Wind Farm Multiobjective Optimization using Nested Extremum Seeking Controls

Turaj Ashuri, Reza Hamidi and Subhanjan Bista (presenting author)
College of Engineering and Applied Sciences
Arkansas Tech University

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Problem statement

- Most of the control algorithms available to maximize the energy capture or reduce structural loads are model-based controllers and based on the ideal state of the system
- Previous studies mainly shown the effectiveness of the algorithm to only maximize the energy capture without considering the adverse alteration of structural loads

Goals of this research are:

- To develop a computational framework for concurrent multi-objective optimization of power output and structural loads
- To maximize power output at both individual wind turbine level and wind farm level
- To minimize the structural loads at the tower and shaft as the two main load carrying components of the system

Methodology

Three different controllers are used:

- Baseline controller of the 5 MW NREL turbine for power optimization of each turbine
- Extremum Seeking Controls (ESC) for power optimization of each turbine
- Nested Extremum Seeking Controls (NESC) for multiobjective optimization of the power and loads

The turbine aeroservoelasticity is modeled using an in-house code

The computational model is coded in MATLAB/SIMULINK

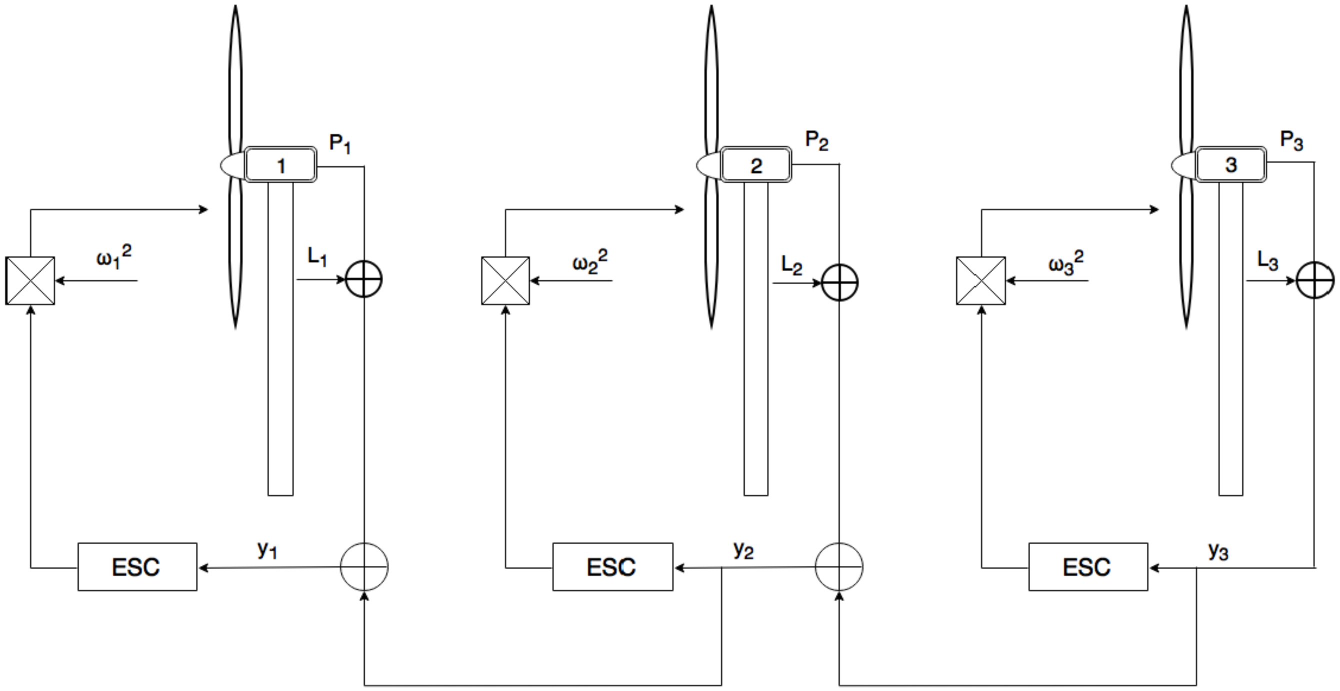

Fig 1. Cascaded NESC implementation.

