

TurbOPark examples

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Example 1

Simple square wind farm with identical turbines.

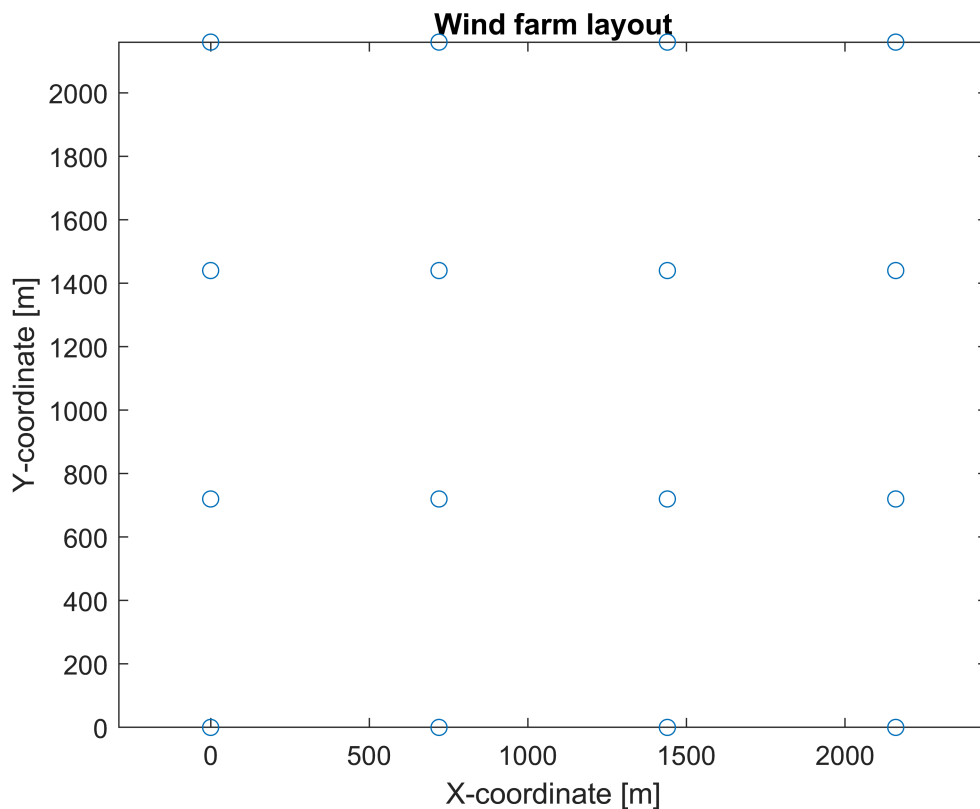
Define wind farm

4x4 wind farm with 6 rotor diameter distance (rotor diameter beeing 120 m)

```
[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

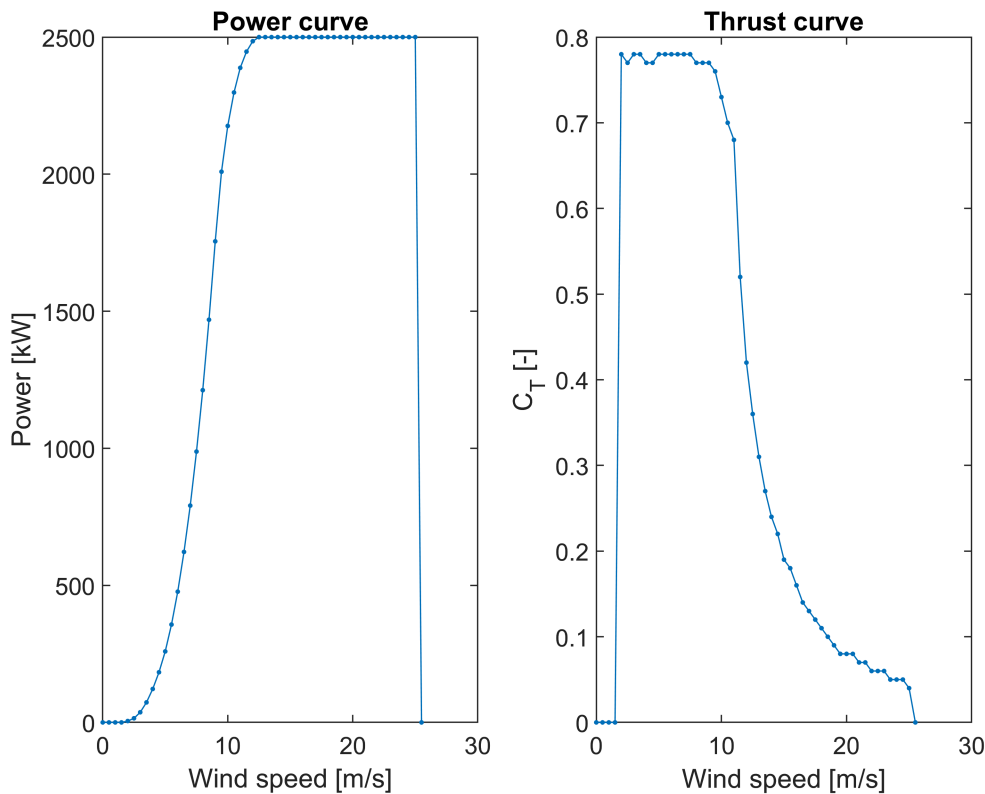
```
v = 0:0.5:25.5;
```

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 2447 2485 2500 2500 2500 2500 2500 2500 2500 2500 2500 2500 2500 2500 2500,...
       2500 2500 2500 2500 2500 2500 2500 2500 2500 2500 2500 2500 2500 0];
ct = [0 0 0 0 0.78 0.77 0.78 0.78 0.77 0.77 0.77 0.78 0.78 0.78 0.78 0.78 0.78 0.77 0.77,...
      0.77 0.76 0.73 0.7 0.68 0.52 0.42 0.36 0.31 0.27 0.24 0.22 0.19 0.18 0.16 0.14 0.13,...
      0.12 0.11 0.1 0.09 0.08 0.08 0.08 0.08 0.07 0.07 0.06 0.06 0.06 0.05 0.05 0.05 0.04 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 height 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);
```

