DYNAMIC CONDITIONING OF STOCHASTIC FLUCTUATING ENERGY FROM WINDPARKS

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Abstract – The stochastic fluctuating offer of wind energy limits the capacity of supply in electrical grids by means of technical and economical reasons. To increase the supply, a concept of dynamic conditioning with the objective to increase the quality of supply was developed. The concept envisages support and management of the electrical grid respectively through compensation of active and reactive power with static converters ("Electronic Synchronous Machine") and short time storage. By the four-quadrant operation of the converters, short time fluctuation of the energy sources and changes of the load can be absorbed or smoothed directly on location. By the use of dynamic storage systems an intermediate storage of the stochastic offered primary energy is done. This low order energy can thereby be converted into high order recallable energy, which even can be used to satisfy peak demands. The local compensation of the fluctuation of the energy supply on the one hand and of the changes of the demand on the other hand, allows a more steady energy demand from the nation-wide electrical grid.

Keywords: power conditioning, dynamic storage, renewable energy systems

1 INTRODUCTION

Generally a conditioning of the energy is necessary if, due to strong fluctuation of the local power flows or non-sinusoidal currents, a rigorous reduction of the power grid quality is caused at the relevant point of common coupling.

By means of energy supply from statistic fluctuating sources, the mentioned unfavourable conditions can easily occur, especially within network spurs with low short circuit power output or in isolated grids. As well the maximum allowable connection load is highly restricted. Besides the non-periodical fluctuating active power, caused by the stochastic fluctuating source, the causes of low or unsteady quality of supply in coupled grid units can be switch on/off incidents, emission of harmonics caused by systems with converters, and not appropriate adapted system control or operation. The low, respectively unsteady, quality of supply is the cause for voltage fluctuation (flicker effect) and voltage alterations (demand of reactive power) in coupled part grids.

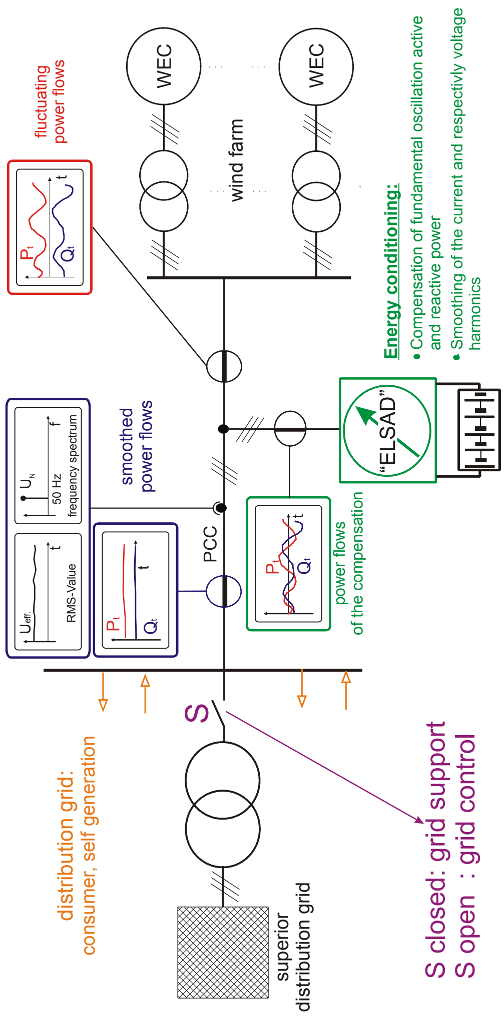

Figure 1: Basic concept for energy conditioning in dezentralized electrical energy supply systems

The major tasks of the dynamic "energy conditioning" are smoothing of the long term fluctuation of the renewable energy supply, dynamic compensation of short term power variation, and filtering of harmonics (grid support) (fig. 1).