Extremum seeking controls (ESC)

Employs gradient-based search technique to find the derivatives of the power and loads with respect to the blade pitch angle

Components of ESC:

- Dither signal
- High pass filter and low pass filter
- Demodulation signal
- Integrator

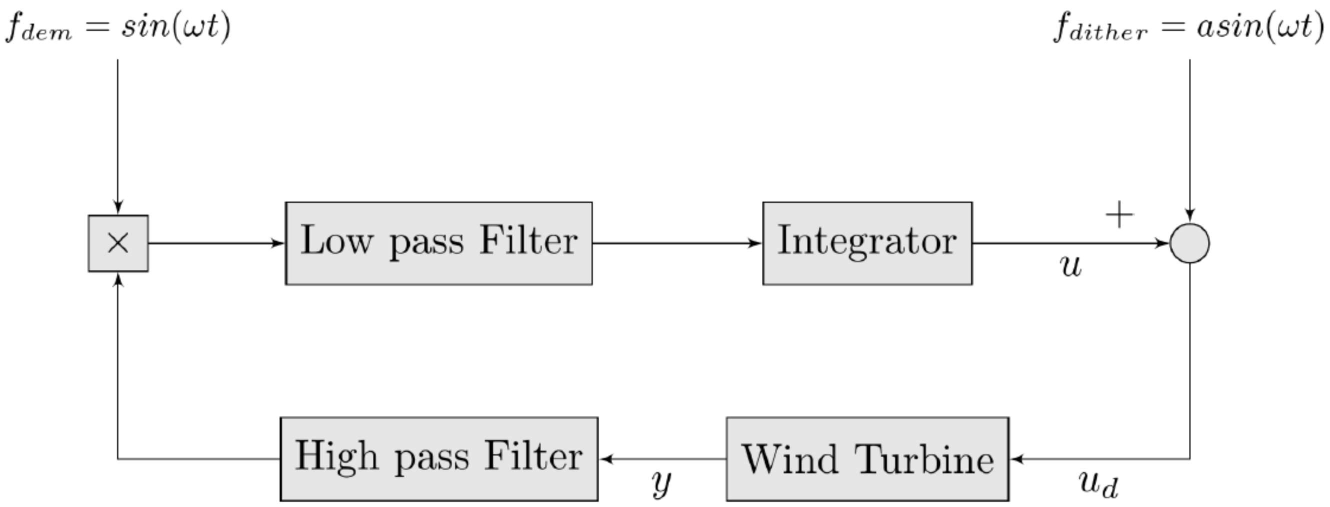

Fig 2. Block diagram of the ESC for a single wind turbine.

Nested ESC (NESC)

The objective function (power output) is modified to incorporate a NESC with load feedback as a penalty function with two different type of formulation:

- Additive penalty

$$K^i_{+}(t) = \boxed{Kp^i(t)} - \boxed{K^i_{load}(t - T_i)}$$

Objective function ← $Kp^i(t)$; $K^i_{load}(t - T_i)$ → Penalty function

$$K^i_{load}(t) = \left(\frac{U_0}{w_3}\right) \times \left[\left(\frac{w_1{}^i M^i_{tower}(t - T_i)}{M^*_{tower}}\right) - \left(\frac{w_2{}^i M^i_{shaft}(t - T_i)}{M^*_{shaft}}\right)\right]$$

- Multiplicative penalty

$$K^i_{\times}(t) = \boxed{K_p{}^1(t)} \times \boxed{[1 - K^i_{load}(t)]}$$

Objective function ← $K_p{}^1(t)$; $[1 - K^i_{load}(t)]$ → Penalty function

$$K^i_{\times}(t) = \left(\frac{P^i(t-T_i) + \sum_{n=1}^{j} P_a{}^n(t-T_i)}{\frac{1}{2}\rho A U(t-T_i)^3}\right) \times \left[1 - \left(\frac{w_i \times M^i_{tower}(t-T_i)}{M^*_{tower}}\right) - \left(\frac{w_i \times M^i_{shaft}(t-T_i)}{M^*_{shaft}}\right)\right]$$

Results (impact of ESC on different turbines)

Adjustment of the torque gain of individual turbines to increase the power output of the entire farm and reduction of loads

