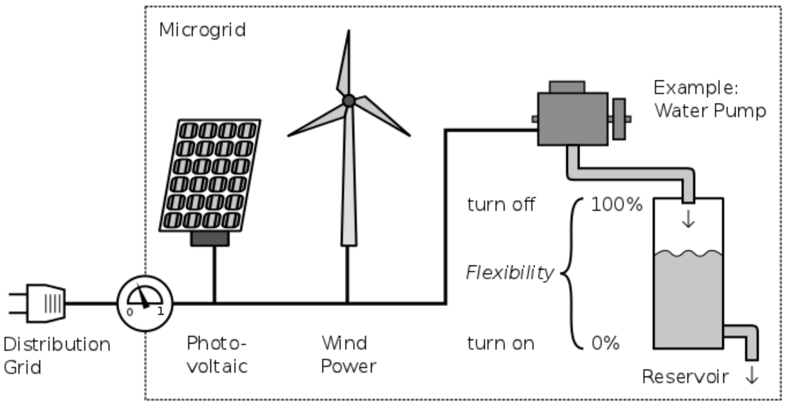


Figure 1: Scenario Fig. 1 shows the scenario. Renewables supply electricity into a micro grid. Base and peak energy are provided by a traditional supplier. This may be a grid operator, or, in an island grid, a diesel generator. We wish to influence potentially flexible consumers to use renewables as much and conventional energy as little as possible. The requirements can be listed as:

- ✓ Simple operation and integration into existing system (low requirements on infrastructure, use of standard components, upward compatibility – no adaptation need for the other users)
- ✓ Use of different flexibility types, no need for user interaction (except for initial configuration)
- ✓ Response to variations in energy supply in real time (seconds)
- ✓ Scalability (benefit from one to very many users)
- ✓ Resiliency (failure of communication or other users control devices).

Fig. 2 gives an example of energy availability during the day: Base load is provided by the supplier. In the morning, a bio gas plant starts, sun and wind follow. In the late evening hydro power becomes available. On the load side, four pumps must run for 10 hours a day to keep a minimum water level in their reservoir, each of which covers 10 hour's consumption. An ideal operation schedule to maximize use of renewables and minimize consumption of conventional sources is sketched in Figure 2, bottom. Our objective is to achieve this operation without central optimisation and the associated effort and side effects.

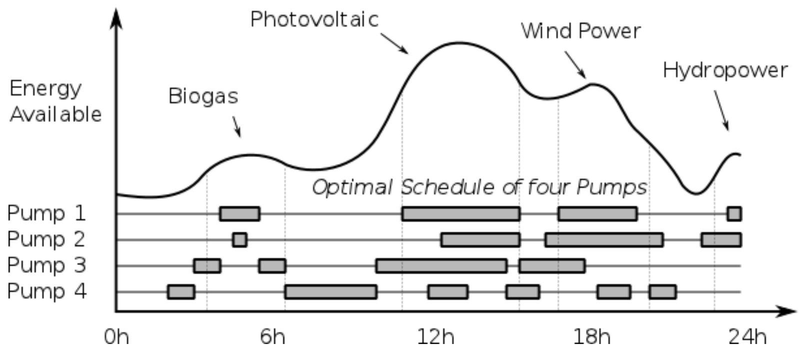
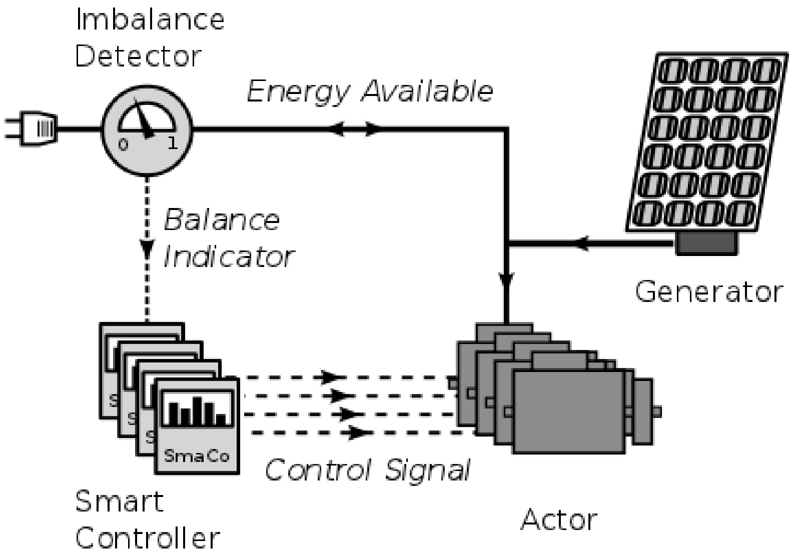


Figure 2: Operating schedule

2. Solution Approach

Our approach is based on a swarm of controllers (SmaCo or „Smart Controller") following one signal (balance indicator). The balance indicator depends on current shortage or abundance of energy. As an example, a group of consumers within an area could measure energy flow at the interface to their supplier. Outflow indicates abundance, inflow shortage of energy in the area.