2 FUNCTION PRINCIPLE OF ENERGY CONDITIONING

The synchronous machine can basically be used for energy conditioning, because of the special subtransient and transient behavior as well as the possibility to adjust the stator current versus the stator voltage by alternating the synchronous internal voltage over the excitation voltage and the load angle over the drive torque in all four electric quadrants during grid parallel operation. Therefore disadvantageous for active power smoothing are the fixed rotation-torque characteristic, the poor control dynamic of the synchronous internal voltage, and the rotor displacement angle at the range from 100ms to several seconds, and phase swinging.

Using the simplified model of the rotating synchronous machine with damper cage, it can be seen as a real voltage source with frequency-dependent operator impedance X(p) and variable (amplitude, phase angle) source voltage. With increasing frequency the reactance decreases until the subtransient reactance x_d'' is reached and operates as a harmonics drain. In case of transient behavior caused by switching operations in the grid, the effect of grid support results in means of dynamic increase of the grids short-circuits power at the PCC. Therefore voltage drops are reduced without intervention of the control.

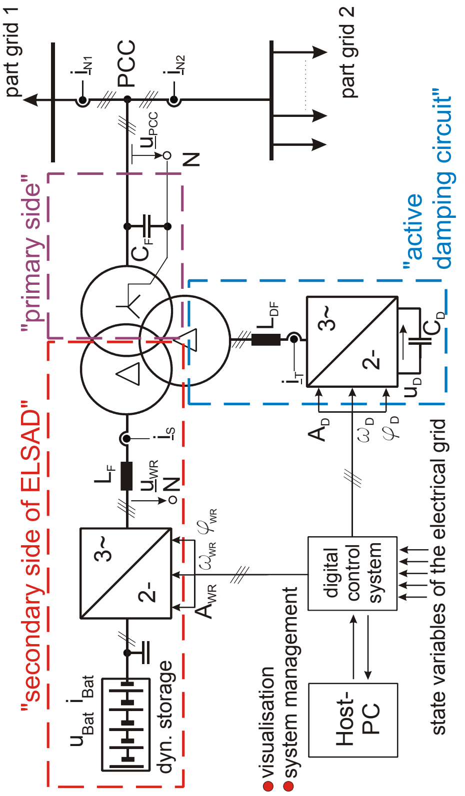

Figure 2: Electronic Synchronous Machine with active damping circuit for energy conditioning

At stationary operation, X(p) of the synchronous machine equals the synchronous reactance at fundamental oscillation mode (e.g. for reference value of the controlled system). The characteristics during this period are only determined by the dynamic of the superior control loop (e.g. for the terminal voltage).

The behavior of the synchronous machine is simulated within the energy conditioner. By the use of a short term accumulator for the active power input and output, the system becomes a static energy conditioner (fig. 2). Additional requirements are short-circuit proof operation and application in a large range of performance.

The introduced system, in the following known as Electronic Synchronous Machine with Active Damping circuit (ELSAD), is able to control the active and reactive power at the PCC. Therefore it can increase the energy quality to the demanded degree at this point.

3 CONTROL STRUCTURE

The concept of a cascaded PI-state control, pictured out in this paper (fig. 3), establishes among the known advantages of a PI-state control the possibility to accomplish detaching control circuits by cascading state control circuits with given limits for the setpoint values.