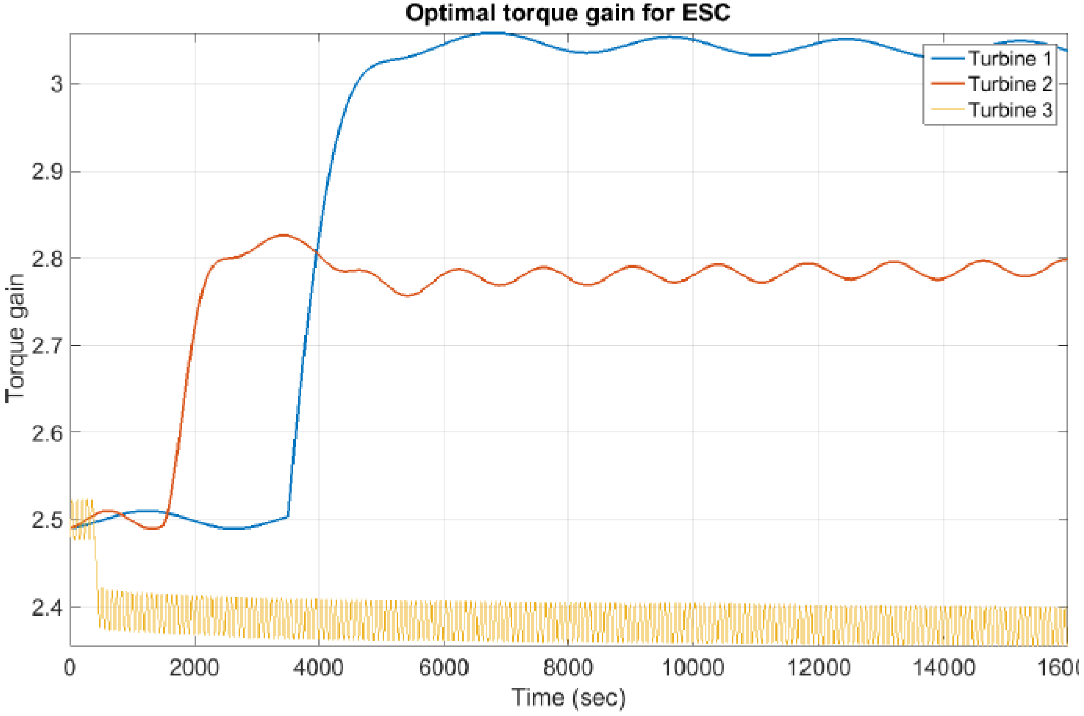

Fig 3. ESC without feedback.

