

Unified Control Fatigue Distribution and Active Power in Wind Farms

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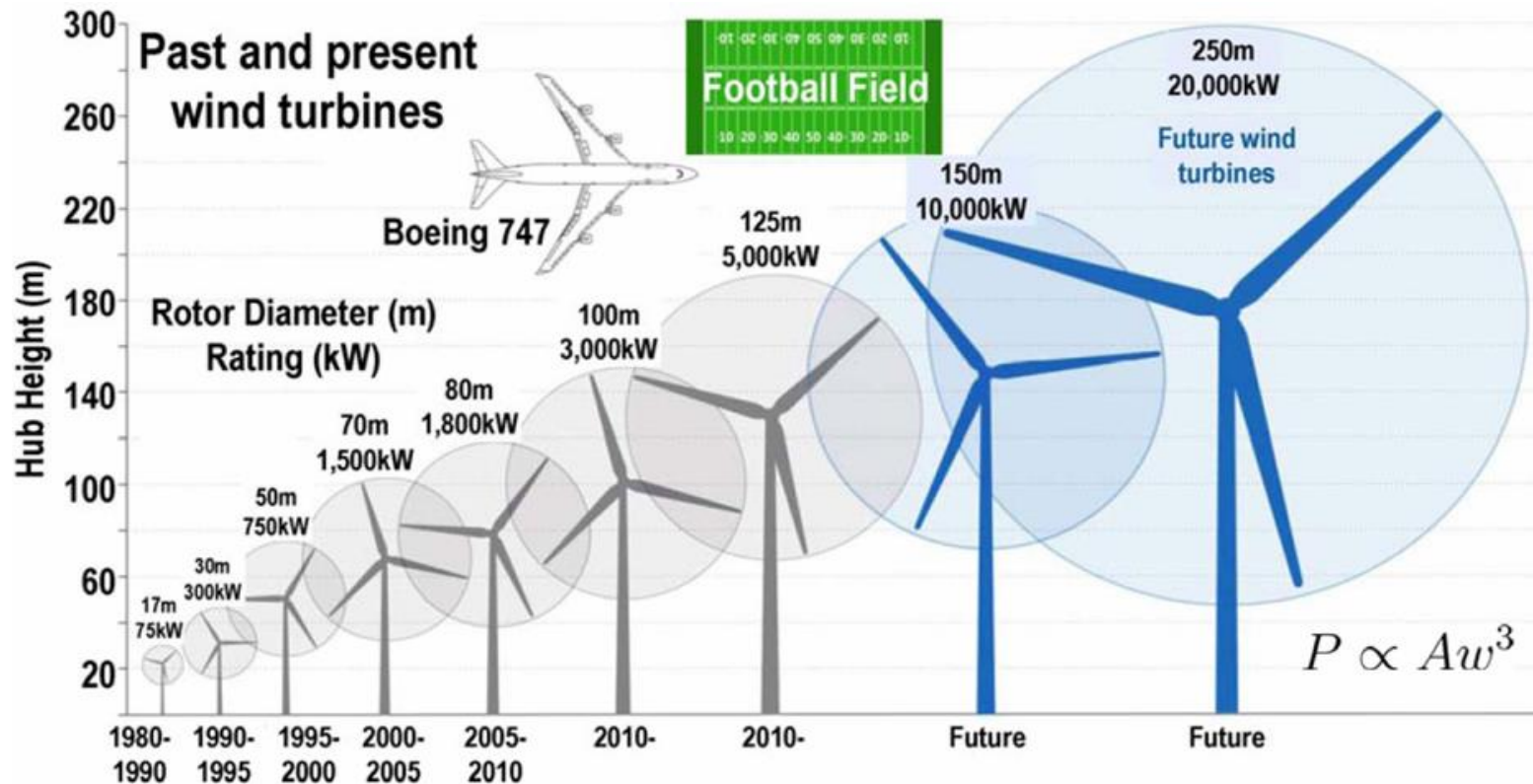
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Introduction



The typical size of wind turbines has grown dramatically. The components of wind turbines become more flexible and expensive.

