Comparison of Individual Blade Control and Individual Pitch Control for Wind Turbine Load Reduction

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The size of wind turbines has been growing fast in recent years with the largest now exceeding 7MW. Furthermore, this trend is expected to continue for the offshore sector. However, this increase in size is accompanied by an increase in the dynamic loading on the structure, in particular, unbalanced loads on the blade and hub. Apart from making wind turbine components more load tolerant, e.g. through advances in materials, this issue could be addressed by active reduction of the loads. The latter approach has great potential to enable the optimisation of turbine design and reduce the cost of energy (CoE).

A great amount of research has been conducted to attenuate the dynamic loading through advanced control methods. There are two well established approaches, which need no modification of blade design and utilise the existing blade pitch system; that is, namely, individual pitch control (IPC) and individual blade control (IBC). There are many publications discussing both algorithms which present their capability to reduce the turbine loads [1-4]. This paper provides a comparison of IPC and IBC based on a 5MW generic wind turbine simulated in DNV GL BLADED.

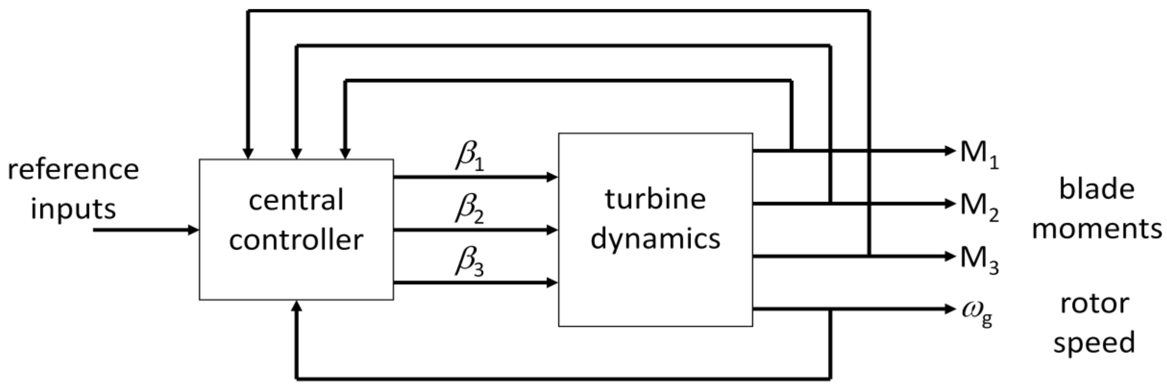

Figure 1: Systematic structure of IPC

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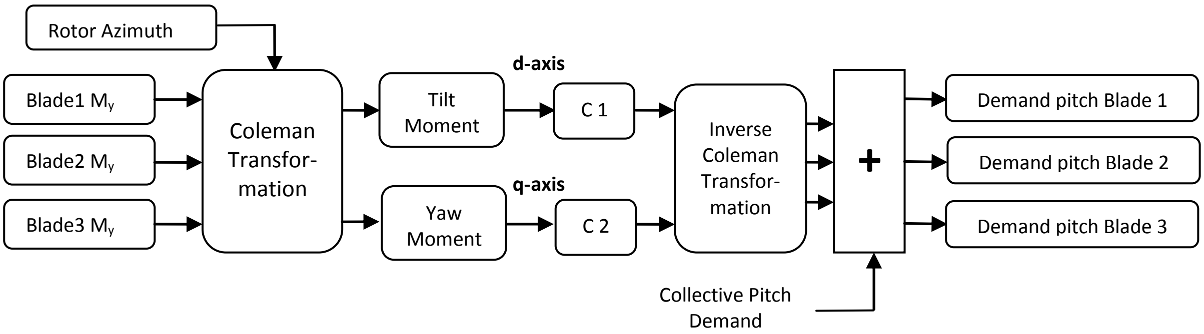

Figure 2: IPC structure based on Coleman Transformation

Figure 1 shows the structure of IPC for a three bladed wind turbine. Its performance depends on the full wind turbine dynamics including the interaction between the blade and the rest of the flexible structure. The Coleman transformation (CT) is essentially applied to convert the load measurements and controlling from rotating (rotor) reference frame to fixed (hub) reference frame, see Figure 2. The conventional classical design techniques are used for C1 and C2 tuning which normally consist of simple PI controller in series with some filters. Although previous researches indicate that d and q axes can be treated as being almost independent so that a same compensator (C1 = C2) can be implemented for both loops, the controllers are usually manually tuned.

