TurbOPark examples

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Example 1

Simple square wind farm with identical turbines.

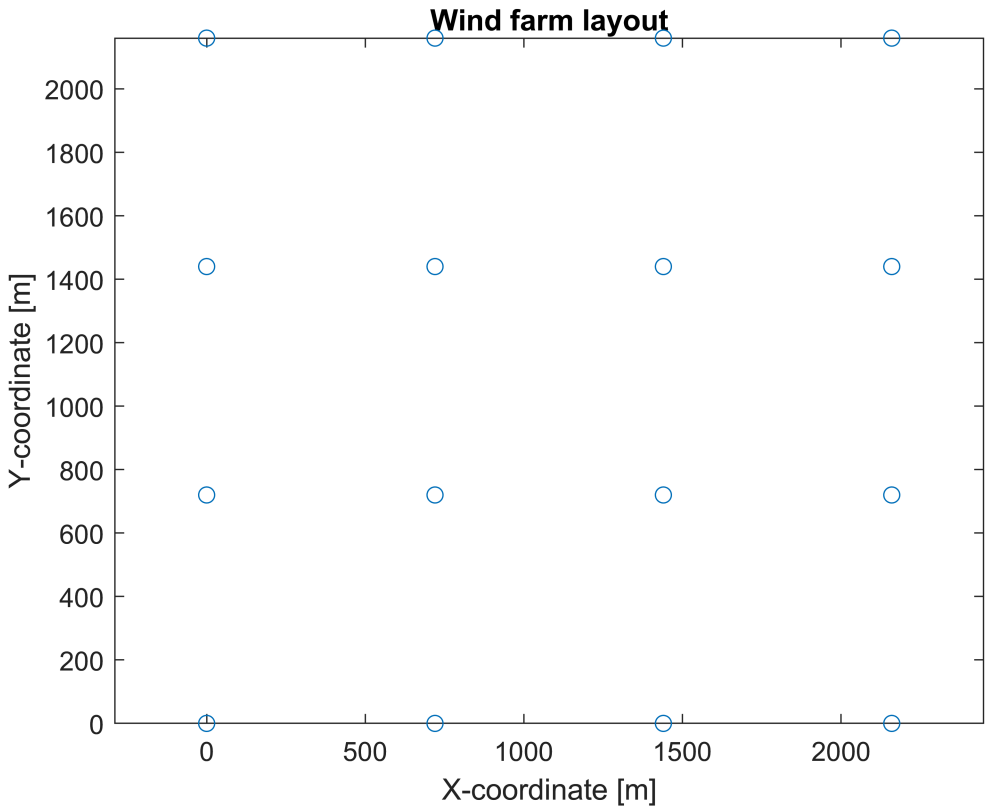
Define wind farm

4x4 wind farm with 6 rotor diameter distance

```
[X,Y] = meshgrid((0:3)*120*6, (0:3)*120*6);
```

Plot the layout

```
figure; plot(X(:),Y(:),'o')
axis equal
title('Wind farm layout'); xlabel('X-coordinate [m]'); ylabel('Y-coordinate [m]')
```



Define the power curve struct

Wind speed bins that the power curve is defined at

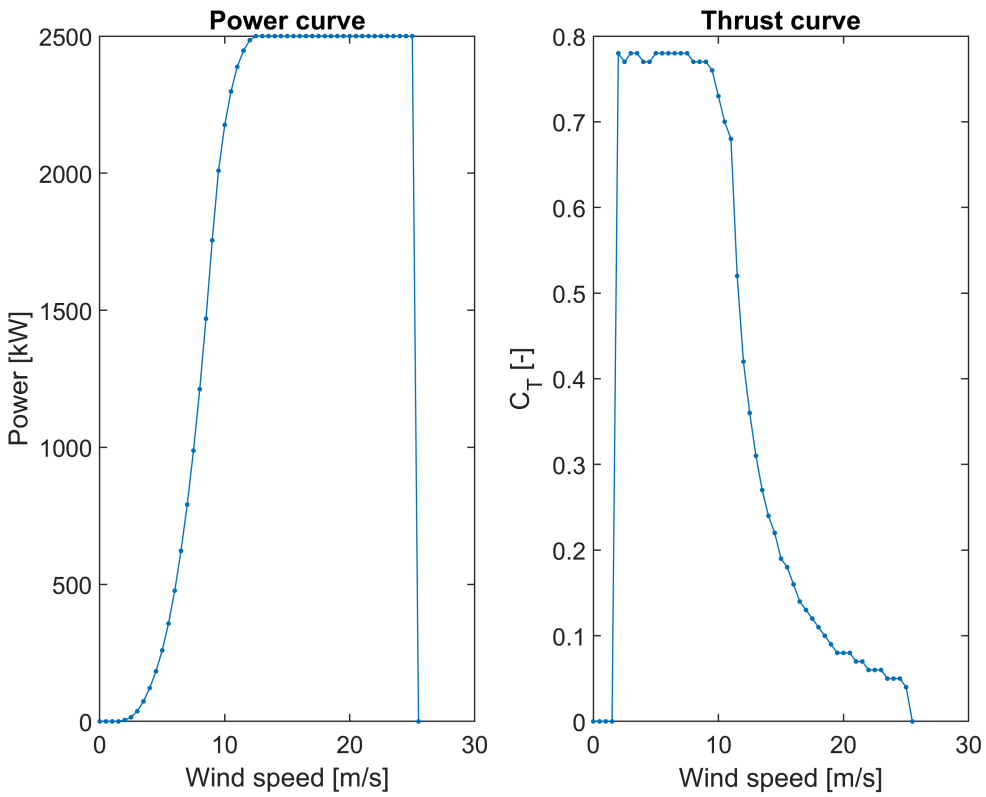
```
v = 0:0.5:25.5;
```

And the corresponding power and thrust values

```
pow = [0 0 0 0 5 15 37 73 122 183 259 357 477 622 791 988 1212 1469 1755 2009 2176 2298 2388 24
ct = [0 0 0 0 0.78 0.77 0.78 0.78 0.77 0.77 0.78 0.78 0.78 0.78 0.78 0.78 0.77 0.77 0.77 0.76 0
```

