LOAD-FREQUENCY CONTROL SUPPORTED BY VARIABLE SPEED VARIABLE PITCH WIND GENERATORS – FROM THEORY TO TESTING

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Abstract:

Wind power (WP), among all Renewable Energy Sources (RES), has shown the fastest growing rate and has the largest share of all RES represented in the national and international energy portfolios. A considerable drawback in the further increase of WP deployment is its stochastic nature, which poses dangers for the power system (PS) integrity and quality. To rectify this, research efforts have been conducted towards the participation of wind generators (WGs) in ancillary services. That way, WGs can participate in healing PS disturbances, similarly to conventional generation. The load-frequency phenomena, especially the unexpected loss of power or the sudden load increase, should be dealt with also by WP, since a great amount of active power is contributed to daily PS operation by WGs. Numerous studies, synoptically presented in this paper, have offered ideas for WP to participate in the load-frequency control (LFC) service. The main idea is to procure for the reserve that the WG will later contribute, either by storing the excess power on the rotor (over-speeding), or by de-loading aerodynamically the wind turbine (pitch-controlled). This study will show how the former methodology is inferior to the latter and has limited applicability. Lastly, the paper includes tests of LFC contribution by a wind park comprising of Vestas WGs in the island of Crete, where favorable pitch-controlled de-loading has been utilized.

Keywords: Ancillary services, load-frequency control, over-speeding, pitch-controlled de-loading.

1 Introduction

Environmental concerns, expressed strongly by governments, organizations, policy makers and

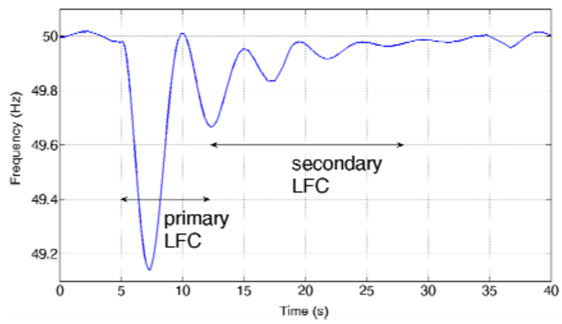

Figure 1: Load-frequency control realization when a considerable load increase has occurred

local communities, have led to the adoption of codes and initiatives towards the even further and greater increase of WP in the international energy portfolios [1]-[3]. Nevertheless, technical limitations and inherent drawbacks of WP have been seen as considerations obscuring the feasibility of the above target.

A great amount of conventional generation has already been displaced due to high WP penetration. This means that the total inertia of the PS is reduced and is thus, more vulnerable to load-generation imbalances [4] leading to frequency phenomena which have to be healed according to the system operator requirements as shown in Fig. 1.

Moreover, the stochastic nature of the output of WGs adds up to the problem. These points, justify the obligation for WP to participate in the ancillary service of LFC. Grid codes already list requirements regarding the LFC behavior of WGs, although these are not yet fully active and usually concern WP curtailment when for increased generation or reduced loads in the PS [5]-[7].

However, extensive research has been done in the field [8]-[20]. It emphasized on how a WG can procure the required reserves, by de-loading the wind turbine (WT). That way, when a load-frequency event occurs, active power injection can be accommodated for by the WG. Two main methodologies have been developed. The first suggests that the de-loading does not spill any aerodynamic power, but stores it instead, as kinetic in the rotor of the WG [13]-[17]. The technique, which is addressed as over-speeding, leads to higher angular speeds of the WT for the same (reduced) active power delivered to the grid. The second control strategy suggests that the WG is de-loaded by shedding aerodynamic power from the WT, through increased pitch angle [18]-[20].

In Section II, the WG model and the two aforementioned techniques are briefly presented. Previous literature concerning them is also listed. In Section III, the latest improvement of the two methodologies is given. It is also explained, why over-speeding is inferior to the pitch-controlled de-loading. In Section IV, the LFC strategy employed to the Vestas WGs comprising a wind park in the island of Crete, is outlined. The data of the actual SCADA is thoroughly presented and explained. Conclusion of the work in Section V, sets the goals and expectations for future application of the control schemes here discussed.