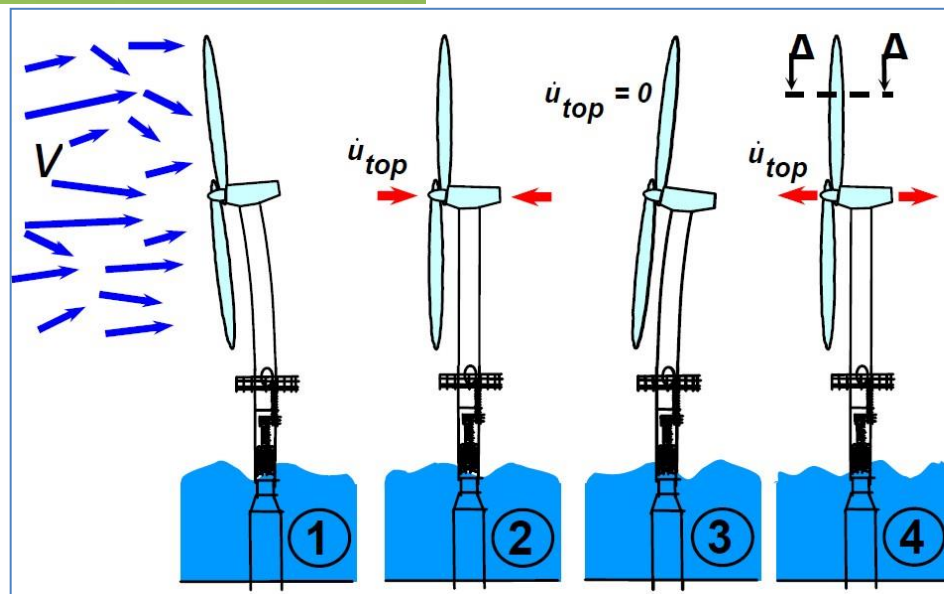
Deterministic
 - Wind Shear
 - Tower Shadow
 - Inflow Angle

Stochastic
 - Turbulence

Combined Effect

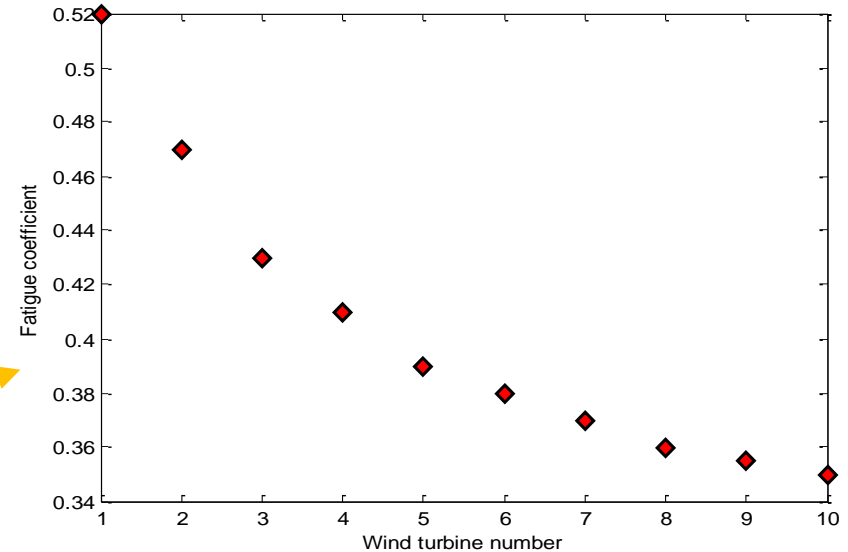


The deterministic wind field is a stochastic component of wind velocity known as turbulence. It cannot be ignored as it is a major source of fatigue loading.