Plot the power and Ct curves

```
figure
subplot(1,2,1)
plot(v, pow, '.-')
title('Power curve'); xlabel('Wind speed [m/s]'); ylabel('Power [kW]')
subplot(1,2,2)
plot(v, ct, '.-')
title('Thrust curve'); xlabel('Wind speed [m/s]'); ylabel('C_T [-]')
```



Make power and ct interpolants, and collect in the struct `pc` together with the rotor diameter

```
pc.interpolant_power = griddedInterpolant(v, pow, 'linear','nearest');
pc.interpolant_ct = griddedInterpolant(v, ct, 'linear','nearest');
pc.rotor_diameter = 120;
```

Define the hub height

100 m aMSL, same for all 16 turbines

```
hub_height = 100*ones(1,16);
```

Define inflow wind speed and direction

The freestream wind speed at a given location (x_0, y_0), at a given hight z_0 (for this example 90 m aMSL). More than one wind speed can be processed in parallel.

```
u0 = [6,10,14];
nu0 = length(u0);
z0 = 90;
```

Wind direction (the wake model can only run for one wind direction at the time)

```
direction = 270;
```

Furthermore, you can define a correction to your free wind speed at (x_0, y_0, z_0) to the specific turbine location and hub height. The correction could stem from a difference between z_0 and the hub height of the turbine, a gradient in the wind speed across the site or the inclusion of blockage - or all of them combined.

In this example we won't include blockage or horizontal gradients (thus (x_0, y_0) are not needed), but we will assume a power law shear profile with a shear coefficient α of 0.1.

```
ws_corr = (hub_height/z0).^0.1;
```

Ambient turbulence intensity values corresponding to the free wind speed values above: 6 m/s will have a TI value of 9%, 10 m/s of 10% etc.

```
ti0 = [0.09 0.1 0.11];
```