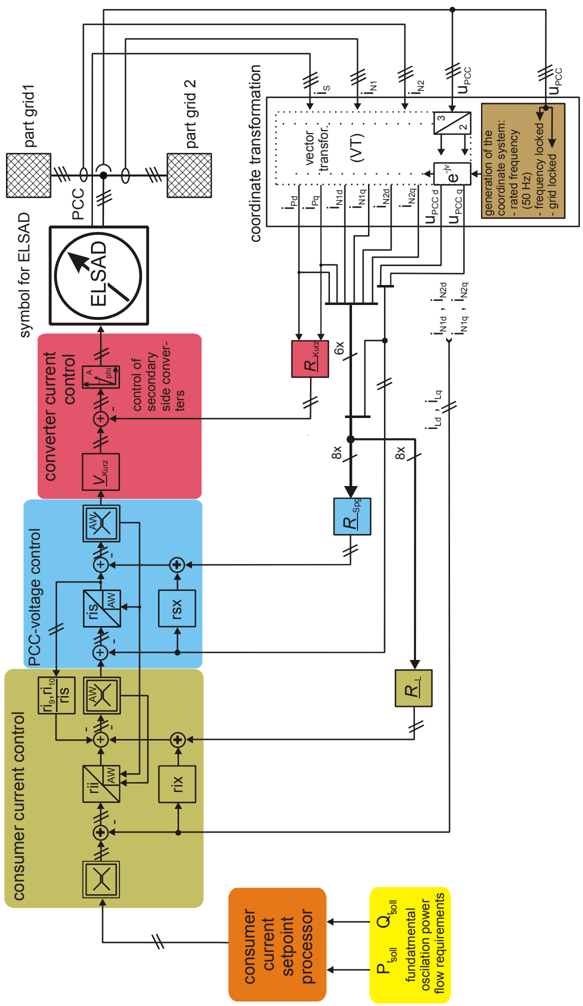

Figure 3: Diagrammed illustration of the fundamental oscillations control

The trait of the controller changes through structure modification, depending on the active limits, by seizing of determined control circuits through the limitation. Thereby the operating behavior is collected by the sub-ordinated control circuits.

The inverter current, control with limitation of the absolute value of the current, establishes the innermost control loop of the dynamic compensator. It is, provided that it has a adequate design, used to limit the current in case of a short circuit. The controller is based on a state control parameterized on the short circuit impedance of the inverter. This impedance depends, unlike to the impedance of electrical grids coupled at the PCC, on time. As a result of this, the parameters of the control circuit don't have to change with the charge states.

The actual voltage value at the PCC is kept in a small range of tolerance at a adjustable setpoint by a superior voltage control circuit. Due to the special control structure the voltage control circuit is only active in case of a actual voltage value outside of the range of tolerance and therefore only then impresses a voltage source like behavior to the system.

The consumer current control is superior to the PCC-voltage control. If this control circuit is active, the dynamic conditioner behaves like a controlled current source at the PCC. Such a mode of operation has advantages at a coupling on a rigid net. This means the nominal power of the dynamic conditioner is slender compared to the coupled grid. In this case there can be no noteworthy impact on the working voltage at the PCC, neither by the load, nor by the dynamic conditioner.

If the setpoint values of the voltage control are in their range of tolerance, the consumer current control should impress its behavior on the system and compensate the subordinated control circuits. To avoid stationary control deviation this outer control circuit is also a PI-state control circuit.

The calculation of the setpoint values of the current control circuit is based on orthogonal active and reactive power components. Hereunto a consumer current setpoint processor is heterodyned on the consumer current control circuit, which calculates the consumer current setpoint value from the power setpoint values forced by the operating control and from the actual voltage value at the PCC.

4 STORAGE TYPES

To be considered as dynamic storage for energy conditioning are:

- accumulators (chemical energy)
- flywheels (kinetic energy)
- compressed-air storage (potential energy)
- pumped storage (potential energy)

Storage Type	Energy density		Dynamic	Max. capacity
	[kWh/m³]	[kWh/kg]		[kWh]
accumulator	200…500	0,02…5	High	< 50.000
Flywheel	1…8	0,006	High	< 100
compressed-air storage	1…2	0,003 … 0,06	Middle	
pumped storage	0,3	0,0003	middle to low	

Table 1: Storage types and their specifications

The accumulator is the most known and used system for the storage of electrical energy (in electrochemical form) by far. It features the possibility of latching bigger amounts of energy at exquisite dynamics. From the technically restricted realizable capacity an application arises in compensating short and medium term fluctuations of the energy demand or supply. Depending on the design of the accumulator there are some disadvantages. The charge/discharge cycle rate and the depth of the discharge have a direct impact on the lifetime of a battery system. These effects are appearing particularly with the, for reasons of economy, most common lead-acid accumulators. By selective structuring of the electrodes (by additives and design) special lead-acid accumulators for the use in decentralized energy supply systems has been developed with charge/discharge cycle rates above 1500 and only a small loss of high current capacity. Another development in this regard is the lead-gel accumulator. It is maintenance free for the whole life cycle and provides flexible installation possibilities.