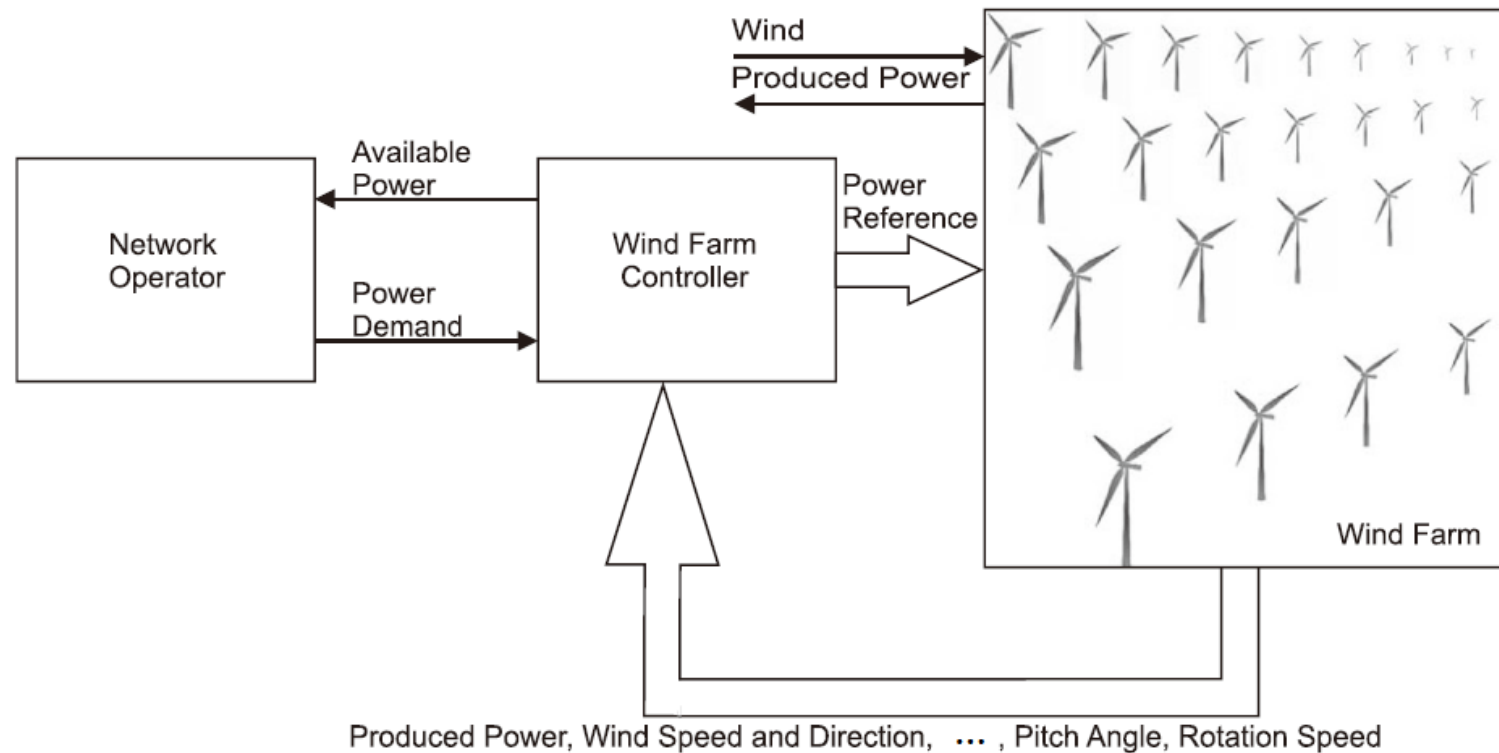


Wind turbines are ‘fatigue machines’.
They should be maintained before
the fatigue damage over the threshold
value.



According to Quinonez-Varela et al., the estimated repair time of a failed subsea power cable may vary from 720 h in summer to 2160 h in winter. A large offshore wind farm, such as the one in Horns Rev, presents a new set of problems that have not been previously encountered, particularly, limited access to the farm because of weather conditions.

One problem is the unbalanced fatigue distribution over the wind farm, which is caused by the uneven wind distribution and conventional wind farm control. This problem leads to frequent maintenance for the overloaded turbines located at boundaries of the wind farm, leading to high costs.



To date, most of the developments within control algorithms and technologies have focused on wind farm power control and the fatigue reduction of a single turbine. However, operation of wind farms show that the individual active control method cannot solve the unequal fatigue distribution in the wind farm. If a control algorithm or technology can take into account the fatigue distribution and balance the individual turbine fatigue without a large power loss, then it can be used to reduce the maintenance costs and increase the wind farm service life.