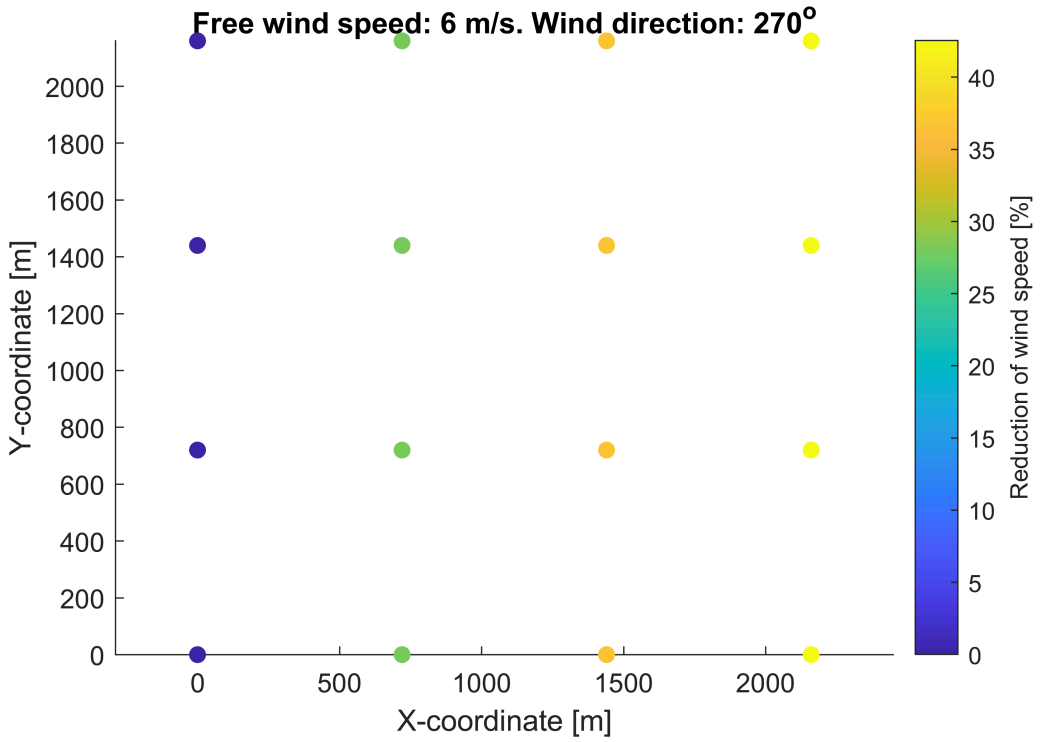
Run the TurbOPark model

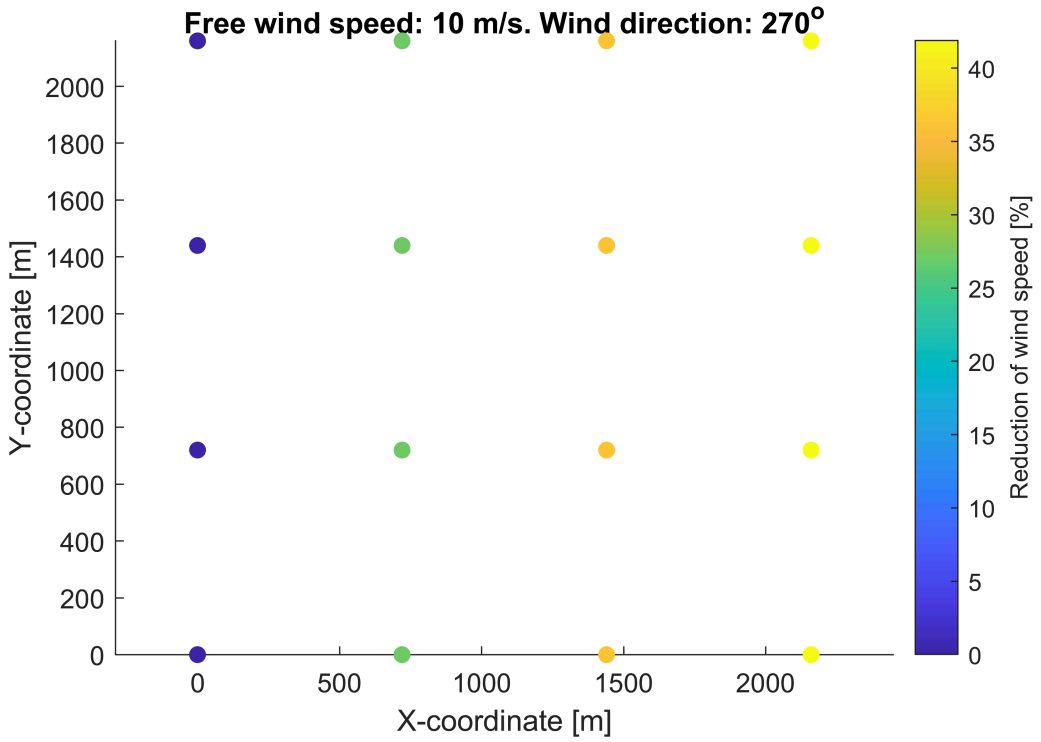
```
[pow_waked, ws_waked] = TurbOPark(u0,direction,ws_corr,X(:),Y(:),...
    hub_height,pc,ones(1,16),ti0);
```

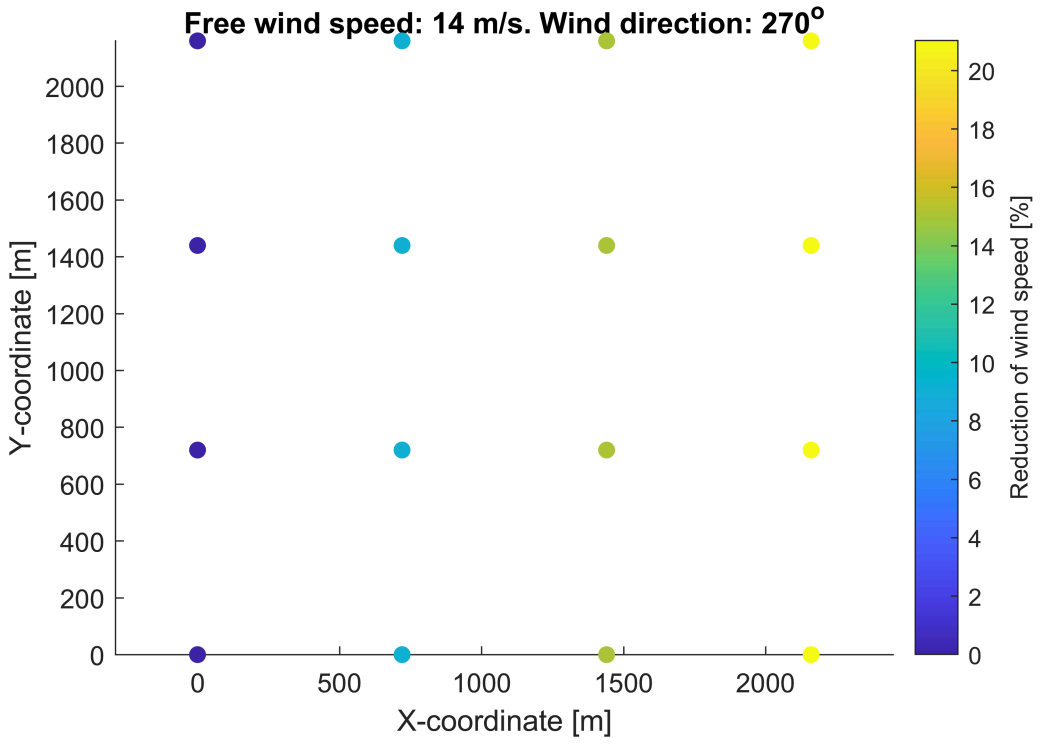
Plot results

For all free wind speeds, plot the reduction of wind speed calculated by the TurbOPark model in percent

```
for i = 1:length(u0)
    figure; scatter(X(:), Y(:), 40, (1-ws_waked(:,i)./(u0(i)*ws_corr'))*100, 'filled')
    axis equal
    cb = colorbar; cb.Label.String = 'Reduction of wind speed [%]';
    title(['Free wind speed: ', num2str(u0(i)) ,' m/s. Wind direction: ' num2str(direction) '^c
end
```