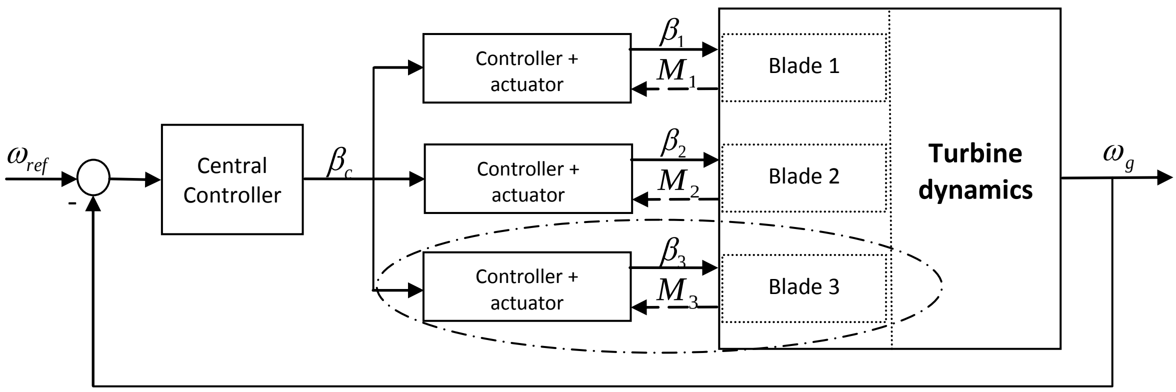

Figure 3: IBC based on single blade model

In IBC, each blade has its own actuator, sensor and controller, see Figure 3. An incremental adjustment to the collective pitch demand is made by each blade controller in response to some blade load measurements. The interaction between the blade dynamics and the rest of turbine are eliminated by introducing the fictitious forces to isolate the blade dynamics from non-inertial reference frame to inertial one. The plant dynamics in the feedback loop are only the blade dynamics and pitch actuator dynamics. Each blade's local control systems is operating in isolation and neither interact with themselves nor the rest of turbine. Detailed explanation can be found in [3, 5].

Comparing with IPC, the greater flexibility of IBC over the choice of controller input in order to target particular (fatigue and ultimate) loads has been demonstrated in the previous work [5, 6]. Furthermore, IBC has greater potential flexibility for dynamic reshaping of the whole control loop making the controller design task more direct, transparent and effective.

For the IPC, a series of controllers are designed at differential levels of pitch activity. The tuning process follows the standard method and leads to the PI-based controller (C1/C2) and some compensators to reduce the 1P/2P spectral peak on blade root out-of-plane bending moment (My).

IPC controllers are essentially designed in the fixed reference frame, whereby, it removes any mean value offset on the hub load. Indirectly, it also achieves a reduction in blade load. In contrast, IBC controller focuses on the blade load directly but indirectly reduces the hub load. This study explores the further IBC design that is modified to remove any mean value offset. The designs also aim to reduce pitch activity.

For IBC, a series of controllers are also designed by using the pre-derived blade dynamic model. Actually, two sets of them are tested to manifest the relationship between pitch actions and load reductions. One (IBC1) weights more efforts to 1P control and thus delivers more load reduction on blade while another (IBC2) gives 1P and 2P control (more or less) the same weighting and thus delivers improved load reduction on hub at a cost of less reduction on blade. The same criteria are applied at each point for the two concepts. These are example designs to give an illustration on how the IBC can be exploited to target different loads. Figure 4 and Figure 5 show all the controller designs for both IBC1 and IBC2, respectively.

Every IBC and IPC designs is tested over full envelope of wind speeds specified in IEC standard using normal turbulence intensity [7]. The results from one 10-minute simulation at mean wind speed 18 m/s are selected for presentation as they have similar amount of increase on pitch duty. The loads from baseline collective control are also superimposed for comparison. Figure 6 shows the spectra for blade root My and it is clear that the 1P/2P spectral peaks are reduced for each case. Figure 7 illustrates the corresponding load comparison for hub tilt bending moment (My) from the same simulation and it can be seen the reduction of mean offset (0P), resulting from 1P control on blade and the reduction of fatigue dominant spectral peak (3P), resulting from 2P control on blade.