Output pow_waked and ws_waked to enable comparison:

```
format longG  
disp(pow_waked)
```

495.429647093727	2201.84387293603	2500
495.429647093727	2201.84387293603	2500
495.429647093727	2201.84387293603	2500
495.429647093727	2201.84387293603	2500
165.681333834342	938.265716039082	2500
165.681333834342	938.265716039082	2500
165.681333834342	938.265716039082	2500
165.681333834342	938.265716039082	2500
105.264701735512	607.531414199904	2485.83000221364
105.264701735512	607.531414199904	2485.83000221364
105.264701735512	607.531414199904	2485.83000221364

105.264701735512	607.531414199904	2485.83000221364
71.8241034924664	446.254939675813	2408.31291455241
71.8241034924664	446.254939675813	2408.31291455241
71.8241034924664	446.254939675813	2408.31291455241
71.8241034924664	446.254939675813	2408.31291455241

disp(ws_waked)

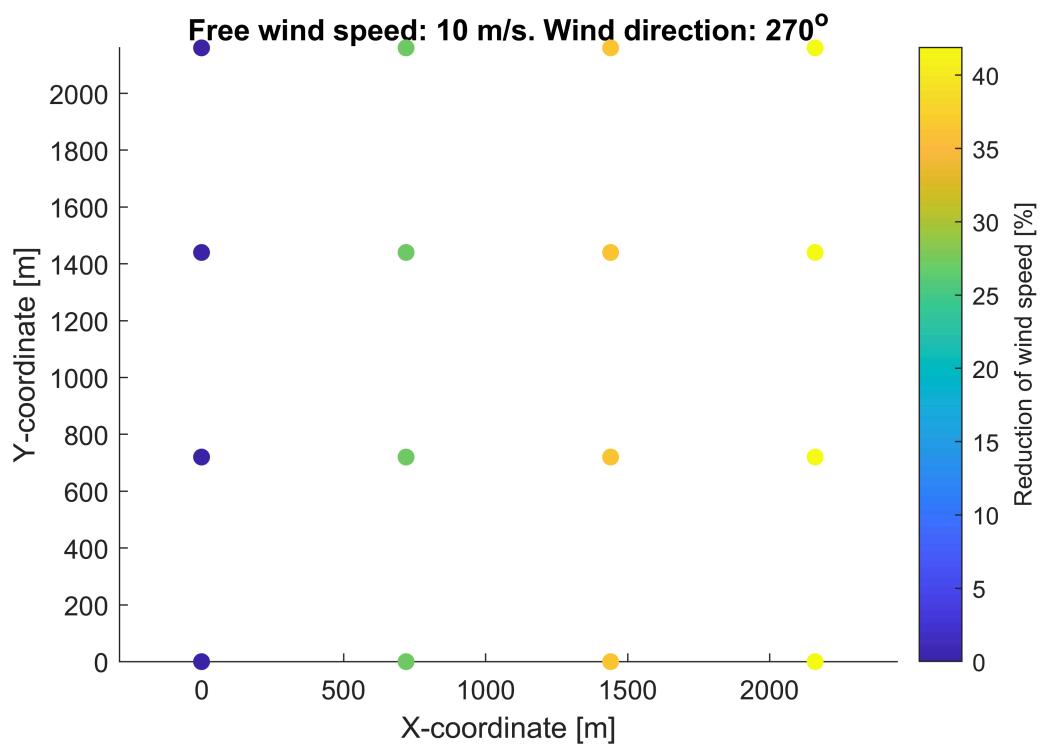