Fatigue balance method

- A. Fatigue coefficient

$$F^r(t) = f_{work}^r + f_{dis}^r = \frac{\int_0^t P^r(\tau) d\tau}{P_{rate}^r T_{ser}^r (1 + C_{rep}^r)} + D_{dis} \frac{\int_0^t I_{eff}^r(\tau) d\tau}{T_{ser}^r (1 + C_{rep}^r)}$$

The superscript r denotes the serial number of a wind turbine. $F^r(t)$ is the fatigue coefficient of turbine r and consists of two parts: i) f_{work}^r means fatigue caused by the power generation, named working fatigue; ii) f_{dis}^r is the fatigue caused by wind turbulence disturbance, named disturbance fatigue. $P^r(\tau)$ is the power of turbine r at the instant of time τ . P_{rate}^r , T_{ser}^r , C_{rep}^r is the rated power, the designed service life (typically, 20 years), the reparation coefficient of turbine r , respectively; D_{dis} is the effective disturbance coefficient, which is a constant, determined by the wind farm layout, the wind turbine material structure and the local climate factors. $I_{eff}^r(\tau)$ is the turbulence intensity of turbine r at the instant of time τ .

$$F^r(t) = f_{work}^r + f_{dis}^r = \frac{\int_0^t P^r(\tau) d\tau}{P_{rate}^r T_{ser}^r (1 + C_{rep}^r)} + D_{dis} \frac{\int_0^t I_{eff}^r(\tau) d\tau}{T_{ser}^r (1 + C_{rep}^r)}$$

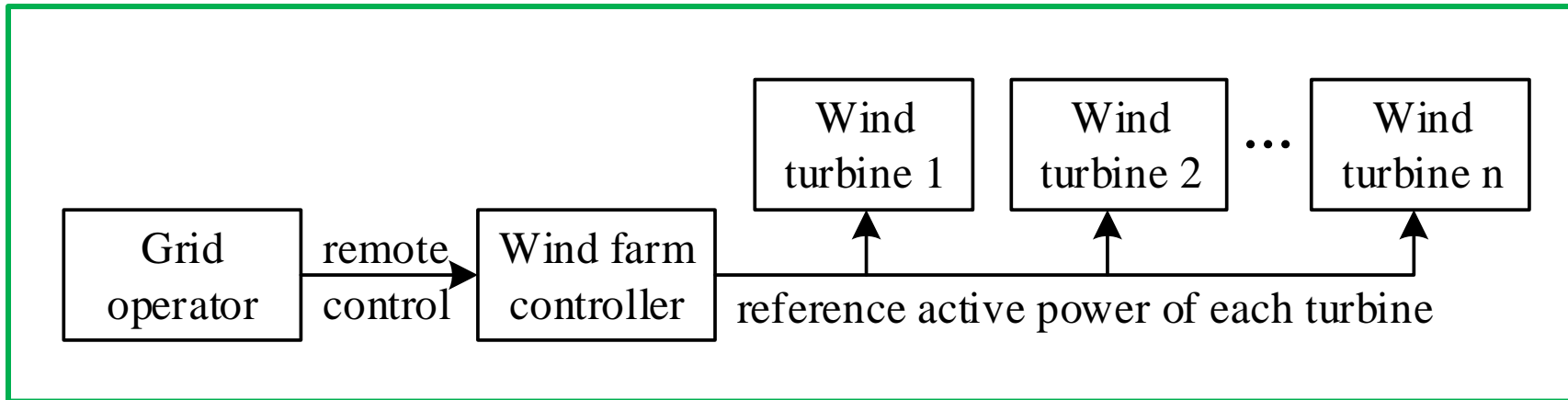
$$\eta^r = \frac{f_{dis}^r}{f_{work}^r}$$

$$F^r(t) = \begin{cases} F^r(t_0) + (1 + \eta^r) \frac{\int_{t_0}^t P^r(\tau) d\tau}{P_{rate}^r T_{ser}^r (1 + C_{rep}^r)}, & \text{power production} \\ F^r(t_0) + D_{dis} \frac{\int_0^t I_{eff}^r(\tau) d\tau}{T_{ser}^r (1 + C_{rep}^r)}, & \text{no power production} \end{cases}$$

The equations indicate that we can optimize the fatigue of a wind turbine via regulating active power output of wind turbines. The equations also show that wind turbine fatigue is cumulative. Therefore, the unbalance wind farm fatigue distribution cumulating in some time slices can be optimized in other time slices by harmonizing active power of wind turbines.