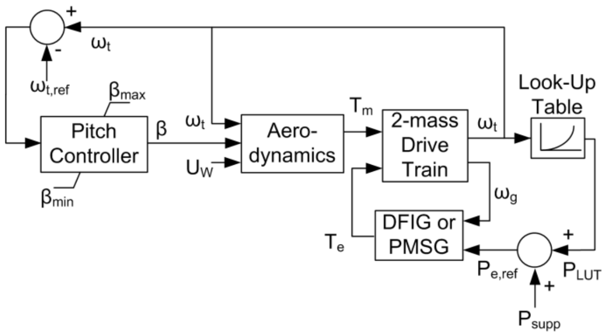

Figure 2: Wind generator general representation and control scheme.

2 Wind Generator De-Loading Techniques

In order for the de-loading methods to be discussed, a short description of the WG topology is required. A WG, as indicatively shown in Fig. 2 consists of:

a. the WT (mechanical part) which captures the aerodynamic power from the wind. Care so that the WT will not exceed the nominal rotational speed, is given by a pitch angle controller.
b. the generator (electrical part) which absorbs the power of the WT through the rotor of the WG. In most cases it is either a Doubly-Fed Induction Generator (DFIG), or a Permanent Magnet Synchronous Generator (PMSG). A gear-box is required for the case of the DFIG.

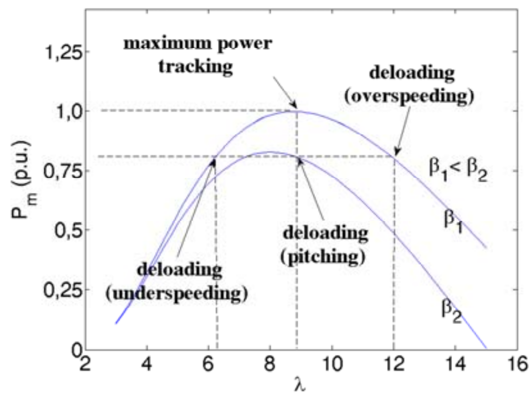

Figure 3: Three alternative operating points for de-loading a WG.

If no curtailment is required by the system operator and the wind speed is below nominal, the WG absorbs the maximum available aerodynamic power at any given moment. For wind speed equal or above nominal, the nominal active power is drawn. The generator follows this scheme by monitoring the rotational speed of the WT and draws the corresponding active power as advised by a look-up table. This strategy of operation is the Maximum Power Tracking (MPT) and for wind speed below nominal is directed by equation (1). Information about the parameters can be found in detail in [21].

$$P_m = \frac{1}{2} \cdot \rho \cdot A \cdot U_w^3 \cdot C_p(\lambda, \beta) \qquad (1)$$

If the WG is required to participate in LFC, some power has to be de-loaded compared to the MPT. The various ways are given in Fig. 3.

2.1 Over-speeding De-Loading

The general method of over-speeding suggests that the generator will use an alternative look-up table (referring to Fig. 2), which for each set-point of rotational speed, will require less active power, thus allowing the WT rotor to accelerate (compared to the MPT strategy). Previous methods [13]-[17] of over-speeding involve serious drawbacks such as the use of wind speed measurement as an input variable and allowing the WT rotor to over-speed even above nominal values. Wind speed measurement drives the control strategy based on the particularly fast and random nature of wind, while over-speeding above nominal angular speed leads to over-loading both of the rotor and the under-rated power electronics of DFIG-based WTs. The excess power for the LFC action will be requested according to a control topology such as the one depicted in Fig. 4.

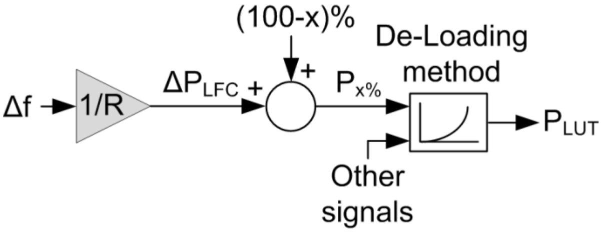

Figure 4: LFC block for a WG.

2.2 Pitch-Controlled De-Loading

When MPT is applied, the pitch angle is kept at its minimum for wind speed below nominal, thus allowing maximum power extraction. That said, an increased pitch angle will de-load the WG by the spillage of aerodynamic power from the WT. A look-up table of reduced power extraction is used by the generator and an additional look-up table drives the corresponding pitch angle for each level of required de-loading. The main drawback of the technique as suggested by past literature, is its slow response due to the pitch servo time constants. Fig. 5 summarizes the above described. Obviously, the control of Fig. 4 is also required for this topology.