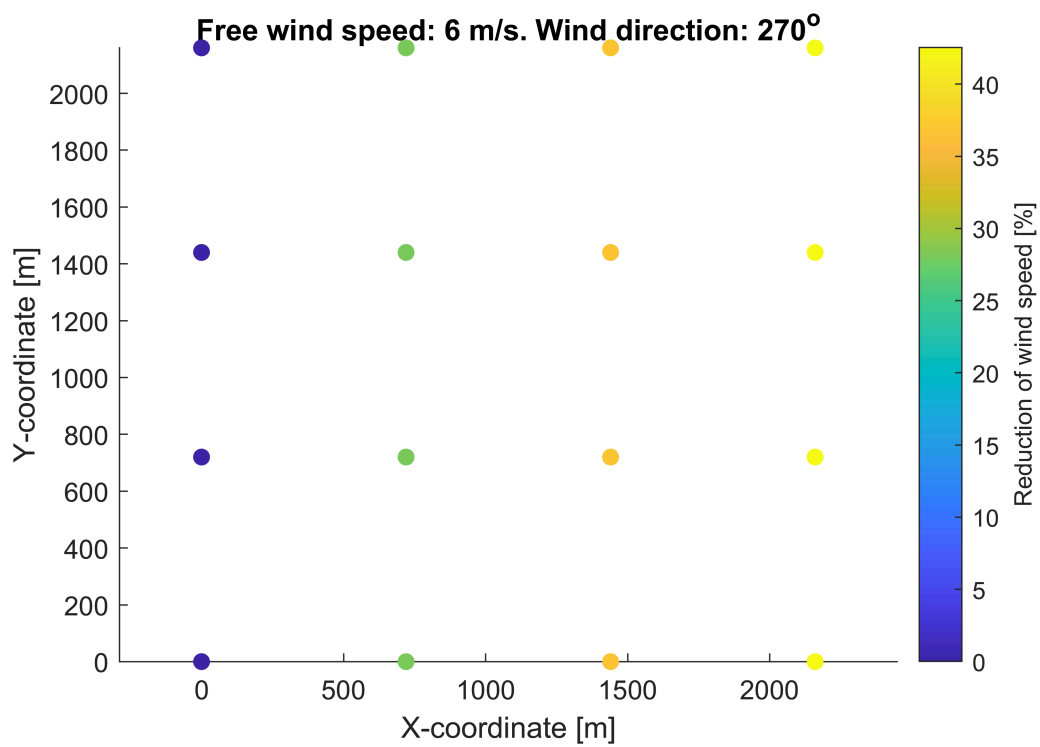
6.06355050721975	10.1059175120329	14.1482845168461
6.06355050721975	10.1059175120329	14.1482845168461
6.06355050721975	10.1059175120329	14.1482845168461
6.06355050721975	10.1059175120329	14.1482845168461
4.35804371995363	7.37377085289107	12.8635577397301
4.35804371995363	7.37377085289107	12.8635577397301
4.35804371995363	7.37377085289107	12.8635577397301
4.35804371995363	7.37377085289107	12.8635577397301
3.82923165036237	6.45010832482725	12.0276667404546
3.82923165036237	6.45010832482725	12.0276667404546
3.82923165036237	6.45010832482725	12.0276667404546
3.82923165036237	6.45010832482725	12.0276667404546
3.48366810406203	5.87189558198255	11.1721433436644
3.48366810406203	5.87189558198255	11.1721433436644
3.48366810406203	5.87189558198255	11.1721433436644
3.48366810406203	5.87189558198255	11.1721433436644

