Grid control via power converter

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The purpose of this paper is to investigate the possibilities of power converter driven instantaneous power for regulation applications in Germany of the year 2030. Two viable options, one special for wind turbines and a universal solution are rated for the German needs of 2030.

1 Introduction

The gradually changing constellation of power generation in Germany will lead to a ecologically more friendly generation. This development is approved by the German government and subsidized by them. But this change will expose a weakness of the renewable energies as they are right now. Without a substitute for the inertia of conventional generators the stabilization of the grid will cause huge problems, cause the frequency droprate is related to the inertia. According to the survey "dena-Studie Systemdienstleistungen 2030" of the "Deutsche Energie-Agentur GmbH (dena)" two thirds of the instantaneous power and energy have to be compensated for the year 2030. Possible solutions for this problem are investigated in this and the associated paper [1].

2 Generation

The predicted change (Tab.1) will have a intense impact on the stability of the electrical grid. Due to the rising percentage of renewable energy plants.

	installed power generation in Germany in [GW]				
	konv.	hydro power	biomass	wind	photovoltaics
2030	76	16	11	91	65
2014	90	14	7	34	37

Tab. 1: power generation constalation in germany of 2014 [4] and 2030 [2]

The total installed amount of conventional power plants will not drop significantly but the booming renewable energy plants will displaces them in the normal operation. And therefore a decreasing inertia of the power grid. No substitution of generator inertia will lead to more fluctuation of the frequency, in case of a loss in generation. [2] projects this deficit with 254MW and 0,68 MWh for the year 2030.

3 possible approaches

A: capacitor driven system

This option is for almost all renewable energy power plants feasible. The two topologies are shown in Fig. 1. A basic converter is used and for this application modified to deliver instantaneous power with a triggered launch. Two topologies were investigated, topology 1 uses the usual software but gets a separated DC-DC-converter and capacitor. Topology 2 uses a reviewed software and a bigger capacitor that enables the converter to shift the voltage level of the DC-link capacitor. Both systems have advantages over each other and are further evaluated in [1].

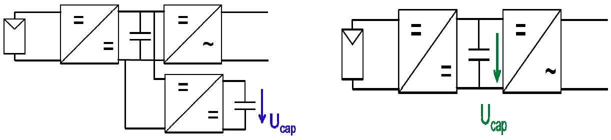

Fig. 1: Topology 1 (left) , topology 2 (right)

B: mechanical based system

A system like this uses the rotational mass of wind turbine (WT) rotors, this is although called emulated inertia or virtual inertia because it acts like a inertia but is actively controlled. Though reduction of the rotating velocity of the rotor energy can be extracted and used as instantaneous energy.

4 Problems with emulated inertia for WT

The usage of this stored energy comes a price, due to the reduced revs per minute, the plant is not in the optimum operation point anymore, it cannot extract the maximum out of the wind. A lower power input is the result. This is the reason why this feature was not requested for a long time. But though the growing penetration of wind and photovoltaic generation in power grids the necessity will rise for them to take part in the grid regulation.

5 Reference plant

To simulate the wind turbine power plant a reference was created. It had to be done to get general valid set of data for the rotational mass, power output and usual operation wind speed. First a current referent plant was calculated, according to [5] 34,6 GW of wind power are installed in Germany with a number of 23.875 plants in total for the year 2013. combined to an average of 1,449 MW per plant. To consider the rising trend in plant size for the next decade a plant size of 2 MW (electrical) was chosen, this is although an common size for new plants. This could now be scaled up with the installed power provided by [2] of 91 GW for the year 2030.

The plant V80-2 from the manufacturer Vestas was selected, [6] provides the necessary specifications for the calculation, although shown in Tab. 1.

Rotor diameter	80 m
Rated refs	16,7 1/min
Rated power	2 MW
Rotor mass	37 t

Tab. 1: specification of V80-2

The mass distribution in the rotor was approximated with a quarter at the end and three quarter of the total mass in the center, since detailed information was not available.

$$J = \sum_{i}^{N} {r_i}^2 * m_i$$

Calc. 1: inertia torque

$$E_{rot} = \frac{1}{2} * J * \omega^2$$

Calc. 2: rotational energy

Applied to Calc.1 a inertia torque of 13.616.000 kg*m² was calculated. Inserted to Calc. 2 a total of 5,77 kWh of energy are stored in the rotation of the referent plant. To use that the turbine had to be slowed down to the point of zero revs. But a reduction of only 0,04 revs per minute would fulfill the requirements of [2].