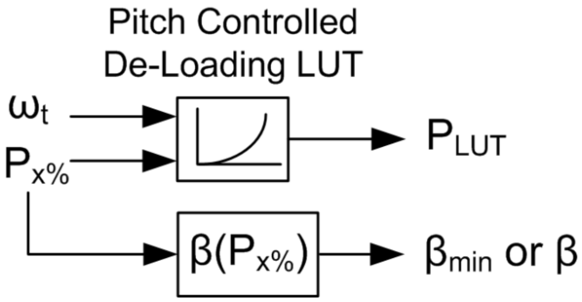

Figure 5: Pitch-controlled de-loading for a WG.

A direct comparison of LFC response after prior de-loading by pitch control and by over-speeding, shows that the latter is considerably faster to the former.

3 Improved De-Loading of Wind Generators

Lately, a combination of methods and some complex strategy have been used to rectify all aforementioned disadvantages of the previously suggested approaches [22].

A hybrid over-speeding which is assisted by pitch action (when nominal rotation speed is reached), manages to avoid both the wind speed measurement and the over-loading of the generator that the over-speeding methods have faced so far. An additional look-up table of two inputs variables (level of requested de-loading and pitch angle) drives the technique. Figures 6 and 7 present the above control philosophy.

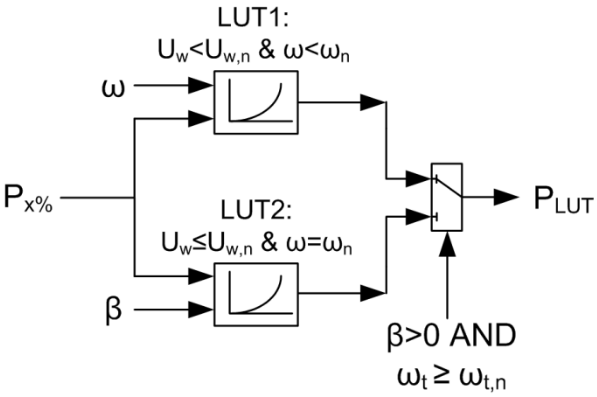

Figure 6: Control topology of the hybrid-overspeeding [22].

Pitch-controlled de-loading has been made faster by combining it with an extra control block offering inertial support [9] on behalf of the WG. Since there is no coupling of the WT rotor to the grid, a signal of active power increase for negative rate of change of the PS frequency, acts as the inertial response of the conventional generators. That way, the WG covers for the pitch servo time delay. The technique suggested is given in Fig. 8.

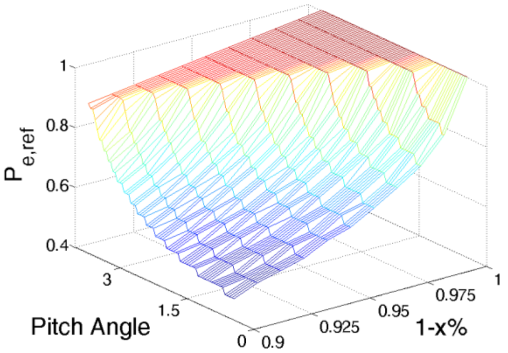

Figure 7: Additional look-up table for the hybrid-overspeeding de-loading [22].

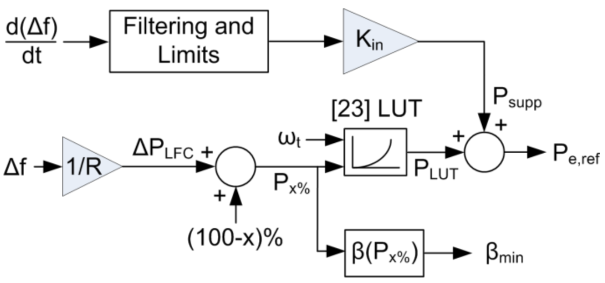

Figure 8: Combined pitch-controlled de-loading with inertial support [22].