High energy density has been realized with Ni-Cd and Li-Ion accumulators. Because of their high own consumption (e.g. Li-Ion accumulators), the memory-effect (Ni-Cd accumulators) and the high actual costs, these accumulators are only used in applications with a big need of reduction in weight.

Another alternative for the use as a high dynamic storage system are high-speed flywheels. Unfortunately the realizable capacity is today still 10-times smaller than the capacity of lead-acid accumulators. In contrast to electrochemical storage systems flywheels don't show a memory-effect. Just as little as there is an impact of the charge/discharge cycles or the depth of the discharge on the lifetime of the flywheel. The fundamental disadvantages are based on the fact, that they have a high own consumption, caused by the bearings and the air friction, despite an operation at low pressure ($P_{abs.} \approx 2 \ldots 10$ mbar). Furthermore the flywheel systems are subject to abrasion as the case may be lifetime reduction even in "stand-by-mode".

By compressed-air storage, in combination with subterranean caverns, storage depth are realizable which allow the compensation of long term fluctuations in the energy offer of renewable energy sources and the energy demand. An enhancement of the energy density aspired by nearly adiabatic compression and expansion of the gas.

Equivalent to the storage pressure of compressed-air storages, the height of fall determines the energy density and the storage depth of pumped storage systems. The topology of the surrounding defines, besides other factors, the realizable storage depth and energy density. This stands in conflict with a use in combination with renewable energy sources (e.g. the wind energy), because regions with good wind speed rates normally have a physiography which doesn't allow the construction of pumped storage systems.

From today's point of view lead accumulators and flywheels can cover the task of energy storage in decentralized energy supply systems. Above that it is possible to reach a higher level of utilization of the renewable energy sources on location by a middle and long term application optimization through a combination with compressed-air systems or pumped storage systems.

5 MEASUREMENTS AT THE TEST BAY

The ELSAD was put to test in a test bay. Measurements were made under grid parallel and isolated operation conditions. With a computer controlled wind energy converter-test bench, including a asynchronous generator, the characteristic of the active and reactive power curve, as shown in fig. 4, were reproduced. A 60kVA ELSAD-test plant was then used to condition and smooth the energy that was supplied to the public power grid.

The influence of the simulated gusts and tower effects could be decreased by more than the factor of 10 and the reactive power consumption from the supply grid was completely compensated.

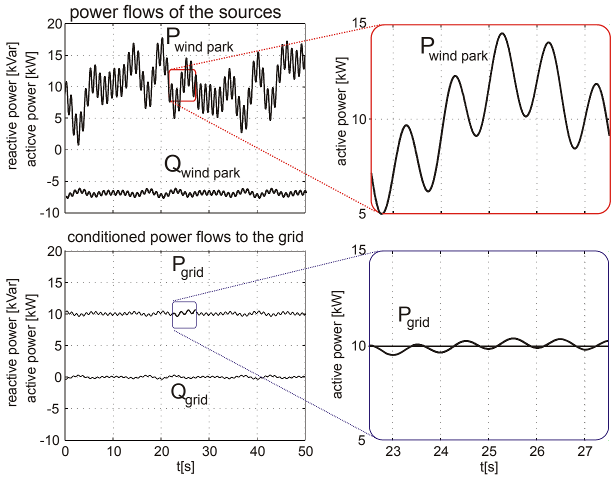

Figure 4: Smoothing of wind caused power fluctuations and compensation of tower effects

Figure 5 shows the voltage curves at the PCC when an asynchronous machine (ASM, 10 kVA) at a grid short-circuit power of 150 kVA is engage (motor start-up) at the time t_1 with and without the ELSAD system. The measurement results show the effect of the dynamic increasing of the short-circuit power by means of the subtransient and transient system characteristics of the ELSAD. The relative voltage drop at the PCC during engaging was decreased from 20% to 7% and was completely compensated after 50 ms.