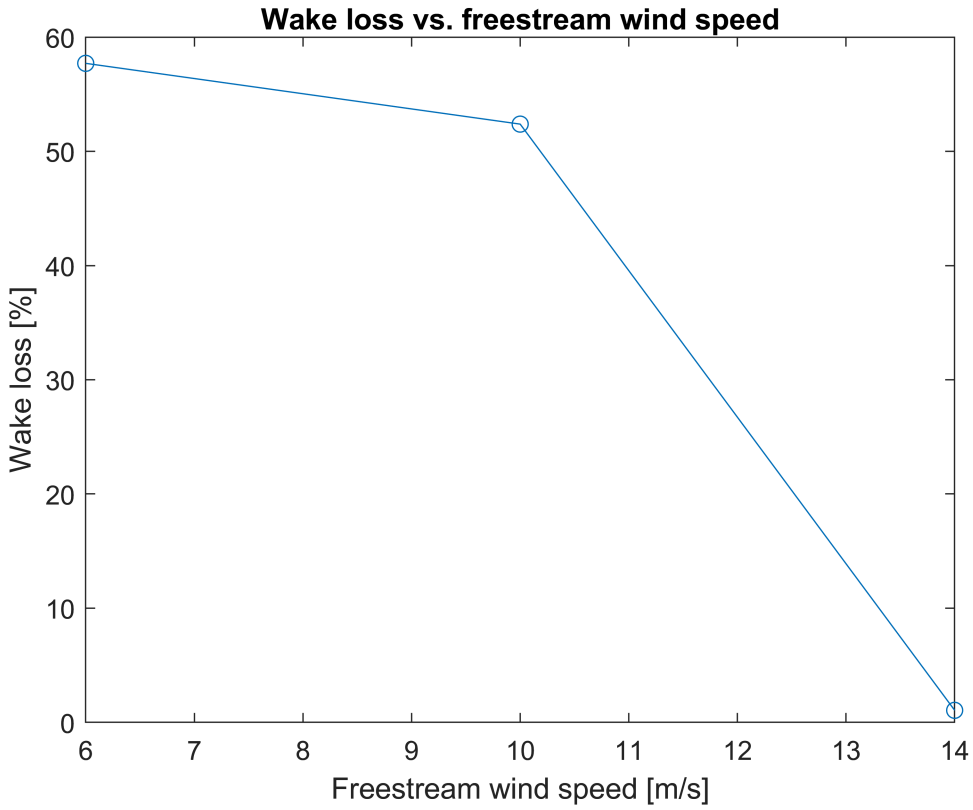

Free wind speed: 6 m/s. Wind direction: 270°
Y-coordinate [m]
X-coordinate [m]
Reduction of wind speed [%]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
500
1000
1500
2000
0
5
10
15
20
25
30
35
40


Free wind speed: 10 m/s. Wind direction: 270°
Y-coordinate [m]
X-coordinate [m]
Reduction of wind speed [%]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
500
1000
1500
2000
0
5
10
15
20
25
30
35
40



Wake loss for the wind farm at each inflow wind speed (ignoring blockage so the front row represents the gross power)

```
figure
nwtg = numel(X);
plot(u0, 100*(1-sum(pow_waked,1)./max(pow_waked)./nwtg), 'o-')
title('Wake loss vs. freestream wind speed'); xlabel('Freestream wind speed [m/s]'); ylabel('Wa
```



Example 2

Same wind farm as in example 1 but with two different turbine types (most northern turbines of type 1 and most southern of type 2), and with a wind speed gradient included.

Define and distribute the two turbine types

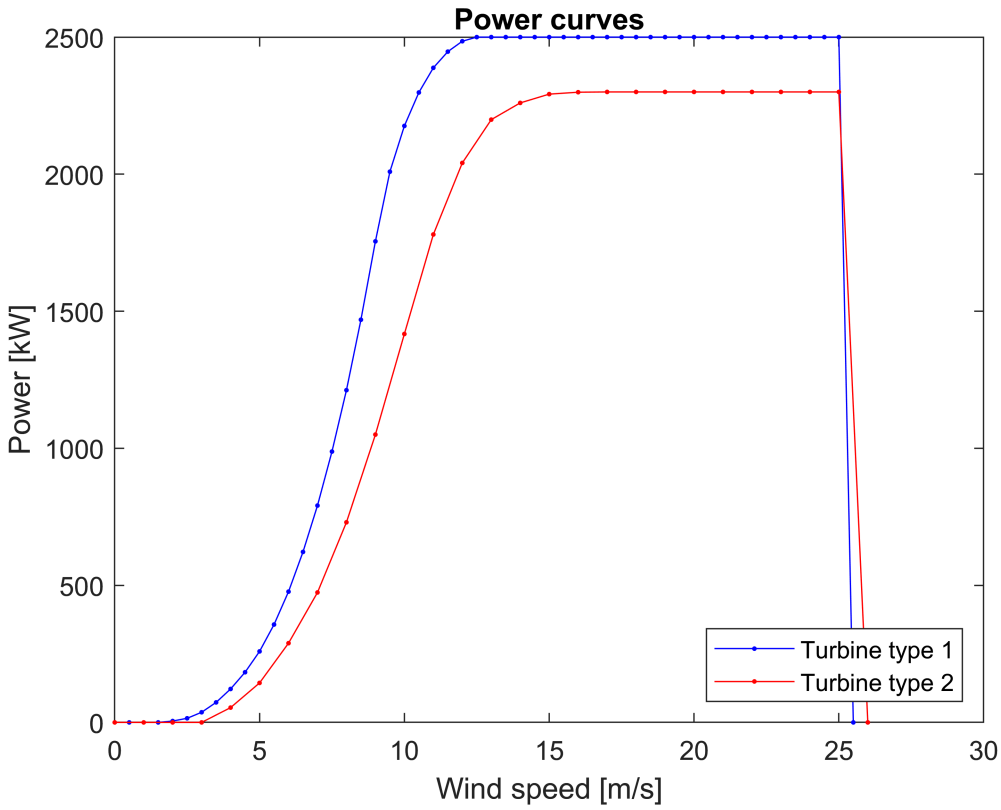
```
pc1 = pc;

v2 = 0:26;
pow2 = [0 0 0 0 54 144 289 474 730 1050 1417 1780 2041 2199 2260 2292 2299 2300 2300 2300 2300
ct2 = [0         0 0 0 0.94 0.82 0.76 0.68 0.86 0.83 0.77 0.68 0.66 0.52 0.47 0.41 0.38 0.34 0.

pc2.interpolant_power = griddedInterpolant(v2, pow2, 'linear','nearest');
pc2.interpolant_ct = griddedInterpolant(v2, ct2, 'linear','nearest');
pc2.rotor_diameter = 80;
```