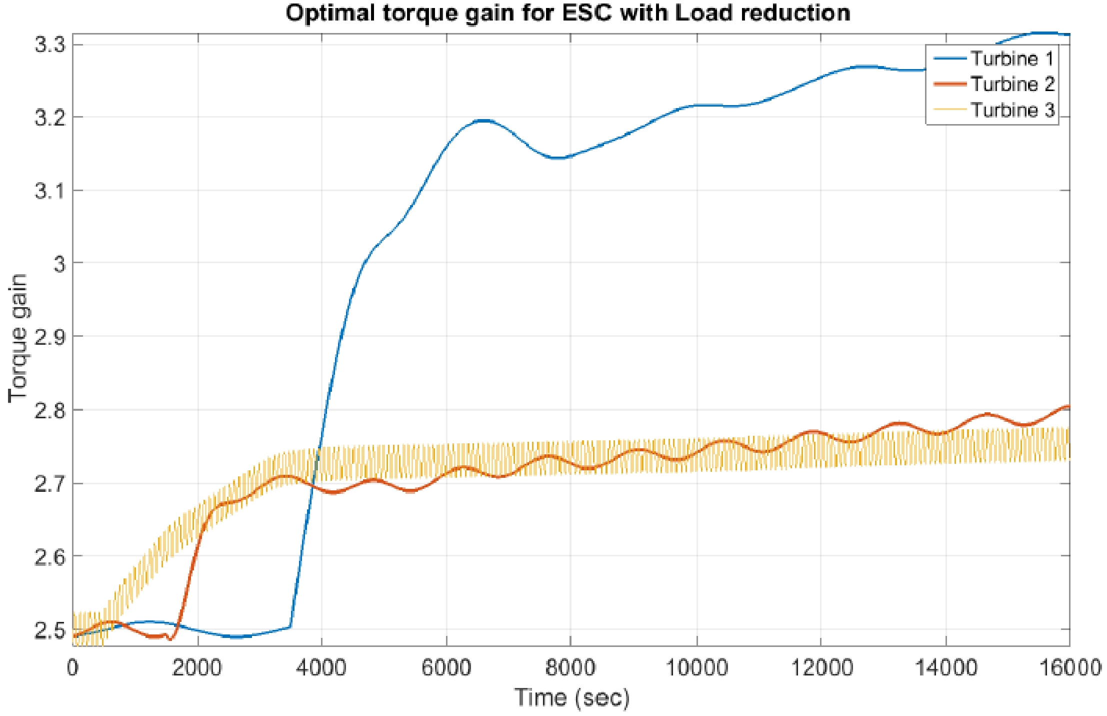

Fig 4. ESC with loads feedback.

Results (moments)

Overall the shaft and tower moments show a reduction compared to the baseline controller

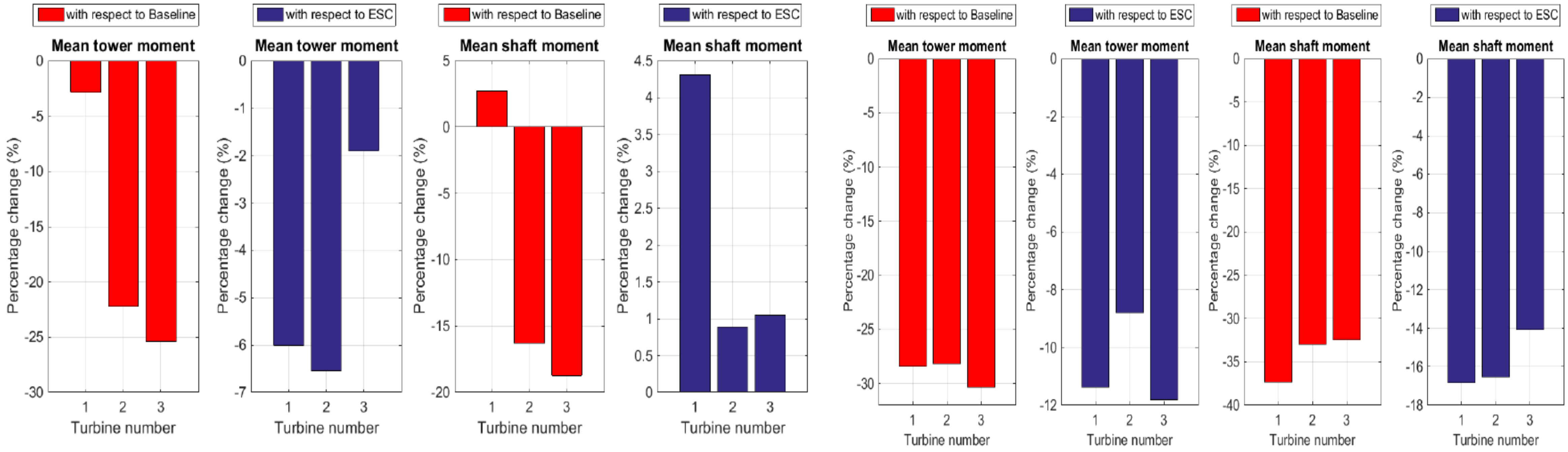

Fig 5. Percent change of damage equivalent loads for the shaft and the tower with respect to the baseline controller and the ESC using additive penalty based ESC and multiplicative ESC.

Results (damage equivalent loads)

Overall the shaft and tower damage equivalent loads (DEL) show a reduction compared to the baseline controller