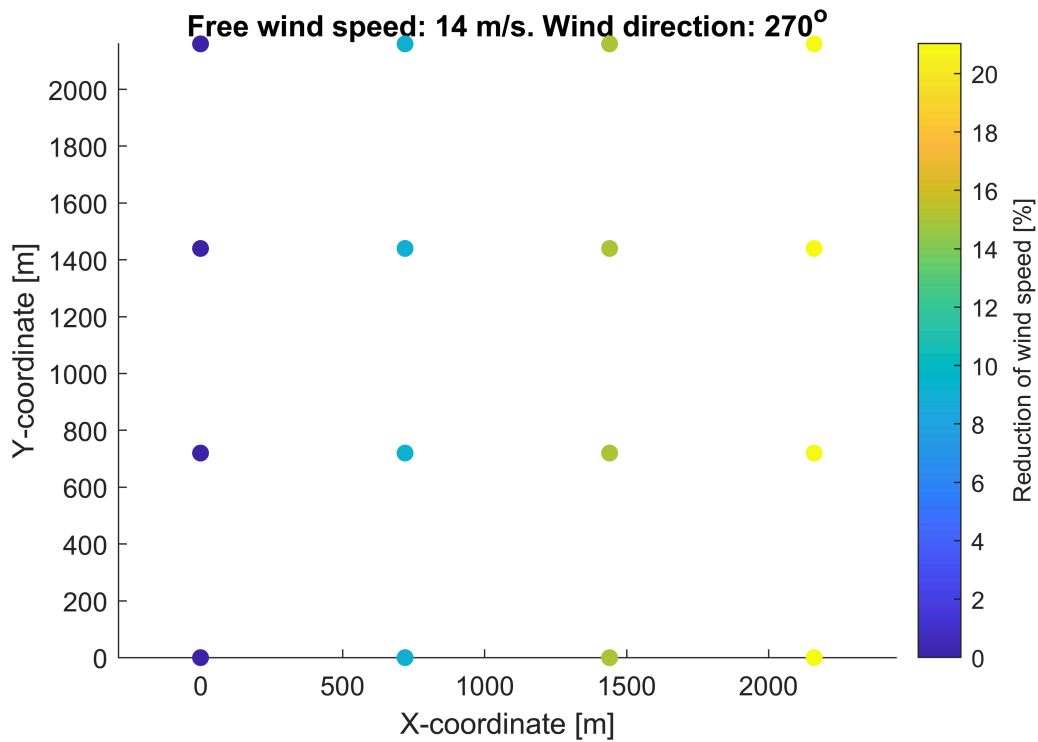
Note that since the hub height is higher than the wind speed reference height z_0 the output wind speed is larger than the free stream wind speed for the front row turbines.

Plot results

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

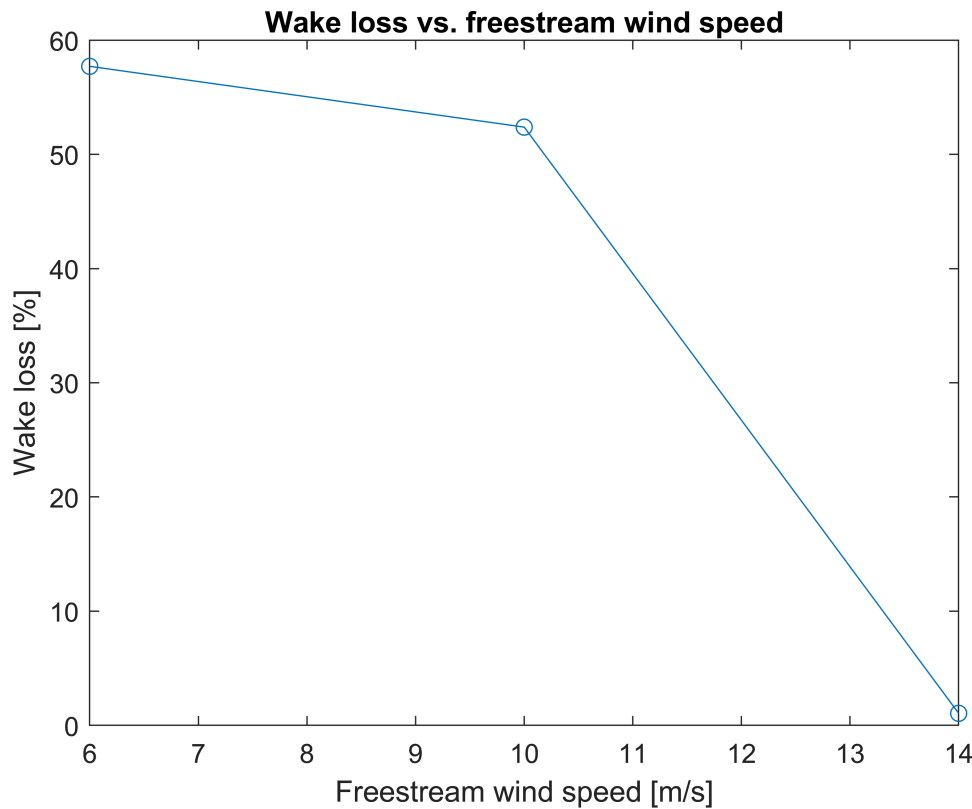
```
for i = 1:length(u0)
    figure; scatter(X(:), Y(:), 40, (1-ws_waked(:,i)./(u0(i)*ws_corr'))*100, 'filled')
    axis equal
    cb = colorbar; cb.Label.String = 'Reduction of wind speed [%]';
    title(['Free wind speed: ', num2str(u0(i)), ' m/s. Wind direction: ' num2str(direction) '^o'])
end
```