6 physical relation

To get the reduction in power output, the physic behind wind turbines had to be calculated. The following equations are relevant for that matter.

$$\lambda = \frac{\omega * R}{v}$$

Calc. 3: Lamda

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0{,}02 * \beta} - \frac{0{,}003}{\beta^3 + 1}}$$

Calc. 4: Lambda$_i$ [3]

$$C_p = 0{,}73 * \left[\frac{151}{\lambda_i} - 0{,}58 * \beta - 0{,}002 * \beta^{2{,}14} - 13{,}2\right] * e^{-\frac{18{,}4}{\lambda_i}}$$

Calc. 5: power coefficient Cp [3]

*this formula is not generally valid, due to different blade geometries

$$P_w = 0{,}5 * \rho * \pi * R^2 * {v_w}^3 * Cp$$

Calc. 6: mechanical power [3]

λ ;rotational velocity; ω: revs per second
v_w: wind speed; β: blade angle; ρ: air density

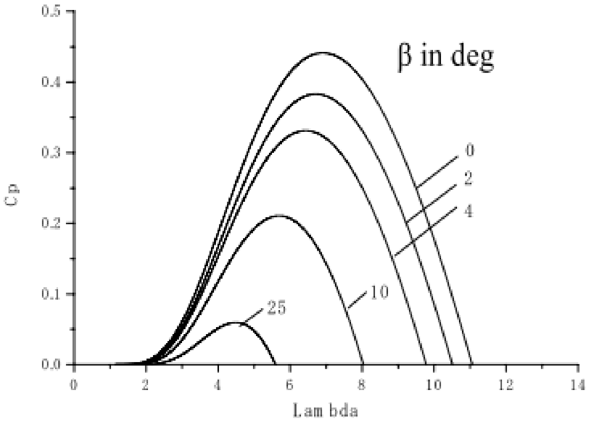

Fig. 2: Cp curves [3]

Fig. 2 illustrates the link between lambda and Cp, due to lower revs, the maximum Cp value cannot be reached and this results in a lower power input. This is shown in Fig. 3 with a simulated graph.

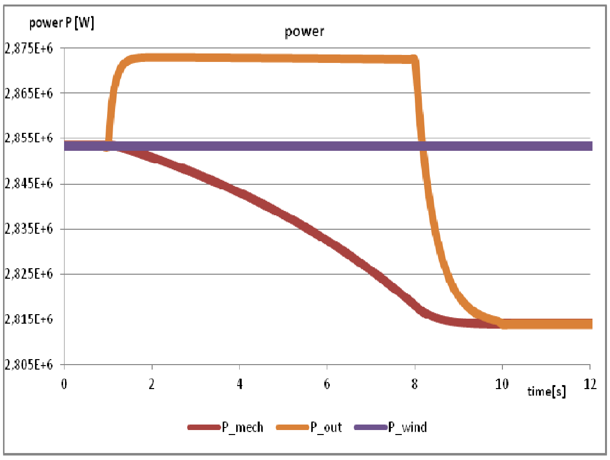

Fig. 3: Power trend with emulated inertia

The in Fig. 3 displayed graphs are the power input (purple), the out of the wind extracted mechanical power (red) and the power output to the grid (orange). After the boost time the difference has to be made up, to rise the output back to normal. This reduced output is a huge disadvantage of this solution.

7 Recovery for wind turbines

The recovery is important to restore the normal power output again. In Fig. 4 the recovery is simulated.

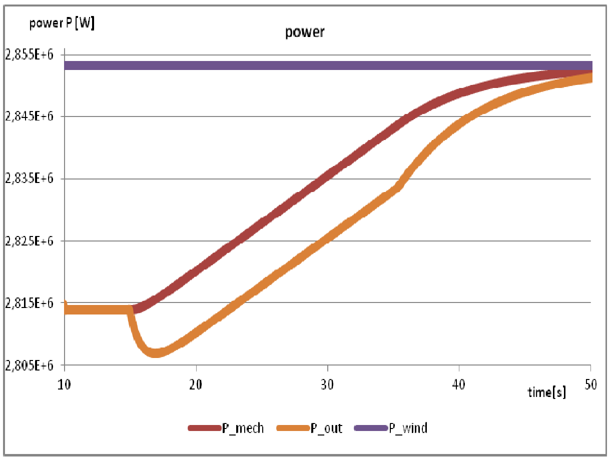

Fig. 4: Recovery process

To start the recovery the output to the grid has to be lowered underneath the mechanical input, this will accelerate the rotor. As soon as the optimum rotational speed is reached the output can be equal to the input and the system is back to a balanced state.

The starting point has to be well adjusted to the grid to prevent a second drop in the frequency. In Fig. 5 three different delays are investigated for a part of the Canadian power grid. How long this delay has to be is dependent mainly on the primary frequency control of the grid. A strong primary control would make it possible the start the recovery earlier and thus the nominal rating.