Fatigue balance method

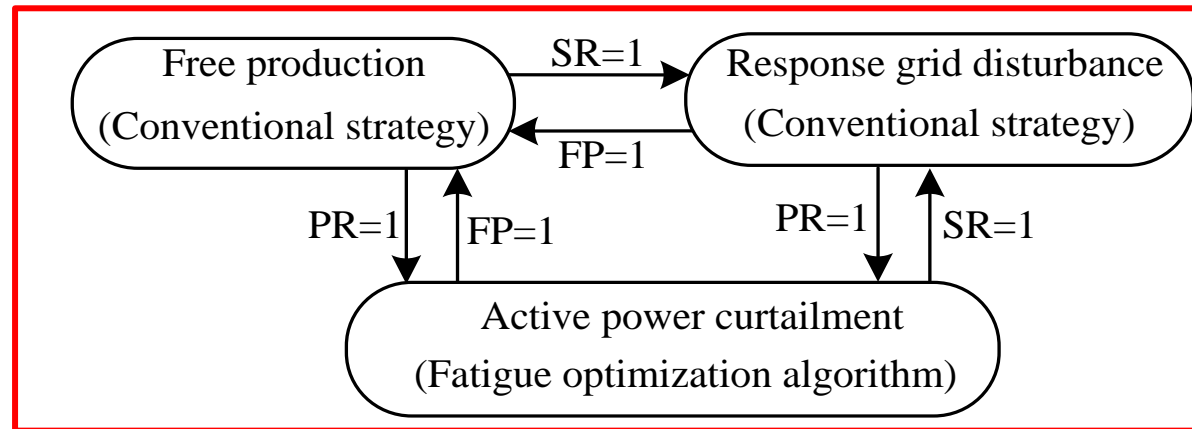
- B. Over all strategy of fatigue optimization



Principle of wind farm active power control

Grid operator set the production mode and reference active power of wind farm to wind farm controller via remote control. The wind farm controller dispatches reference active power for each turbine according to grid demands. Each turbine traces its reference active power via pitch control, torque control.

Over all strategy of fatigue optimization



Free production: When grid security and stability margin is sufficient, the grid operator released the active power limit of wind farm. Each wind turbine operates in conventional maximum power point tracking strategy to meet the wind farm owner's requirement of maximum economic benefit.

Response grid disturbance: When power system is in accident or emergency, such as the frequency beyond specific limits and system stability cannot be guaranteed. The wind farm operates in response grid disturbance state, each wind turbine regulates active power rapidly according to preset conventional control strategies, such as frequency-controlled regulation of the power production strategy and system protection strategy.

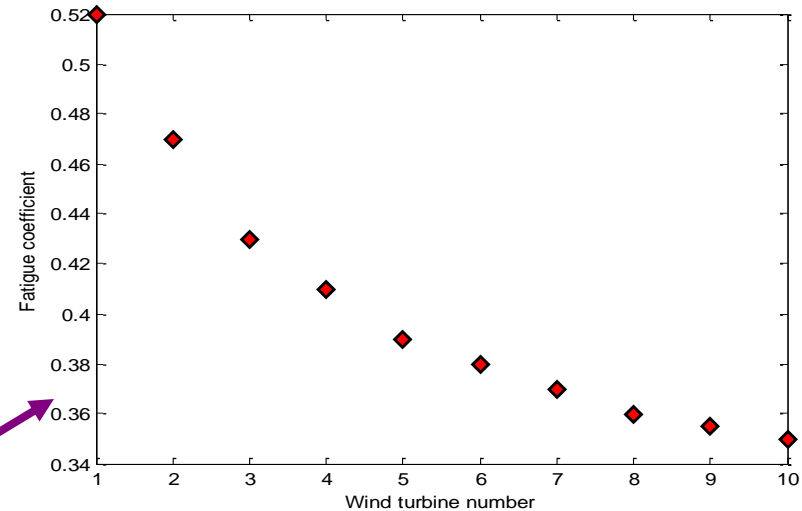
Active power curtailment: Wind speed is available, but the grid operator do not allow the wind farm to put all power on the grid. The wind farm controller harmonizes active power of each wind turbine to balance wind farm fatigue distribution according to fatigue optimization algorithm.

