The efficiency of Genetic Algorithm compared to traditional turbine layout in tidal turbine farm planning

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Introduction

Current tidal turbine farm studies focus on a few types of standard layouts in controlled conditions. However, real world tidal flows are rarely like the controlled flows used for current studies. Hence, it is not known how current layouts will fare in the real world conditions.

The purpose of this work is to study the performance of these layouts in real world flow conditions, as well as to propose methodologies for optimising the farm layout.

Problem formulation

The layout of 50 turbines in a tidally reversing flow is considered in this study, with 3 flow cases being considered.

1. The reversing flow returns in the same direction as the incoming flow
2. The reversing flow returns at an angle to the incoming flow
3. A real time history of the tidal flow at a tidal site in the San Bernardino Strait , Philippines, with characteristics shown in Figure 1

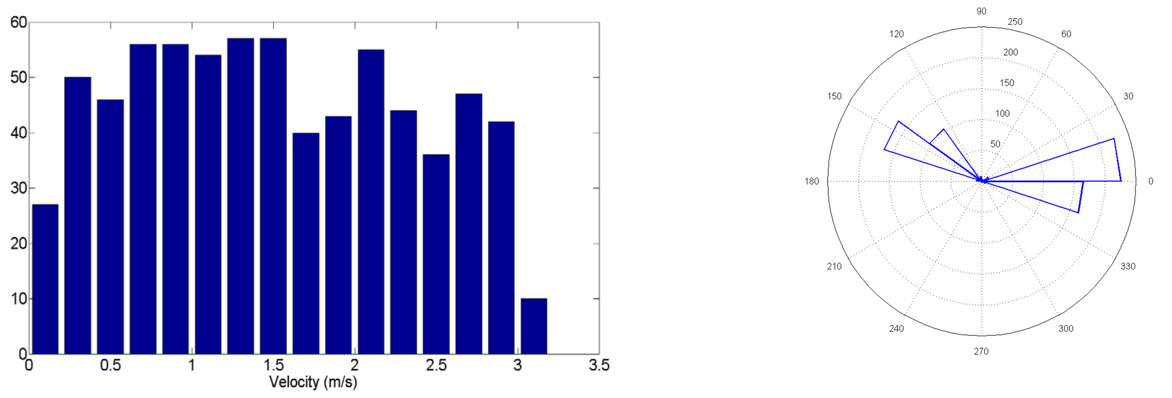

Figure 1: Characteristics of the tidal site used for optimisation

Grid definition

A 10X10 grid was defined, with the grid spacing set to be 3D and 5D in the cross-stream and stream-wise directions respectively. This leads to a rectangular domain with 27 diameters in the cross-stream direction and 45 diameters in the stream-wise direction.

Three reference layouts were created for comparison purposes. Layouts A and B are created on the grid defined above. Layout C is created on a different set of grid, but is included here for comparison purposes.

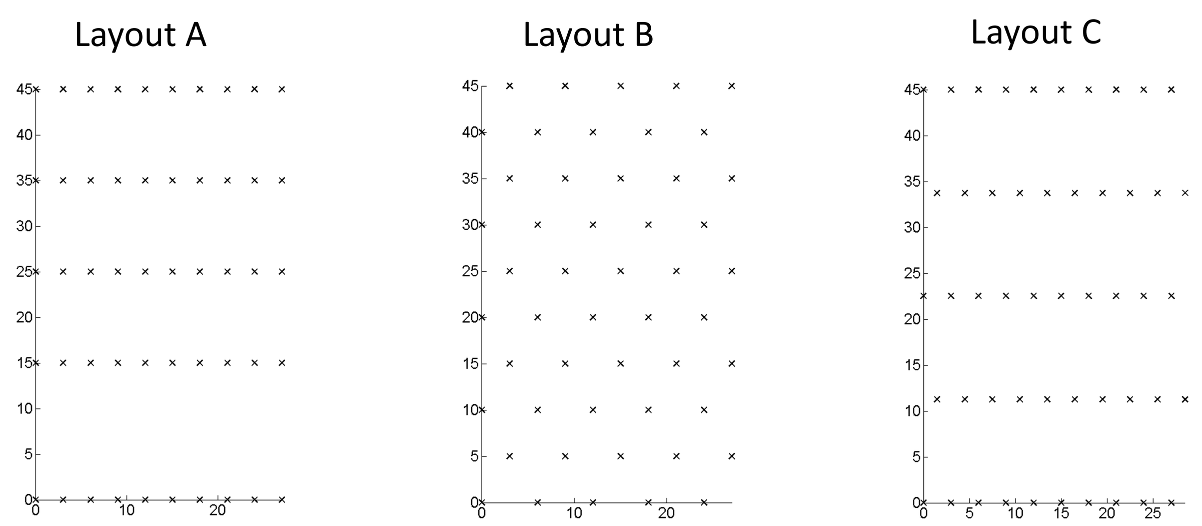

Figure 2: Illustration of the 3 standard layouts used for comparison

Objective function

The objective function was chosen to be the efficiency of the farm, instead of the more common cost of energy. This is because the number of turbines is being fixed, and all other costs are assumed constant.