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

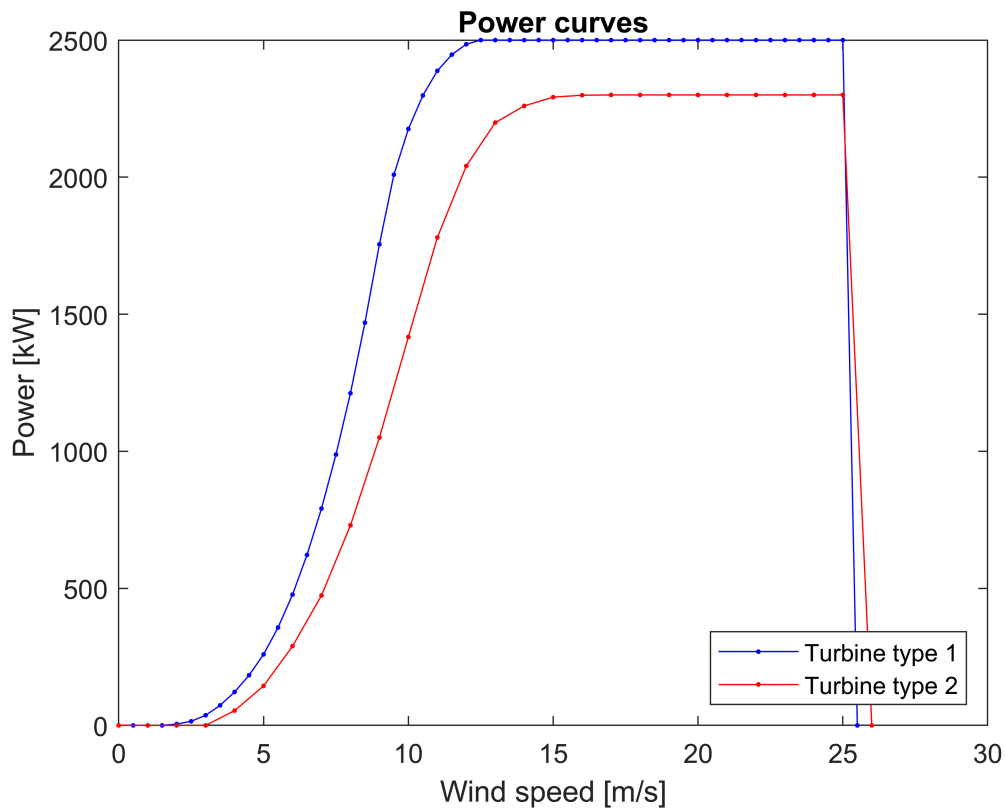
```
pc1 = pc;

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 2300 2300 2300 2300 2300 2300 0];
ct2 = [0 0 0 0 0.94 0.82 0.76 0.68 0.68 0.86 0.83 0.77 0.68 0.66 0.52 0.47 0.41 0.38 0.34,...
        0.27 0.26 0.23 0.22 0.22 0.2 0.16 0.17 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]')
```



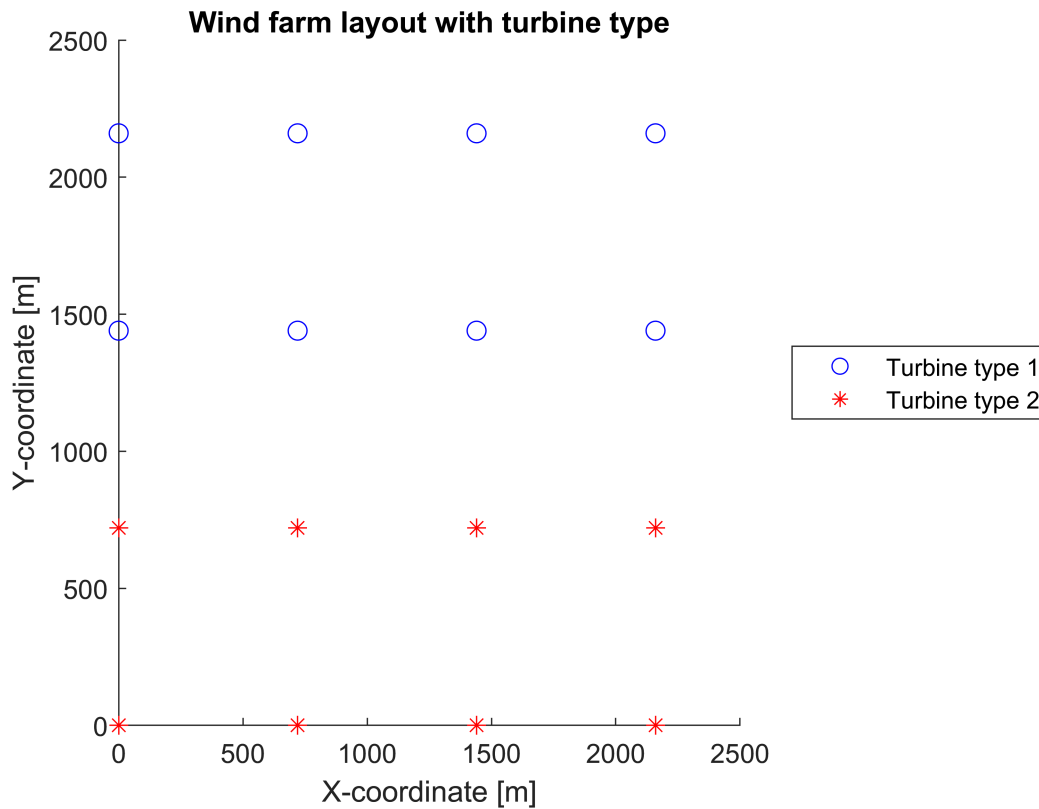
Distribute the two turbine types to the turbine positions using `power_curve_index`