Fatigue balance method

C. Fatigue optimization algorithm



Dispatch active power of wind farm according to inverse proportion of fatigue coefficient of each wind turbine.



$$P_{do}^r = \frac{\frac{1}{F^r(t_p)}}{\sum_{j \in \mathcal{X}} \frac{1}{F^j(t_p)}} P_{todo}^{farm}$$

Planned active power of each wind turbine can be carried out?

calculating P_{avil}^j and $F^j(t_p)$, $j \in \varphi, \varphi \in \text{wind farm}$

find the largest one $F^j(t_p)$,
and delete j in φ

$$\sum_{j \in \varphi} P_{low}^j < P_{ref}^{farm}$$

N

Y

$$\chi = \varphi; P_{todo}^{farm} = P_{ref}^{farm}; P_{plan}^j = 0, j \in \chi$$

$$P_{do}^r = \frac{1}{F^r(t_p)} P_{todo}^{farm}; P_{plan}^r = P_{plan}^r + P_{do}^r$$

$$\sum_{j \in \chi} \frac{1}{F^j(t_p)}$$

if $P_{plan}^r > P_{avil}^r$
 $P_{todo}^{farm} = P_{plan}^r - P_{avil}^r; P_{plan}^r = P_{avil}^r$; delete r in χ

if $P_{plan}^r < P_{low}^r$
 $P_{todo}^{farm} = P_{plan}^r - P_{low}^r; P_{plan}^r = P_{low}^r$; delete r in χ

$$P^j = P_{plan}^j, j \in \varphi$$

Choose wind turbine to avoid wind farm production lower limit being larger than grid demanded active power

Set grid demanded active power to be dispatched; initialize wind turbine reference active power

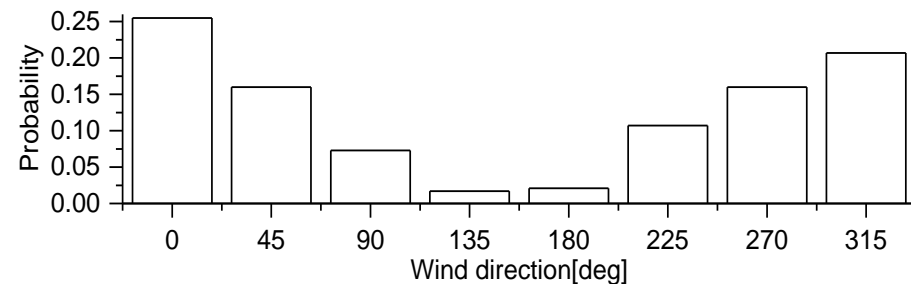
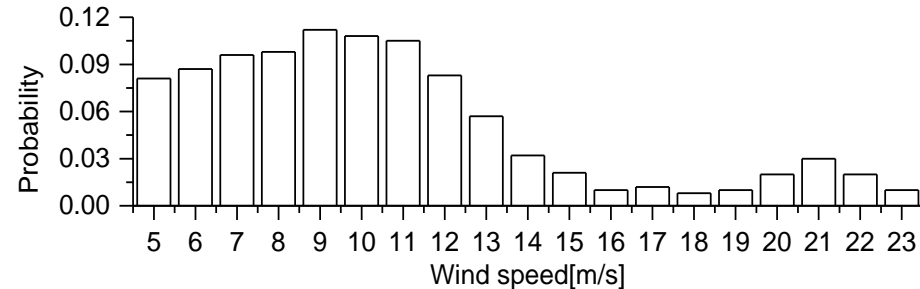
Dispatch active power according to inverse proportion of fatigue coefficient of wind turbines

Constraints: output of a wind turbine must be not larger than available power and not less than lower limit power of a wind turbine; manage the amount exceeded the constraints