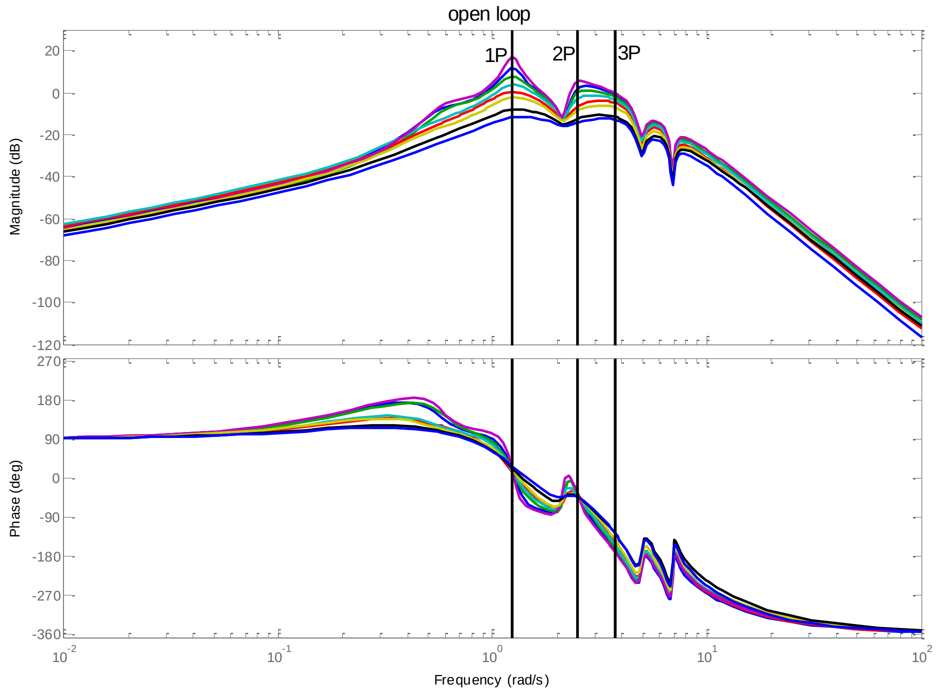

Figure 4: Open loop Bode diagram for IBC1

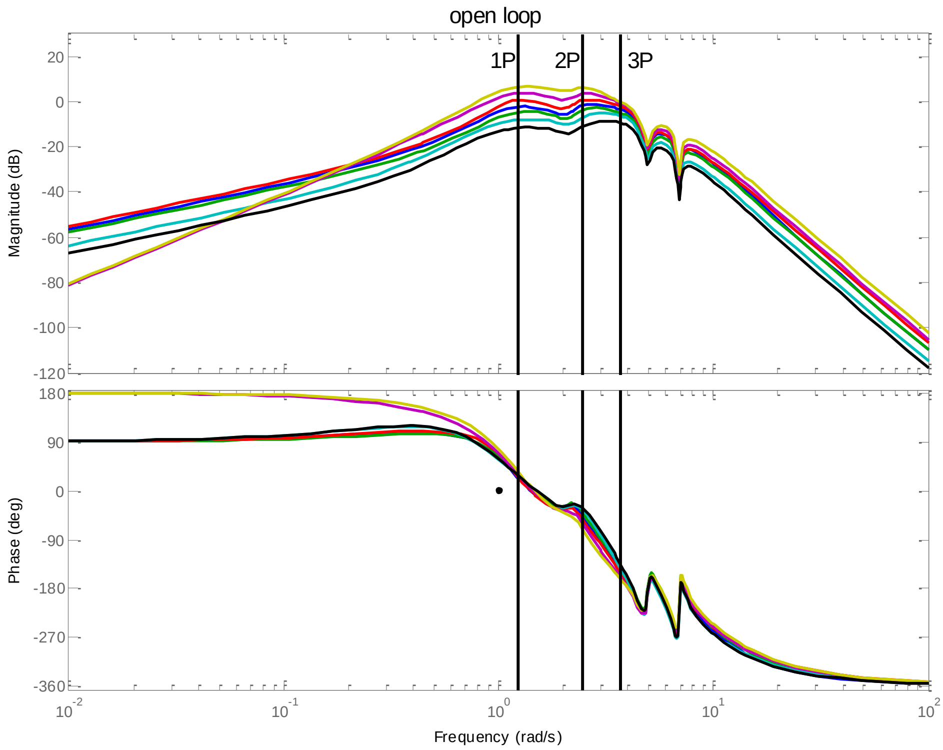

Figure 5: Open loop Bode diagram for IBC2

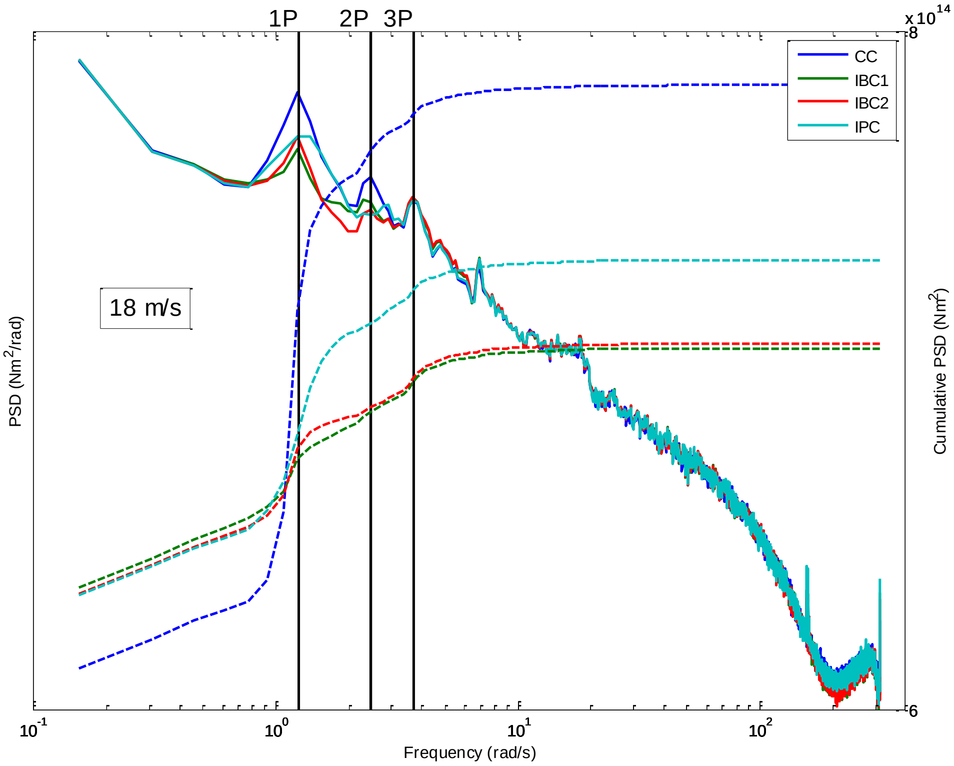

Figure 6: Power spectra comparison of blade root My for different controllers

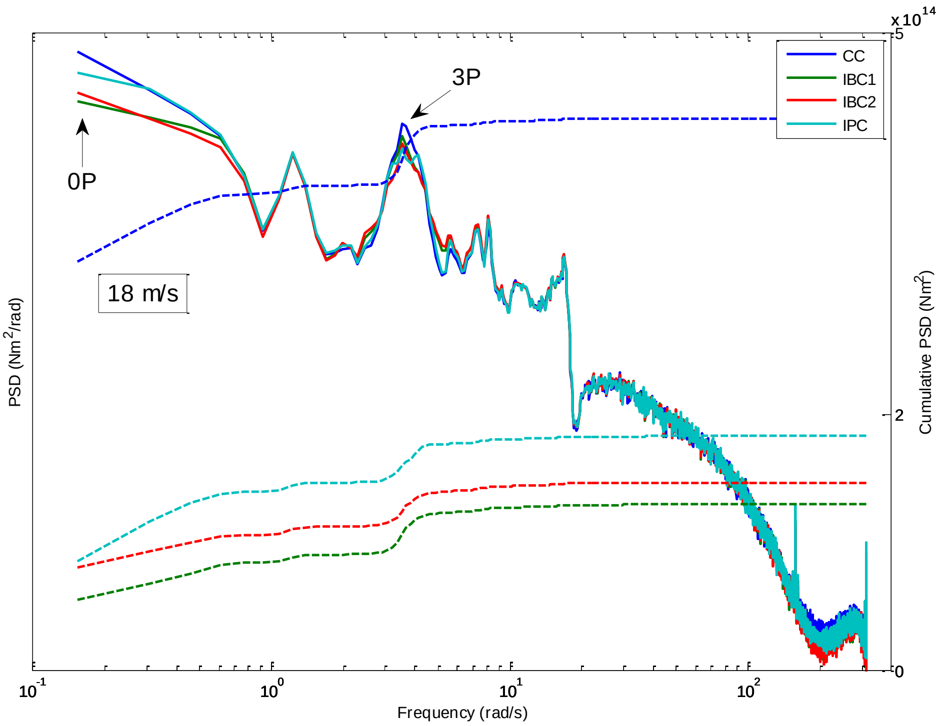

Figure 7: Power spectra comparison for fixed hub My between different controllers

The overall reduction of lifetime equivalent fatigue loads in percentage, comparing to collective control, are outlined in Figure 8 for both blade and hub. At this stage, none of the controller continues to operate in below rated region and a proper scheme has been built for smooth switching. S-N slope of 4 and 10 are used for hub and blade, which are typical for steel and composite material