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

```
power_curve_index = 1x16
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 [m]')
```

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

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

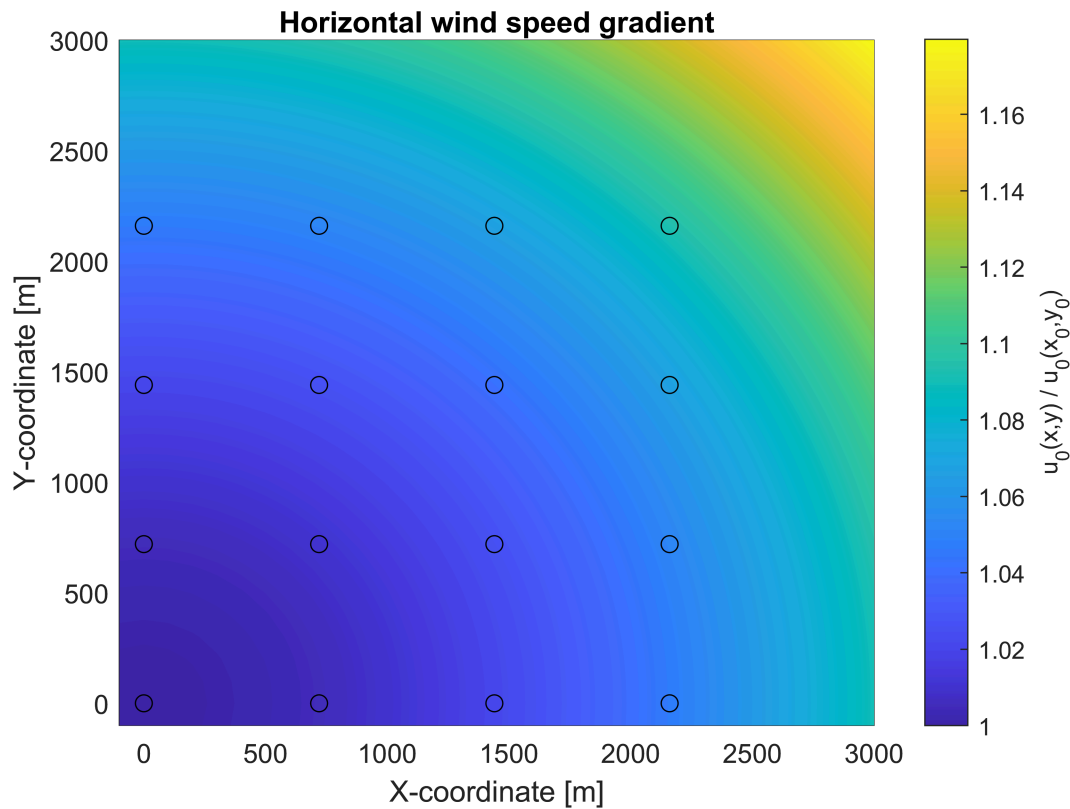
Define a horizontal correction

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 = colorbar;
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 gradient
```

Run the TurbOPark model

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

Output `pow_waked` and `ws_waked` to enable comparison:

```
disp(pow_waked)
```

267.408098975358	1325.91692326387	2238.805191408
271.8198199871	1344.52728661225	2243.13577732067
531.934637441146	2253.03477894046	2500
577.513122499193	2311.97909224055	2500
87.8716269861529	549.915174301573	1860.30802639162
90.029536518109	560.285573640592	1879.96345820567
179.445496763605	1030.67640805119	2500
195.741429267846	1133.76926324207	2500
56.3363587519906	421.529493247156	1453.25377990821
57.8305559469565	426.318770082901	1476.12985730185
120.791650152783	701.169901423848	2500
132.472056081865	765.870852417475	2500
50.9865832982385	379.447075562596	1216.18489248015
51.592223376867	385.115650375366	1238.96287545131

94.521082069401
103.321661723677

557.67685933973
606.468580599153

2496.89121383494
2500

disp(ws_waked)

5.85109033776109
5.88151599991104
6.18942978427981
6.34659697413515
4.37635141095725
4.40032818353454
4.47086472757053
4.58382519255162
4.02595954168878
4.04256173274396
3.9876698995182
4.08583652526119
3.94419598700442
3.95541154401606
3.71960287825919
3.80940471146609

9.75181722960182
9.80252666651839
10.315716307133
10.5776616235586
7.29654364961552
7.33705302203356
7.59525983939998
7.82537781973676
6.71637563917382
6.74226362206974
6.73423047758535
6.92565340951916
6.48890311114917
6.51954405608306
6.27819606668872
6.44644338137639

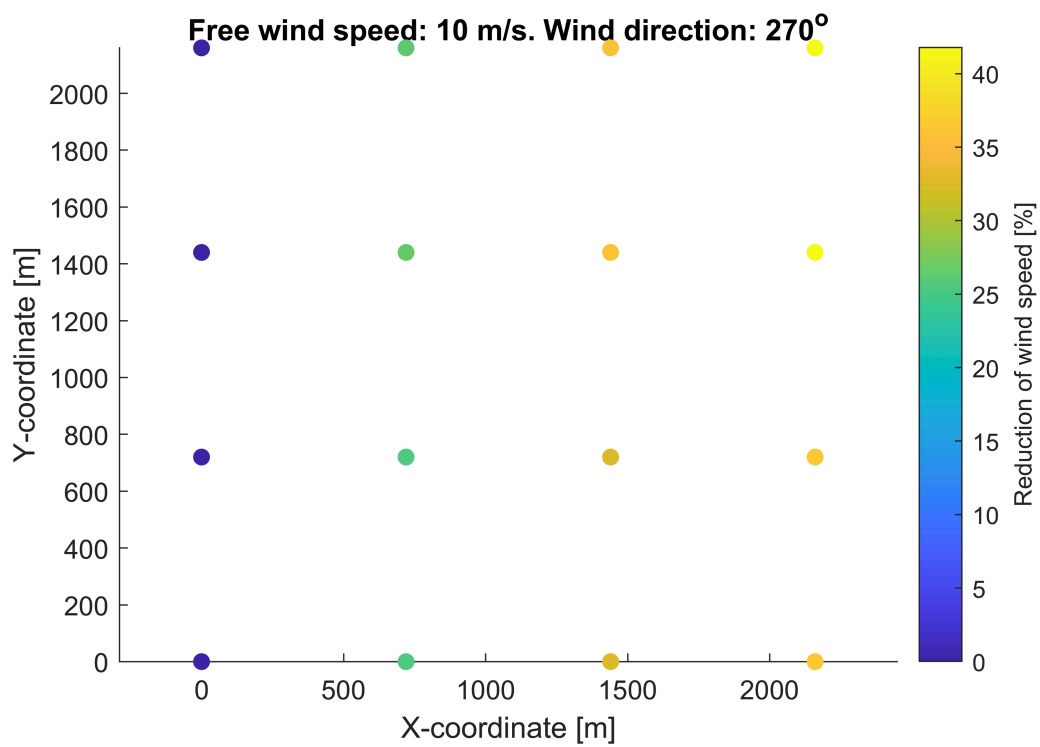