Plot comparing the two power curves

```
figure
plot(v, pow, 'b.-')
hold on
plot(v2, pow2, 'r.-')
legend('Turbine type 1', 'Turbine type 2','Location','SouthEast')
title('Power curves'); xlabel('Wind speed [m/s]'); ylabel('Power [kW]')
```



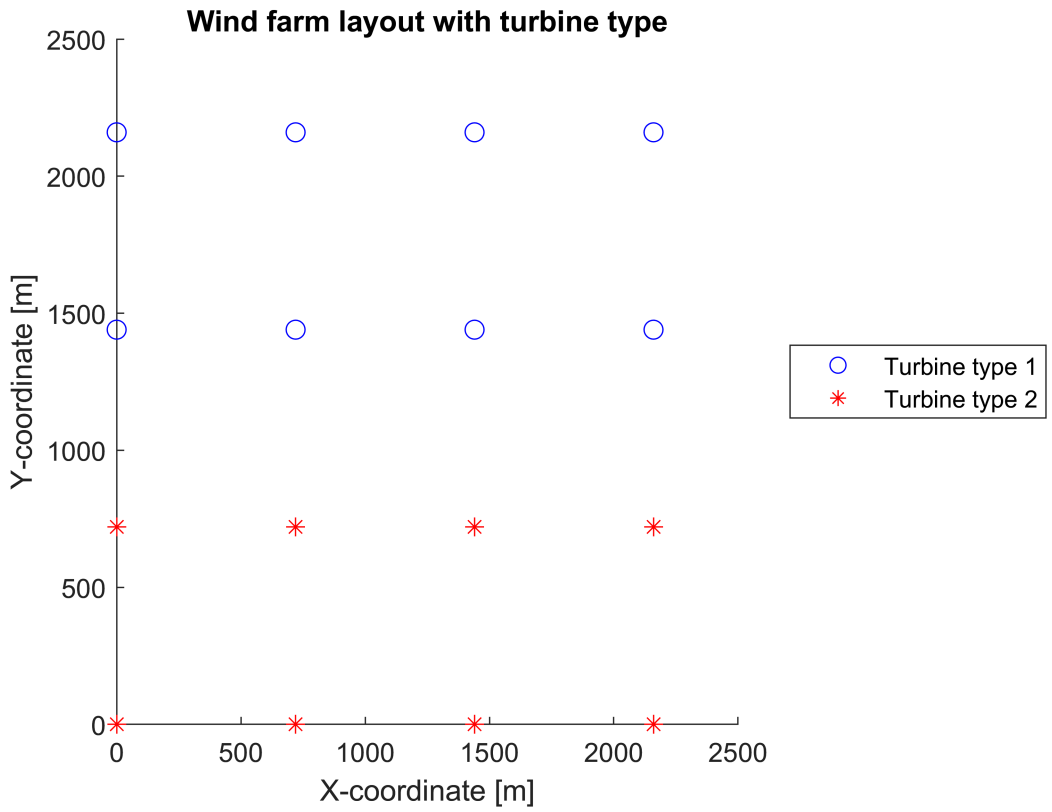
Distribute the two turbine types to the turbine positions using `power_curve_index`

```
power_curve_index = 1 + 1.0*(Y(:)<=720)'
```

```
power_curve_index = 1×16
     2     2     1     1     2     2     1     1     2     2     1     1     2 ···
```

Illustration of turbine type by location

```
figure
idx1 = power_curve_index == 1;
idx2 = power_curve_index == 2;
scatter(X(idx1), Y(idx1), 50, 'bo')
hold on
scatter(X(idx2), Y(idx2), 50, 'r*')
legend('Turbine type 1', 'Turbine type 2','Location','EastOutSide')
title('Wind farm layout with turbine type'); xlabel('X-coordinate [m]'); ylabel('Y-coordinate [
```



Hub height of turbine type 2 is set to 70 m aMSL

```
hub_height(power_curve_index == 2) = 70;
```