Set reference active power of every wind turbine

Fatigue optimization algorithm

Simulations and Results



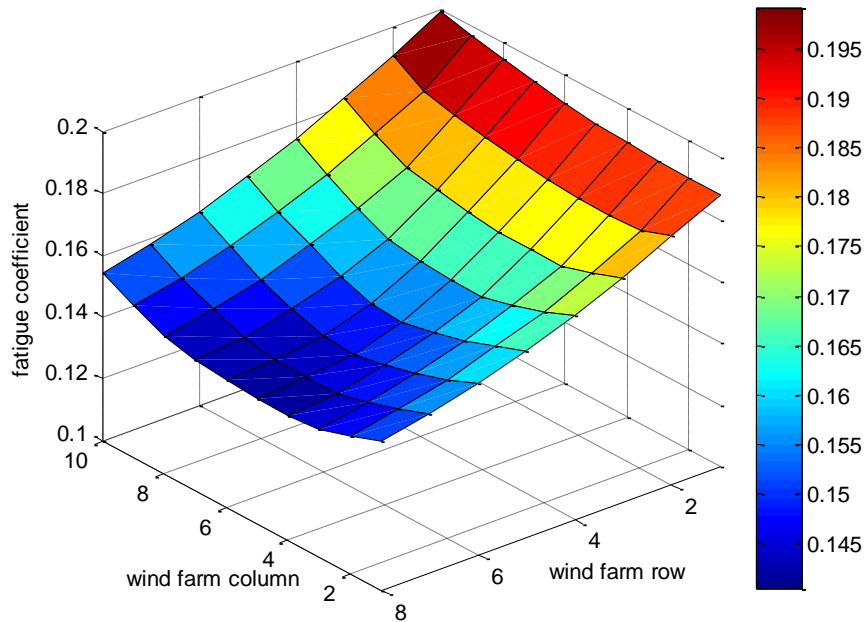
The ratio of the disturbance fatigue to the working fatigue, η^r , is 0.7.

The average wind speed is kept at 12 m/s with a turbulence intensity of 4.5206%.

The power dispatch interval of the farm controller is 15 minutes.

The power curtailment ratio is 5%.