respectively. The pitch actuator duty is evaluated by calculating the accumulative absolute value of pitch rate weighted by wind speed distribution. Each evaluation is then compared with collective control and gives the final data as the raised multiple, e.g. 1.5 means an increase of 150% leading to 2.5 times the baseline value. In the figure, as expected, IBC2 gains more load reduction on hub than IBC1 but with some lost of benefits on blade. Moreover, it is also obviously to see that both IBC designs generally achieve better load attenuation on blade and hub at most pitch activity levels. In other words, for the same amount of load requirements, IBC controller can largely reduce the pitch activity comparing to IPC. There is also a trend that the performance of them would turn to converge at one point, which follows the theoretical observation as well.

The performance achievable for IBC and IPC for a 5MW wind turbine is discussed. The variation of load reduction as a function of pitch activity had been estimated. Two IBC controllers are discussed with the emphasis on the blade loads and hub loads respectively. A better understanding of dynamic reshaping and its connection to the relevant load reduction is obtained. This provides a good guidance towards a more efficient controller tuning. The reduction of pitch activity gained by IBC would be meaningful to the manufacturers especially those with rigid constraints on pitch actuator.

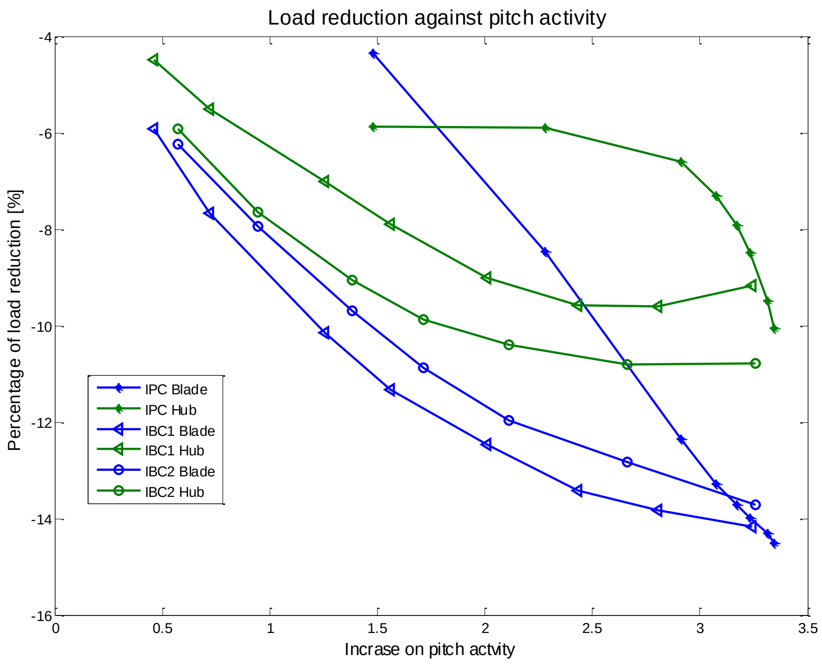

Figure 8: Load reduction against pitch activity for IBC1, IBC2 and IPC

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