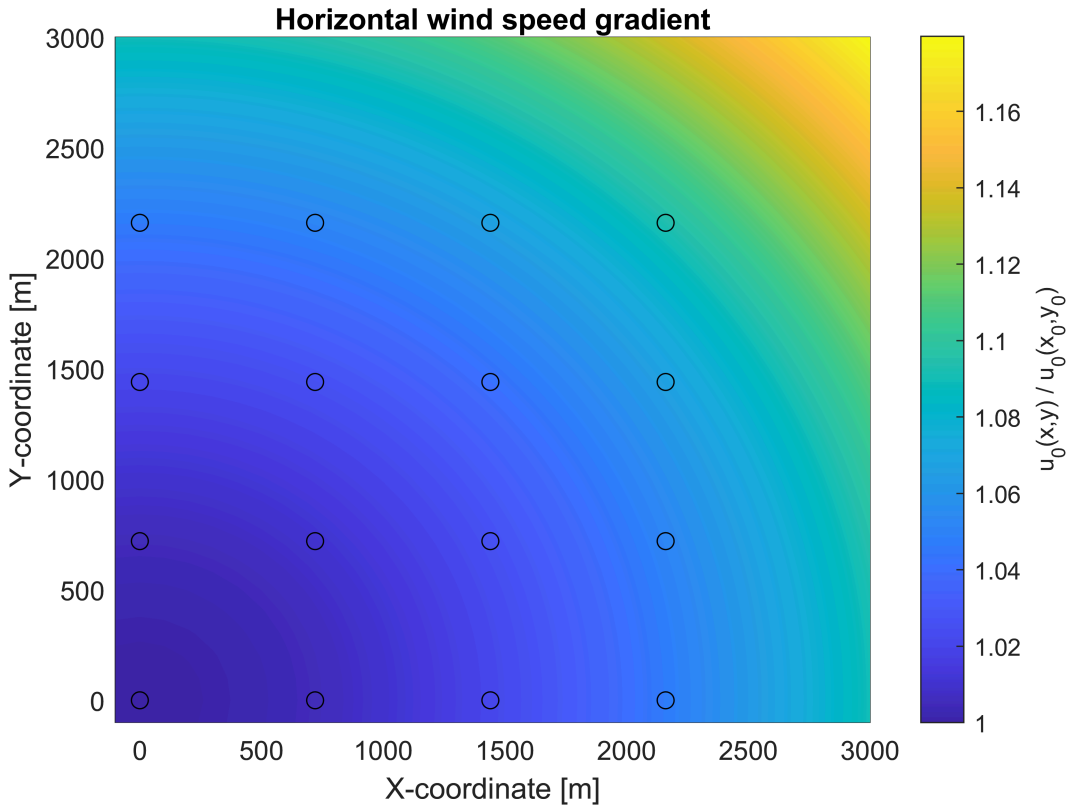
Define a horizontal correction

In this example we will include a "random" wind speed gradient across the site with lower wind speeds in south-west and higher in north-east. We will in this example place the free wind speed reference point (x_0, y_0) at the same position as the first turbine. The reference position where the freestream wind speed is defined is still at a height of 90 m aMSL.

```
x_pt = -100:100:3000; y_pt = x_pt;
[X_pt,Y_pt] = ndgrid(x_pt,y_pt);
grad = ((X_pt-5).^2 + (Y_pt).^2)*10^-8 + 1;
grad_int = griddedInterpolant(X_pt,Y_pt,grad);
```

Plot the wind farm layout on top of the wind speed gradient

```
figure; pcolor(x_pt, y_pt, grad_int(X_pt,Y_pt)./grad_int(X(1),Y(1))); shading interp; c = color
c.Label.String = 'u_0(x,y) / u_0(x_0,y_0)';
hold on
scatter(X(:),Y(:),40,'ko')
title('Horizontal wind speed gradient'); xlabel('X-coordinate [m]'); ylabel('Y-coordinate [m]')
```



Now combine the effect of the wind speed gradient and shear in the correction of the free wind speed `ws_corr` (remember we defined the free wind speed position (x_0, y_0) to be `(X(1),Y(1))`)

```
ws_corr = (hub_height/z0).^0.1; % Effect of shear
ws_corr = ws_corr .* grad_int(X(:),Y(:))'./grad_int(X(1),Y(1)); % Add effect of horizontal grad
```