Both of these methods showed improved results compared to previous similar realizations as this was proven thoroughly in [22]. However, the over-speeding de-loading has been limited in application due to the fact that the additional look-up table is approximated by the Cp curves of the WT blades. That said, an extremely non-linear set of curves will not be able to yield the operational set-point of the additional look-up table of the method. Furthermore, the use of the slow pitch angle as input (which is itself a dependent variable), means that the technique cannot follow changes caused by the rapid nature of the wind, unless a low pass filter is tuned with the pitch-servo response. Fig. 10 depicts how the output wind power would respond to the change of wind speed of Fig. 9 and in comparison to the classic MPT control strategy.

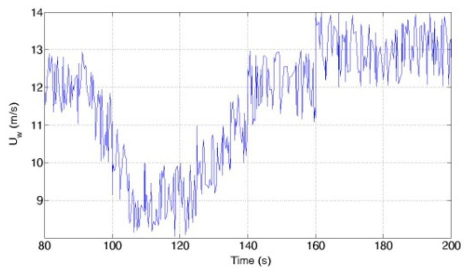

Fig 9: Wind speed time series

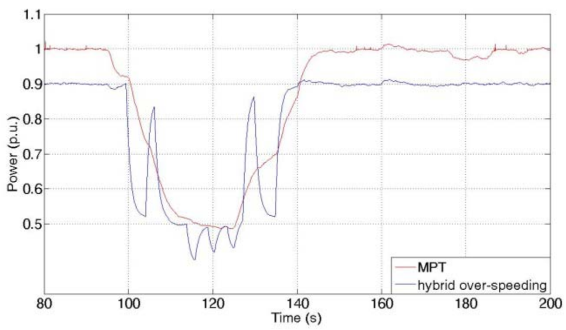

Fig 10: Response of the output wind power of the WG to the wind speed time series of Fig. 9 for the MPT and the hybrid over-speeding techniques.

4 Load-Frequency Control Response Realized by a Wind Park in the Island of Crete

The wind park owned by “Plastika Kritis SA” is located in the area of the Vrouchas settlement, Lasithi province, in the island of Crete. It has a total of 11.9 MW installed capacity, consisting of Vestas WGs. Based on an initiative by Vestas Hellas Wind Systems SA and the Islands Network Operation Department (Office of Crete-Rhodes) of the Public Power Corporation (PPC) SA a frequency control system has been installed in the aforementioned wind park in agreement with the owner.

The system monitors the frequency at the point of common coupling (PCC) and dispatches signals of increase/decrease in active power output to the WGs of the wind park. More specifically the wind power is getting signals for active power regulation by the dispatch center based on a specific algorithm. The algorithm is provided in Fig. 11 hereto.

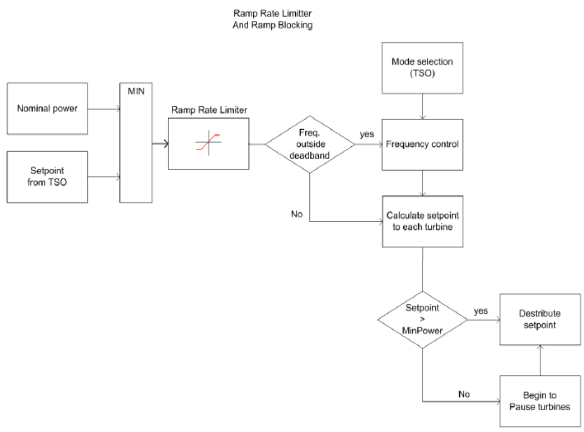

Fig 11: LFC algorithm in wind farm in Crete.

Based on this, in the wind farm control system are provided measurements for active power and setpoint from grid operator. Inputs are following the block diagram which consists of software control modules and the system is deciding the performance of the wind farm following the response curve in PCC as depicted in Fig. 12. The system is triggered, when there is frequency disturbance. Once the power meters installed in the PCC detect frequency disturbance then wind farm SCADA system issues appropriate commands to the wind turbines. In detail, in the cases when the frequency is below 49.8Hz and there is imposed setpoint to the wind farm the wind farm SCADA system ignores the setpoint and injects active power to the grid provided that there is sufficient wind. In the cases that the frequency exceeds 50.2Hz then wind farm reduces active power production following curve in Fig. 12. Both functions are based on the combined operation of the WG as presented previously.