In addition, the energy conditioning system with a limited power compared to the nominal power of the wind energy converter was applied for mid and long term smoothing of wind caused power peaks. The installed power of the energy conditioner represents 20% of the nominal power of the connected wind energy converters. The accumulation depth, defined by

$$T_{SP} = \frac{E_{SP}[Ws]}{P_{N,WEC}}[s],$$

of the test facility was set up with 8.3 s in respect to the nominal power of the wind energy converter.

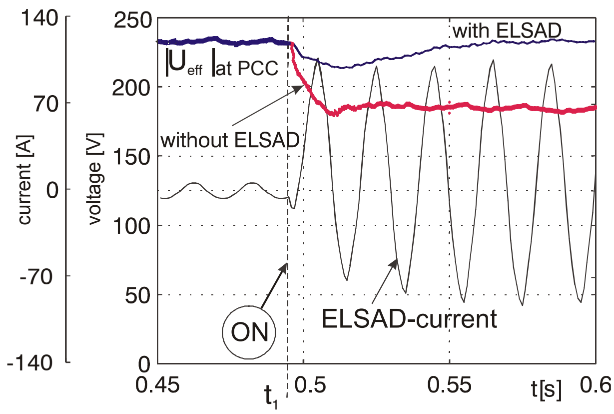

Figure 5: Start-up process of a 10 kW asynchronous machine in a network spur with low short circuit power (ca. 50 kVA)

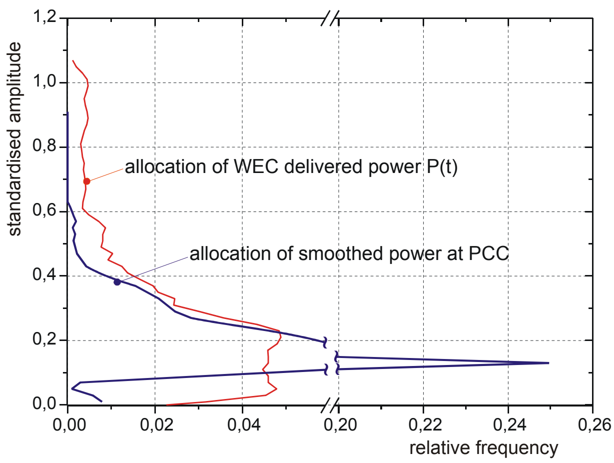

Figure 6: Comparison of frequency distribution of the output power of the WEC with the smoothed power at the PCC

The test results, as shown in figure 6, were evaluated using the classification method. It is obvious visible, that the fluctuation of the supplied electrical power at the PCC could be limited to the designated tolerant band of $P_{mean} \pm 0.2 * P_N$, using the energy conditioner. The distribution of the electrical power provided by the WEC shows values that noteworthy differ from the mean value.

6 RÉSUMÉ

Within the scope of the presented study it was demonstrated, that it is possible, to smooth short term fluctuations in the energy supply of renewable energy sources (e.g. wind power) by the use of a dynamic energy conditioner in combination with dynamic storage. Above that a limitation of the middle and long term changes in power output relating to the average value has been realized. This limitation of the middle and long term gradient of the output power allows long term predictions about the availability of energy from renewable energy sources in electrical public power supplies. Thereby the share of electrical power generated by wind energy converters to cover the basic energy demand can be increased.

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