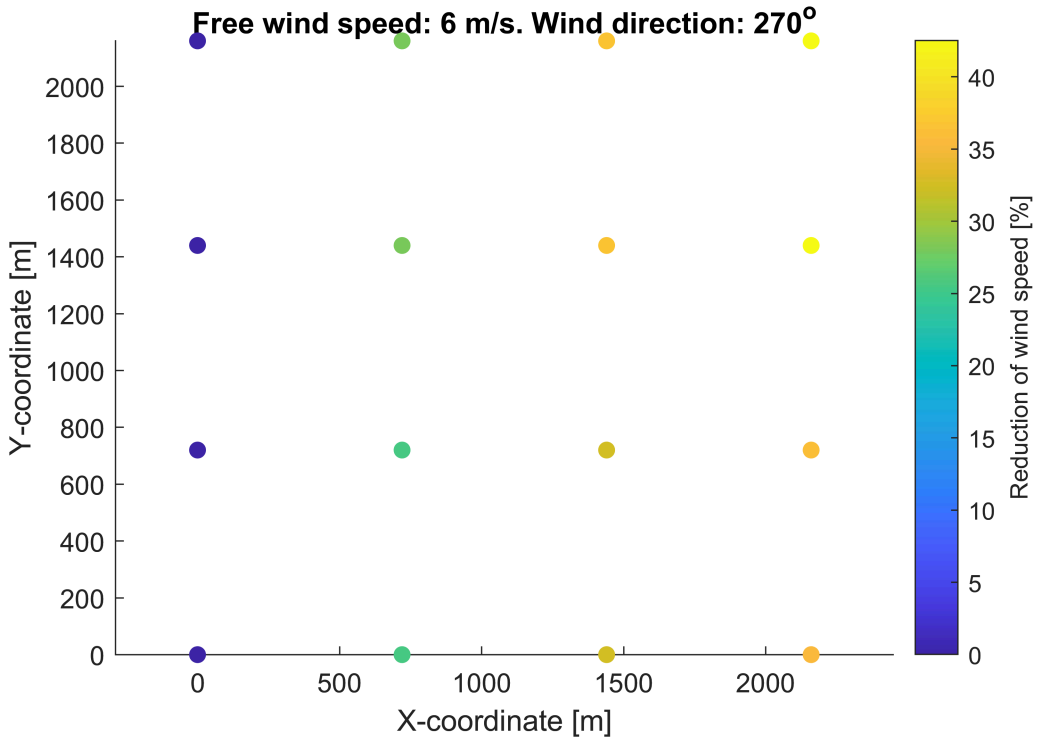
Run the TurbOPark model

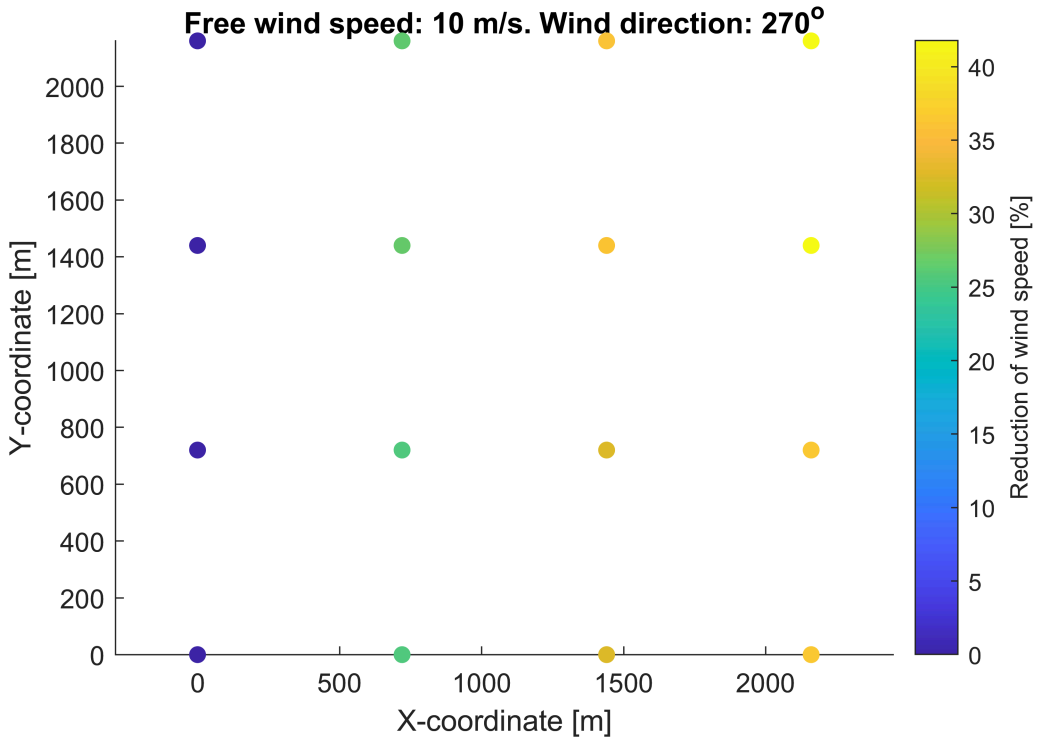
```
[pow_waked, ws_waked] = TurbOPark(u0,direction,ws_corr,X(:),Y(:),...
    hub_height,[pc1, pc2],power_curve_index,ti0);
```