Figure 3: Swarm Control



The energy balance indicator (economists would call it a price signal) is received by all SmaCo's. Each SmaCo uses this balance indicator and the available flexibility of the load it controls to decide when to switch on or off. These decisions solely depend on the balance indicator and local information, without any communication between SmaCo's or with a central optimisation unit, and without the need to disclose or protect private data. The control loop is closed as the balance indicator also reacts on loads.

3. Example Application

Each consumer has an individual potential for load shifting. In Fig. 1 a water pump fills a reservoir. As water level approaches the lower limit, the pump must be switched on to refill. At the upper limit, it must be turned off to avoid overflow. At all other levels the pump is flexible to use otherwise unused renewable energy. As a side condition, a pump may have a minimum runtime to avoid wear. Heating and cooling devices or air-conditioning units which keep temperature within a small range, compressed air storage holding 6-8 bar pressure, and heat or sewage pumps can provide similar flexibility.

Our algorithms take intelligent control decisions on the basis of swarm methods. Their advantage is that individual agents (controllers) need only few and simple rules. Each bird of a swarm only uses two rules: "move to a source of food" and "keep a certain distance from your neighbour". Neither a central controller nor communication are needed that could fail, which increases resiliency.

The source of food in our example is the energy available. As it increases, the "imbalance detector" transmits a shrinking balance indicator (Figure 4 left). When loads are low, sun shines and wind blows, the balance indicator is close to zero (abundance). At night, without wind and under high load condition, it is at a maximum (shortage).

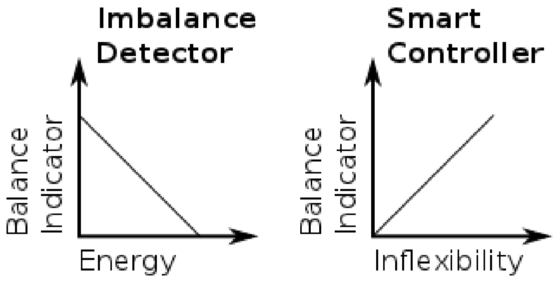


Figure 4: Balance Indicator

4. Implementation of the Smart Controller

Each SmaCo continuously measures the flexibility of the device it controls: With an empty water reservoir, the pump is inflexible and must be switched on. Then the valuation of energy is equivalent to the maximum value of the balance indicator (Figure 4 right, shortage of flexibility). A full tank is equivalent to maximum flexibility. The pump may remain switched off until the end of its flexibility period. Its current energy valuation therefore is zero. The valuation for points in between can be derived the same way.

Each SmaCo decides to switch its load on or off, based on the balance indicator and local information (state of charge, user constraints). Its algorithm may use historic data and any weather forecast available. Minimum switching-on durations or cool-off periods also influence calculation of energy valuation. Within the micro grid the balance indicator establishes the price signal for a real time energy market.

5. Implementation of the Demonstrator

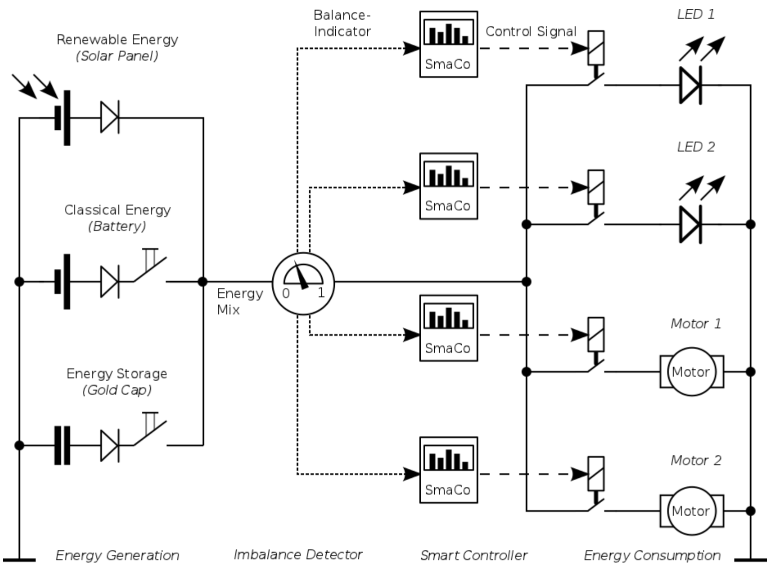


Figure 5: Demonstrator Schematics

The demonstrator implements the swarm described above. We thus check if the technology works as expected, i.e. meets the defined targets. It also helps to assess hardware needs and undesired side effects such as self-stimulated oscillations.