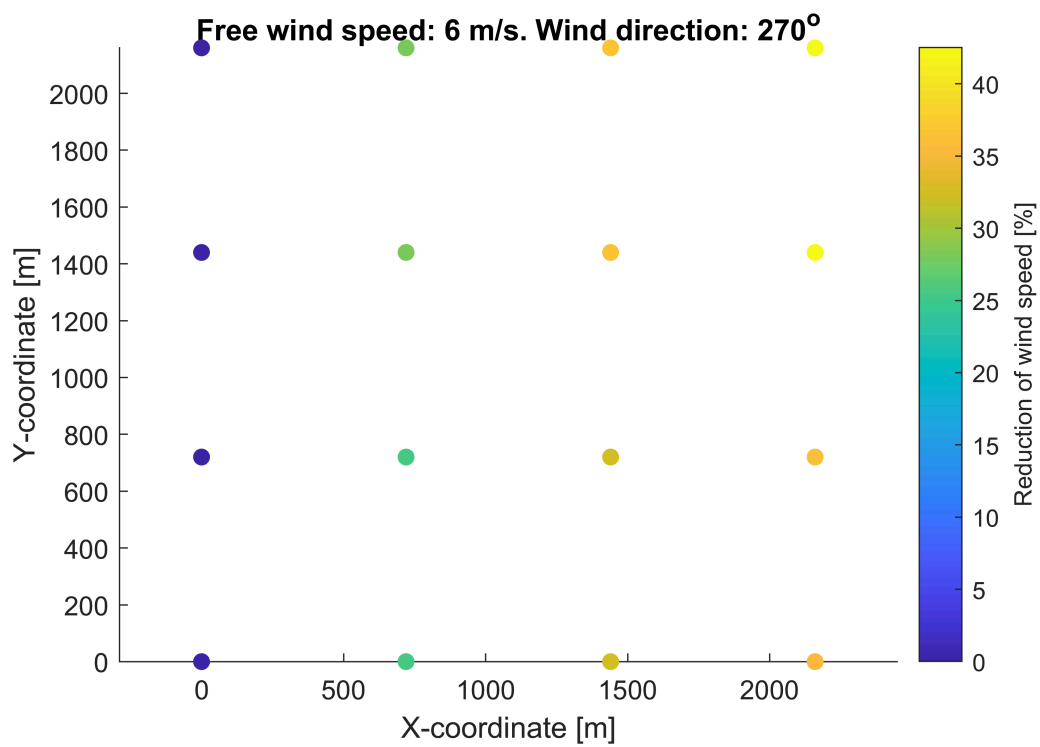
13.6525441214426
13.7235373331257
14.4420028299862
14.808726272982
11.3076935877073
11.3830017555773
13.2633760517144
13.7197242744724
10.0998726719234
10.1628921688756
12.7262841310504
13.2610220831519
9.45281987051811
9.51488521921339
12.396373794498
13.0445573540727

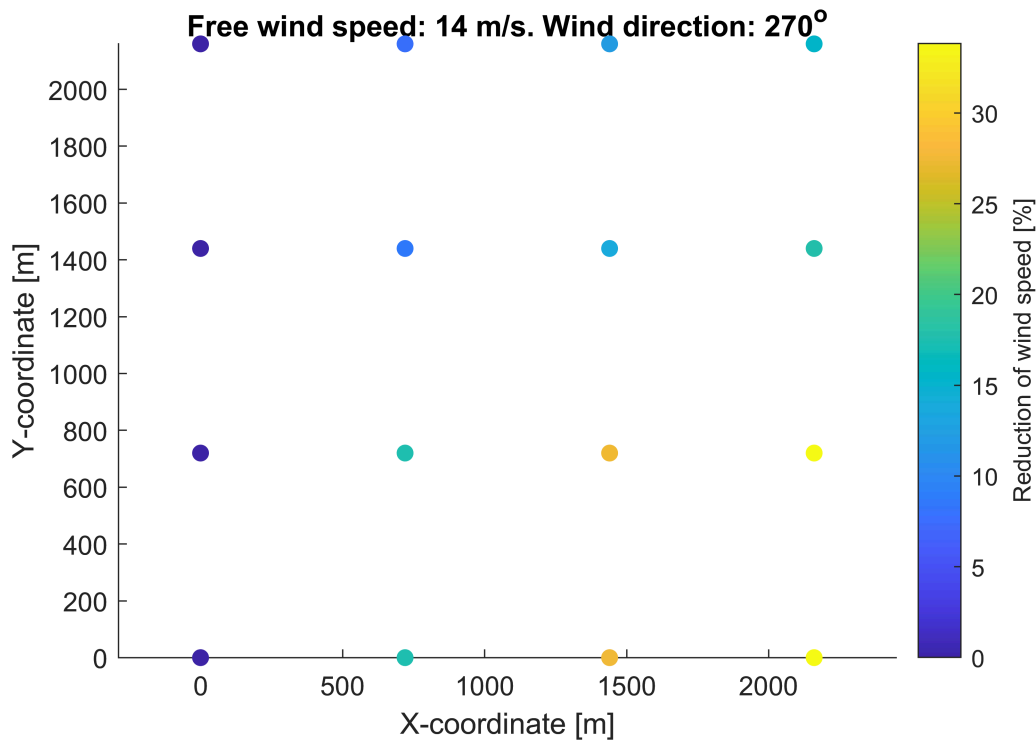
Note that since the hub height of the northern turbines is higher than the wind speed reference height z_0 , the output wind speed at the northern front row turbines is larger than the free stream wind speed (also helped by the horizontal wind speed gradient). Conversely, the hub height of the southern turbines is lower than z_0 and the output wind speed of these front row turbines is less than the free stream wind speed.

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) '^o']);
end
```





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']); xlabel('X-coordinate [m]')
    plot(X(iRow2), pow_waked(iRow2,i),'o-'); title(['Wind speed ',num2str(u0(i)), ' m/s']); xlabel('X-coordinate [m]')
    plot(X(iRow3), pow_waked(iRow3,i),'o-'); title(['Wind speed ',num2str(u0(i)), ' m/s']); xlabel('X-coordinate [m]')
    plot(X(iRow4), pow_waked(iRow4,i),'o-'); title(['Wind speed ',num2str(u0(i)), ' m/s']); xlabel('X-coordinate [m]')
    legend('Row 1','Row 2','Row 3','Row 4','Location','EastOutside')
end
```