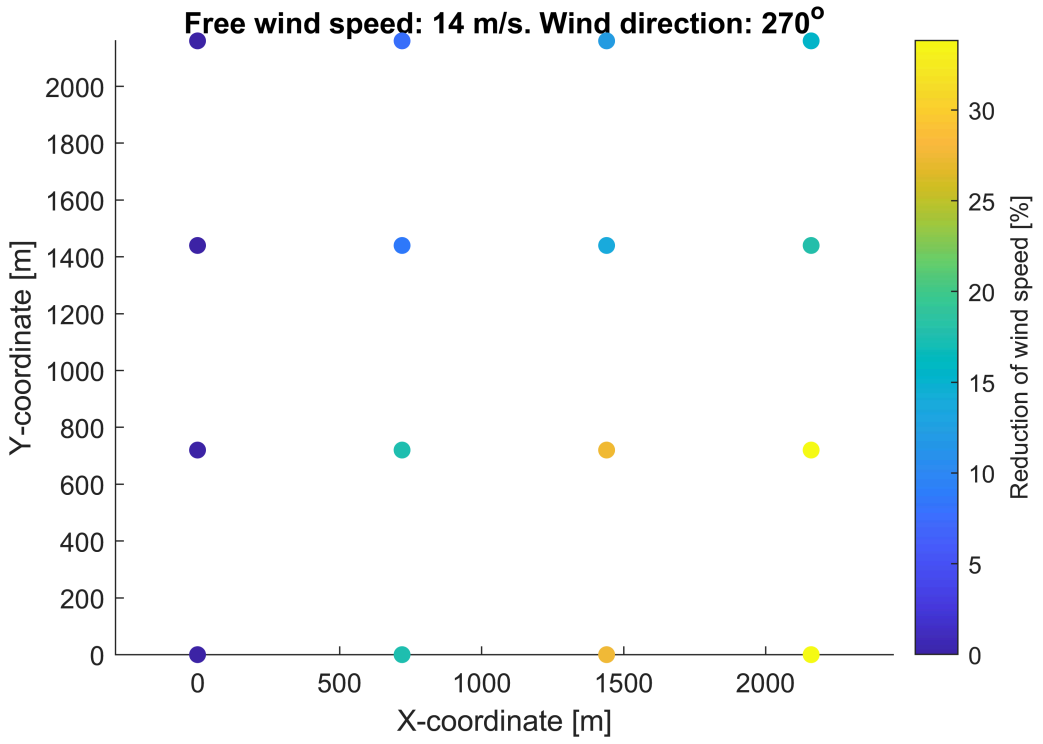
Plot results

For all free wind speeds, plot the reduction of wind speed calculated by the TurbOPark model in percent

```
for i = 1:length(u0)
    figure; scatter(X(:), Y(:), 40, (1-ws_waked(:,i)./(u0(i)*ws_corr'))*100, 'filled')
    axis equal
    cb = colorbar; cb.Label.String = 'Reduction of wind speed [%]';
    title(['Free wind speed: ', num2str(u0(i)) ,' m/s. Wind direction: ' num2str(direction) '^c
end
```

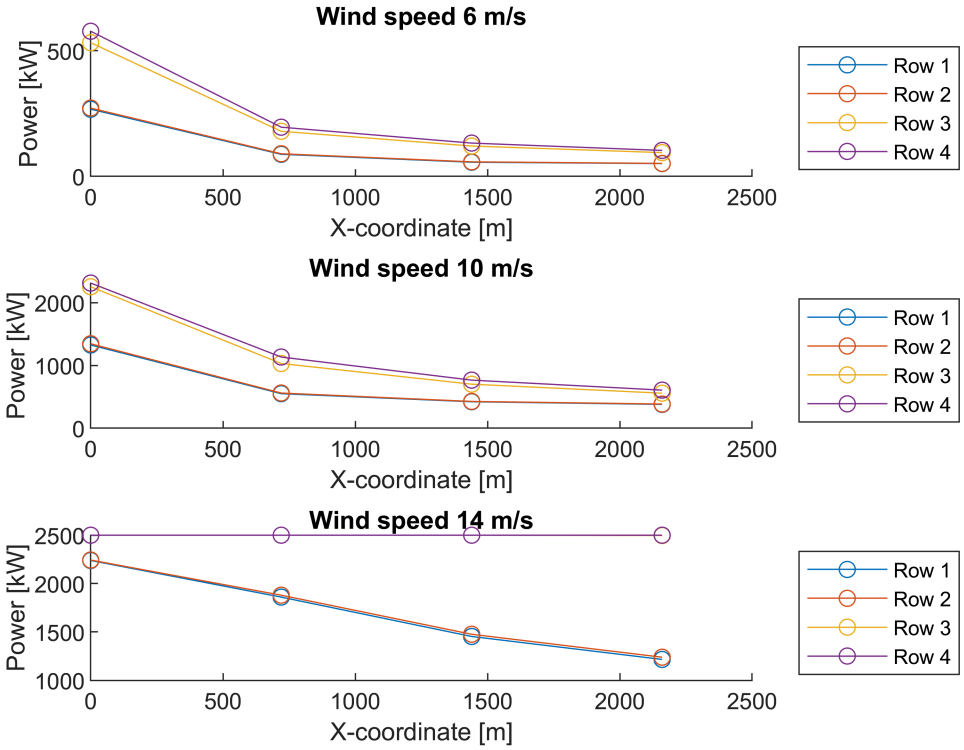

Free wind speed: 6 m/s. Wind direction: 270°
Y-coordinate [m]
X-coordinate [m]
Reduction of wind speed [%]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
500
1000
1500
2000
0
5
10
15
20
25
30
35
40


Free wind speed: 10 m/s. Wind direction: 270°
Y-coordinate [m]
X-coordinate [m]
Reduction of wind speed [%]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
500
1000
1500
2000
0
5
10
15
20
25
30
35
40



Plot of the power along different turbine rows (labelled 1-4 from south to north)

```
figure
ys = unique(Y);
% Turbine row numbers 1-4
iRow1 = Y == ys(1);
iRow2 = Y == ys(2);
iRow3 = Y == ys(3);
iRow4 = Y == ys(4);
for i=1:nu0
    subplot(nu0,1,i)
    hold on
    plot(X(iRow1), pow_waked(iRow1,i),'o-'); title(['Wind speed ',num2str(u0(i)),' m/s']); xlab
    plot(X(iRow2), pow_waked(iRow2,i),'o-'); title(['Wind speed ',num2str(u0(i)),' m/s']); xlab
    plot(X(iRow3), pow_waked(iRow3,i),'o-'); title(['Wind speed ',num2str(u0(i)),' m/s']); xlab
    plot(X(iRow4), pow_waked(iRow4,i),'o-'); title(['Wind speed ',num2str(u0(i)),' m/s']); xlab
    legend('Row 1','Row 2','Row 3','Row 4','Location','EastOutSide')
end
```


Wind speed 6 m/s
Power [kW]
0
500
0
500
1000
1500
2000
2500
X-coordinate [m]
Row 1
Row 2
Row 3
Row 4
Wind speed 10 m/s
Power [kW]
0
1000
2000
0
500
1000
1500
2000
2500
X-coordinate [m]
Row 1
Row 2
Row 3
Row 4
Wind speed 14 m/s
Power [kW]
1000
1500
2000
2500
0
500
1000
1500
2000
2500
X-coordinate [m]
Row 1
Row 2
Row 3
Row 4