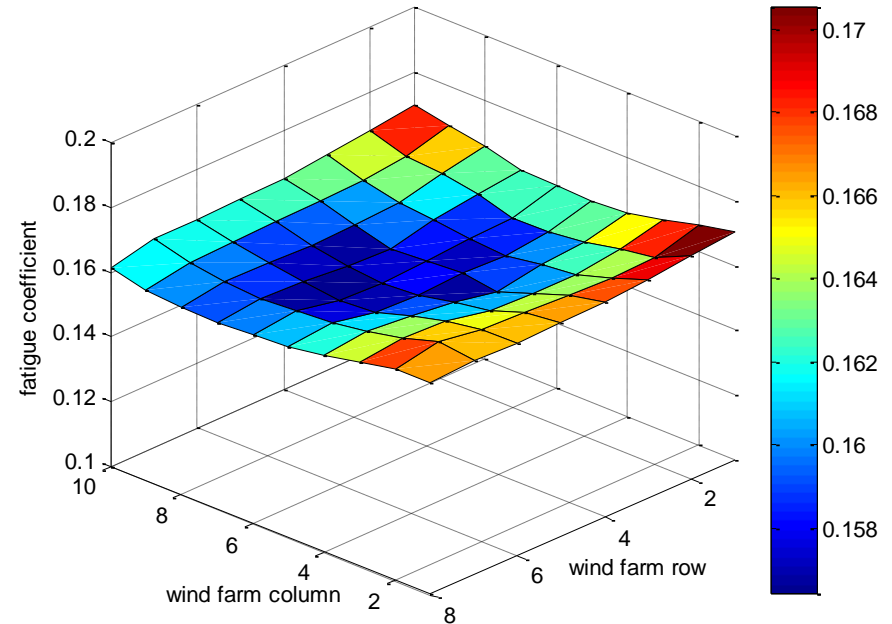
Fatigue distribution



Mean fatigue: 0.1628

Standard deviation: 0.0166

Conventional control method

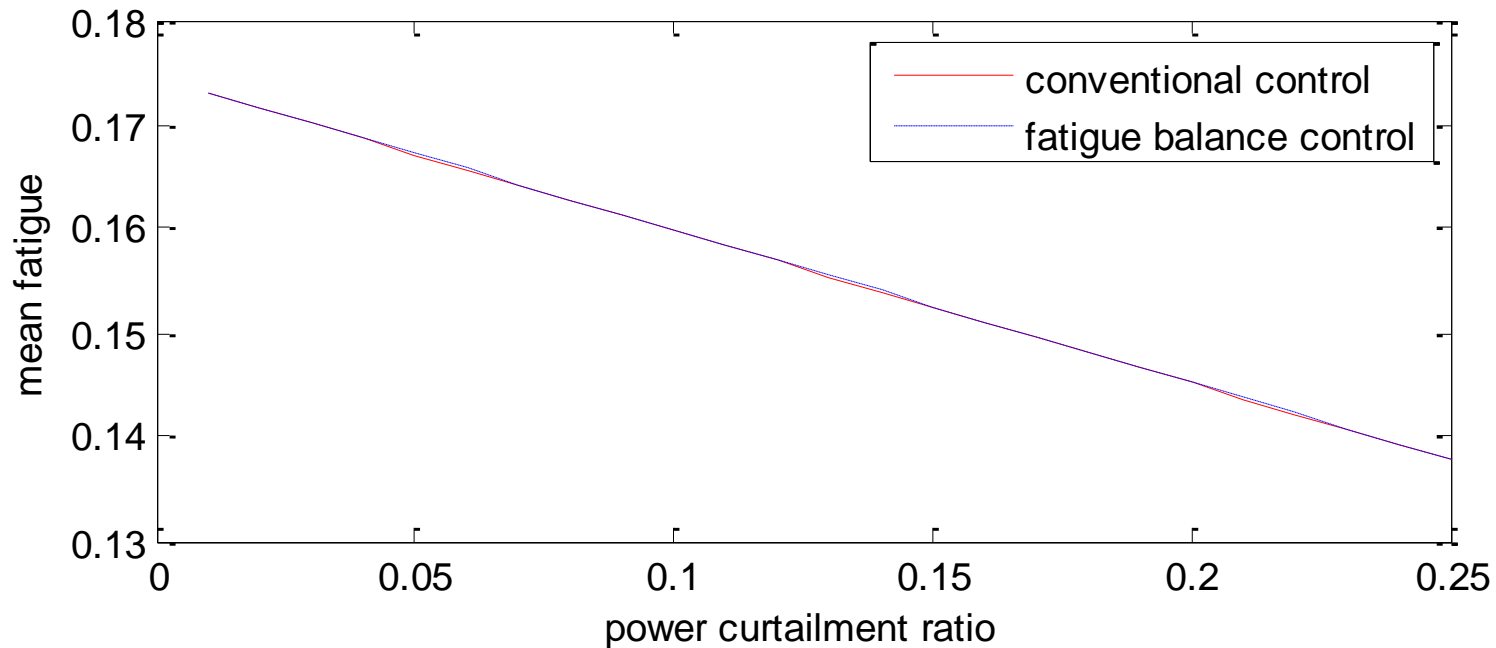


Mean fatigue: 0.1628

Standard deviation: 0.0033

Proposed method

Mean fatigue vary with power curtailment ratio



It means that the proposed method lose no active power and can trace the grid demand.

Conclusions

- Unbalanced fatigue is one of the key causes leading to high maintenance costs in large scale wind farm. Balancing the fatigue can be used to reduce maintenance frequency and the cost of energy.
- The proposed method, dispatching active power for wind turbine based on inverse proportion to fatigue, can make the fatigue distribution flatter and the active power production trace grid demand adaptively.
- The proposed method essentially is a compensation mechanism. This mechanism is based on the fatigue of current time and independent of wake effect, and has nothing to do with the geographical location and layout of wind farm. It is fit for both on-shore wind farm and off-shore wind farm.
- The calculated load of the proposed method is very lite, the task can be executed in existed wind farm control. It's a feasible and cheap way to optimize fatigue distribution in wind farms.

Thank you!