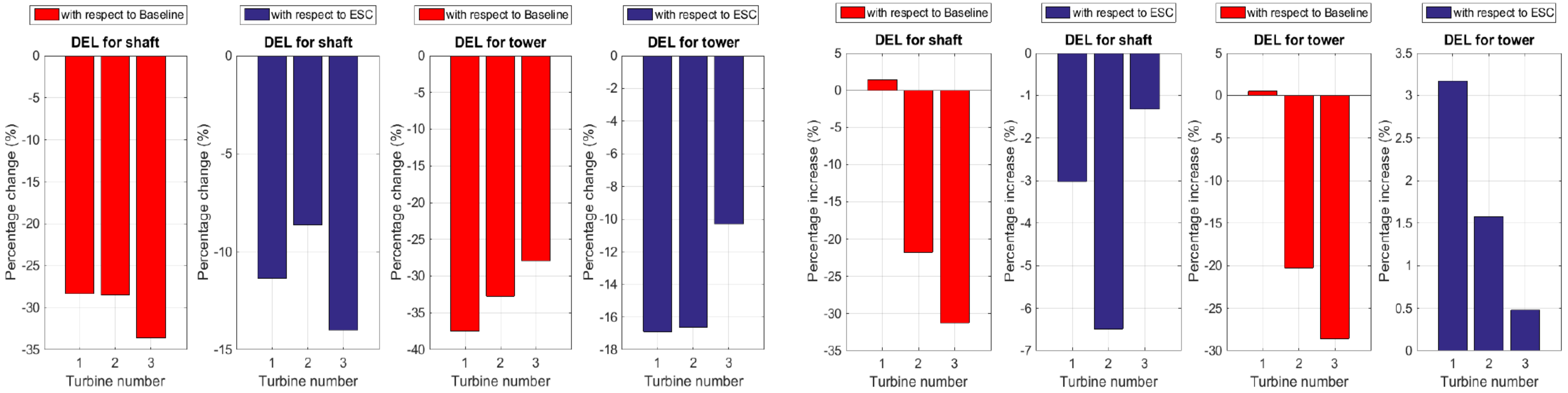

Fig 6. Percent change of mean value of moments for the shaft and the tower with respect to the baseline controller and ESC using additive penalty and multiplicative.

Results (power output)

The wind farm power output shows a total increase of about 1% from all the turbines compared to the baseline controller

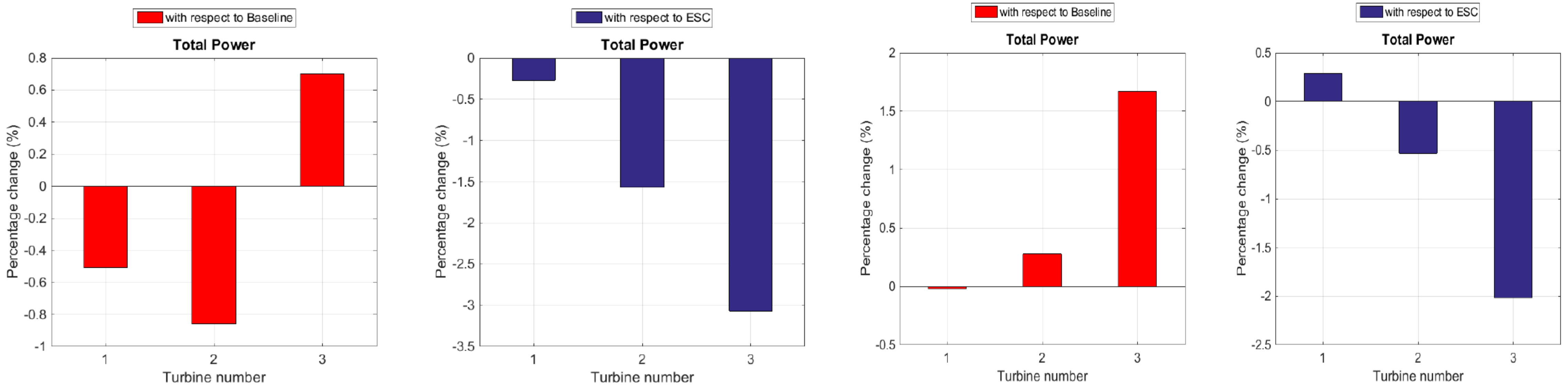

Fig 7. Percent change of total power with respect to the baseline controller and the ESC using additive penalty and multiplicative penalty based ESC load feedback.

Conclusion

Performance of two different types of load feedback were compared and found that the multiplicative penalty based load feedback is simpler to incorporate and is capable of maintaining a balance between the baseline controller and the NESC.

Results obtained in this research can subject to change as per desire. In general, any other combination of loads and power output optimization is possible.

Adding loads as a penalty function reduced slightly the loads while still maintaining (or increasing slightly) the power output.

The results showed 30% reduction of the damage equivalent loads of the main shaft, and 25% reduction of the tower while increasing 1% power output of a wind farm compared to the baseline controller.

Questions

For any questions you may have please contact me at:

sbista2@atu.edu