Fig. 5 gives an overview of the demonstrator. We use two small motors (40mA) and two LEDs (20mA) as consumers, switched via relays. Solar cells produce renewable energy, batteries emulate the conventional energy supplier, a gold cap capacitor can be added as a "storage" device. Balance indicator and SmaCo swarm are computed several times per second by a Raspberry Pi with Raspbian Linux in Java, and a display unit is added for visualisation. We measure system voltage, currents supplied from the sources together with total current consumption, and calculate power and energy from those.

The balance indicator is determined by system voltage of the demonstrator. With full insolation and no load, the solar cells deliver 5 V and the balance indicator reaches its minimum (zero). The battery starts to contribute at 3 V, at maximum load system voltage falls to 1 V where the balance indicator reaches its maximum. Between these points, linear interpolation is used.

It is important to emphasize that the size of loads (we used mW instead of kW likely in practice) and the way to derive the balance indicator have no influence on the demonstrator principle: We used system voltage for simplicity, while in AC grids balance is typically indicated by frequency. Flexibilities have been chosen and implemented in software individually:

Consumer	Reservoir Capacity secs	Time on %	Minimum Time on sec
LED 1	30	50	8
LED 2	60	20	4
Motor 1	25	33	8
Motor 2	120	40	6

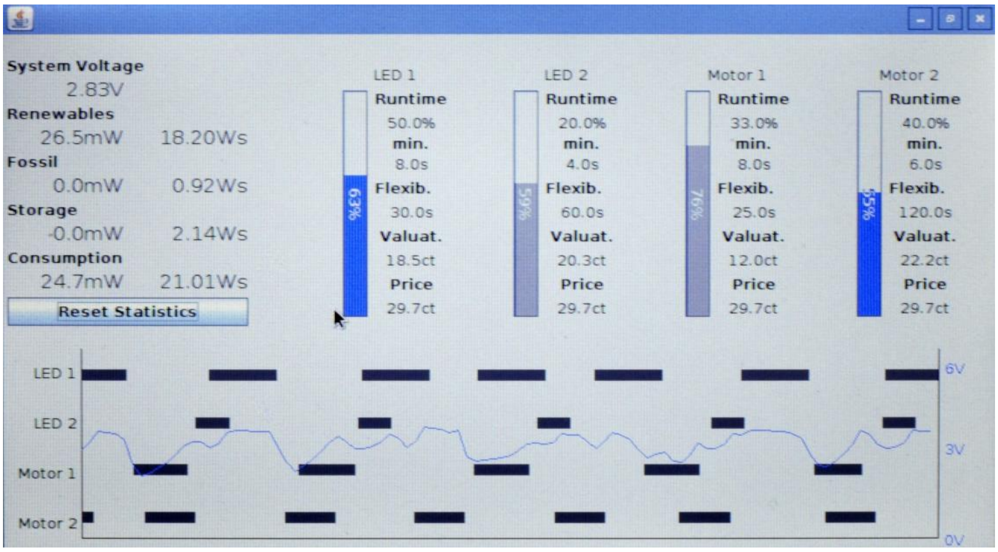


Fig. 6: Demonstrator Results

Swarm technologies work best with many identical units. Our swarm, however, is challenging with only four units which differ in flexibility, which in turn are not integer multiples of each other. It is difficult to find a useful sequence then. Even under these conditions, the swarm organizes itself to minimize battery consumption. The swarm also reacts in a reasonable way to changes in energy availability, addition or removal of consumers or storage just as changes of flexibility parameters.

I wish to thank Dr. Erik Buchmann for the co-operation on this stimulating and insightful project.

6. Next Steps

The complete intelligence for four decentral controllers was realized on a board costing 25€. With suitable quantities cost of hardware could drop below one Euro if – as described in our application note "Conversion of diesel driven grids"- grid frequency can be used to transmit the balance indicator. First, however, industrial modules (some 1000€) will be used as a platform for applications in the 100 kW range. Costs have sufficient potential to shrink with growing quantities and make integration of smaller loads economical.

Research and findings so far are a solid basis for first practical applications. We welcome partners that wish to jointly implement new solutions.

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