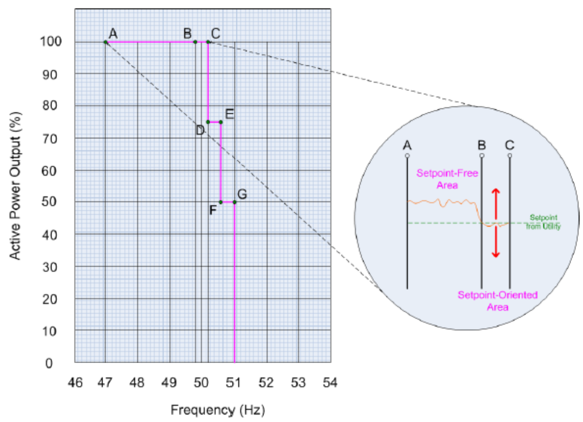

Fig 12: Active Power curve vs Frequency.

This system has been tested in system of Crete and wind farm has supported the grid in frequency disturbance events.

On January 1st 2012, at 4:12 pm a considerable frequency disturbance occurred, with a drop as low as 49.64 Hz. The installed frequency control system received a command and directed for the WGs to increase their output accordingly from 3 MW to 3.1 MW. The figures given are both from the SCADA installed by PPC SA and the measurement devices installed by Vestas Hellas SA. Let it be noted that there was margin for even higher contribution of the specific wind park to the LFC, however due to this being the first test, stricter limitations have been applied.

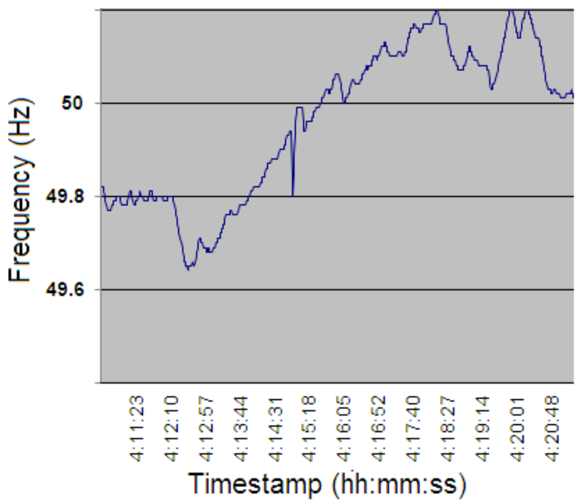

Fig 13: Electric frequency of 1-1-12 disturbance.

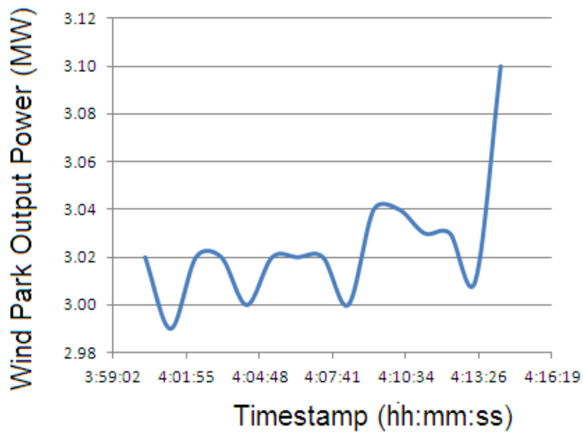

Fig 14: "Plastika Kritis SA" wind park output power during the frequency disturbance of 1-1-12.

5 Conclusions

The LFC service as this can be offered by WGs, has been discussed in this paper. Previously cited methods have been synoptically presented. The improved version of both de-loading strategies – namely, over-speeding and pitch-controlled de-loading, which procure for reserves by WGs in order for them to participate in LFC were briefly given. Over-speeding de-loading has been discussed as a technique offering limited applicability and poor response, due to the fact that is dependent from the highly non-linear approximation of the Cp curves of the WT blades and the slow response of the pitch action. In scope of the above, a novel methodology for the LFC support tested in a wind park in the island of Crete, consisting of Vestas WGs, has been presented. The results of the response of the wind park to a serious frequency disturbance were given.

Since the presented field tests were the first to be conducted, increased active power contribution for the LFC service by the WGs should be considered in future studies. Moreover, the requirements for the curtailment of excess WP should be taken into account and combined with the LFC methodology applied.

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