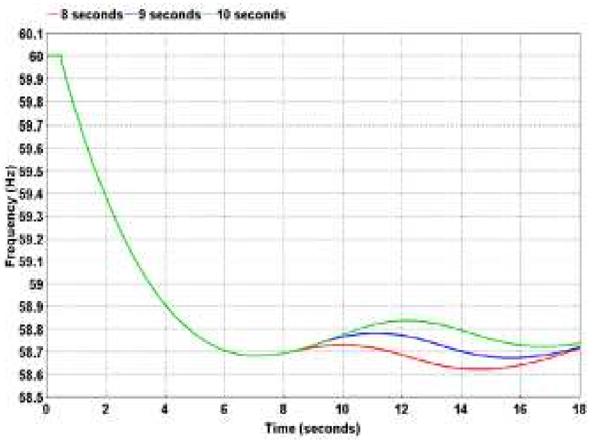

Fig. 5: Time delay of the recovery

The three delays lead to different response of the grid. The fast 8 sec delay produces a second drop of the frequency to a lower point than before the recovery. That behavior is not intended because it puts a burden on the grid. For that simulation a time not shorter than 9 seconds should be chosen as the delay between failure and start of the recovery.

8 emulated inertia for capacitor driven system

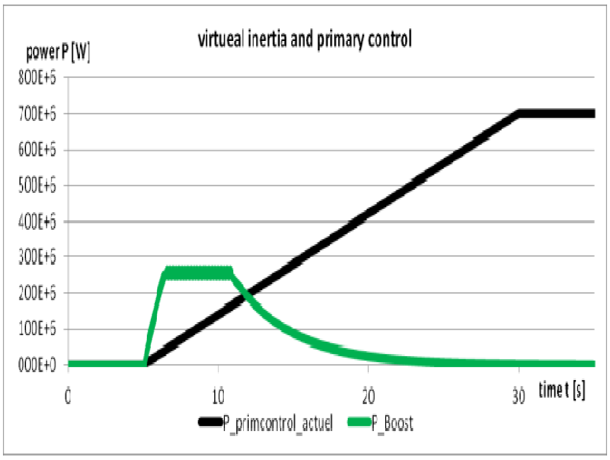

Fig. 6: virtual inertia

The profile for the capacitor version can be designed like in Fig. 6, green represents the emulated inertia power and black the primary control. The emulated inertia should rise as fast as possible and after a definable point it decreases again back to zero. This negative slope commutes the power to the primary control.

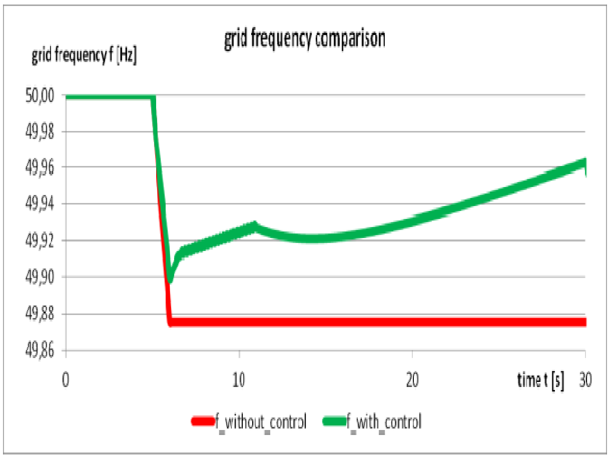

Fig. 7: grid frequency

Fig. 7 shows the result of the combined primary control and emulated inertia, in the grid. Together they are able to support and lift the grid frequency to a higher level.

9 recovery for capacitor driven system

The capacitor driven system has the advantage of a freely selectable point of recovery, there is no reduced power output after the delivery of instantaneous power as it is with the mechanical system. Therefore the recovery point can be set at the best fitted time. This could be after the primary control has reached the maximum like in Fig. 8. This would be a good point because the primary control has stabilized the grid already to a acceptable status.

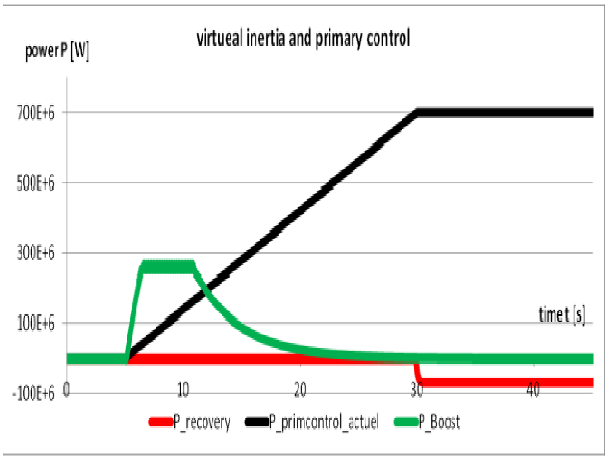

Fig. 8: virtual inertia with recovery

The recovery phase will refill the storage, after that it is back to the normal operating state and ready for the next event.

10 RESULTS AND DISCUSSION

Both systems are capable of delivering a instantaneous power similar effect. The mechanical driven system has the disadvantage of a reduced power output but has a huge potential market. With the right software even old plants could be upgraded to take part. On the other hand the capacitor based system could be installed in almost all new renewable energy inverters but could not be upgraded. Specially for the mechanical based system a new payment system will have to be introduced to compensate the loss in production to make this function attractive for investors.

References

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