Methodology

Turbine model

Hypothetical 1MW turbines with 20m diameter was used. The rated speed was set to be at 2.4m/s. The cut-in speed was set to be 0.5m/s, while the cut-out speed is set at 4m/s.

Wake model

The Jensen wake model was used due to its simplicity in implementation, as well as its accuracy in a wide range of cases [1]. The Root Sum of Squares (RSS) wake combination model was chosen as it is relatively more accurate than other models [1].

Optimisation algorithm

Genetic algorithm (GA) has been used extensively to study the wind farm layout optimisation problem. In this study, the effectiveness of GA to produce optimised layouts under typical tidal flows is investigated.

GA together with a hill climbing local search (LS) algorithm was used to generate layouts to be compared with the 3 reference layouts (A-C) .

Results

Five optimised layouts were obtained by GA for each case, and compared with the 3 reference layouts. Figure 3 shows the comparison of the efficiencies of the best GA layout and the 3 reference layouts for each of the 3 flow cases.

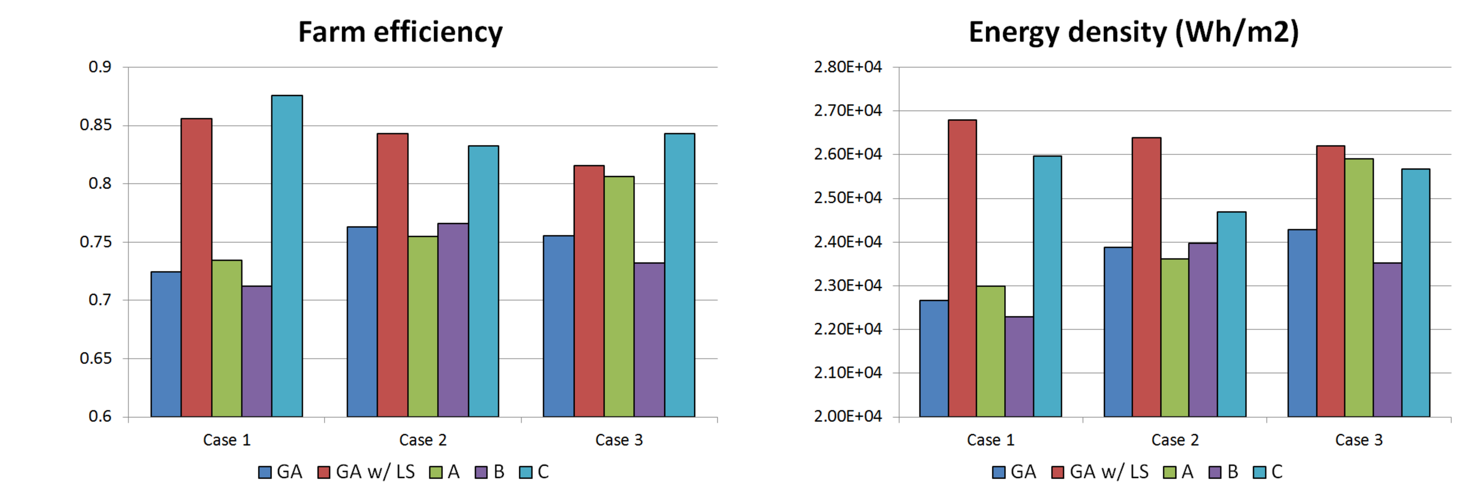

Figure 3: Comparison of the efficiencies and energy density obtained by the different layouts for each case

Figure 3 reveals that the efficiency of the GA layouts fall between that of Layouts A and B. It is seen that Layout C consistently has the highest efficiency of the 3 reference layouts across the 3 flow cases studied. The effect of local search is also illustrated, with the farm efficiency being improved by as much as 10% in Case 1.

Although Layout C may seem the best in terms of farm efficiency, it must be noted that the farm area is also larger. Comparing the energy density of all the layouts, it is seen that Layout C no longer has the best performance, and that the GA derived layout with local search produced the highest energy density.

Examining the velocity plots before and after local search reveals changes made to the layout.

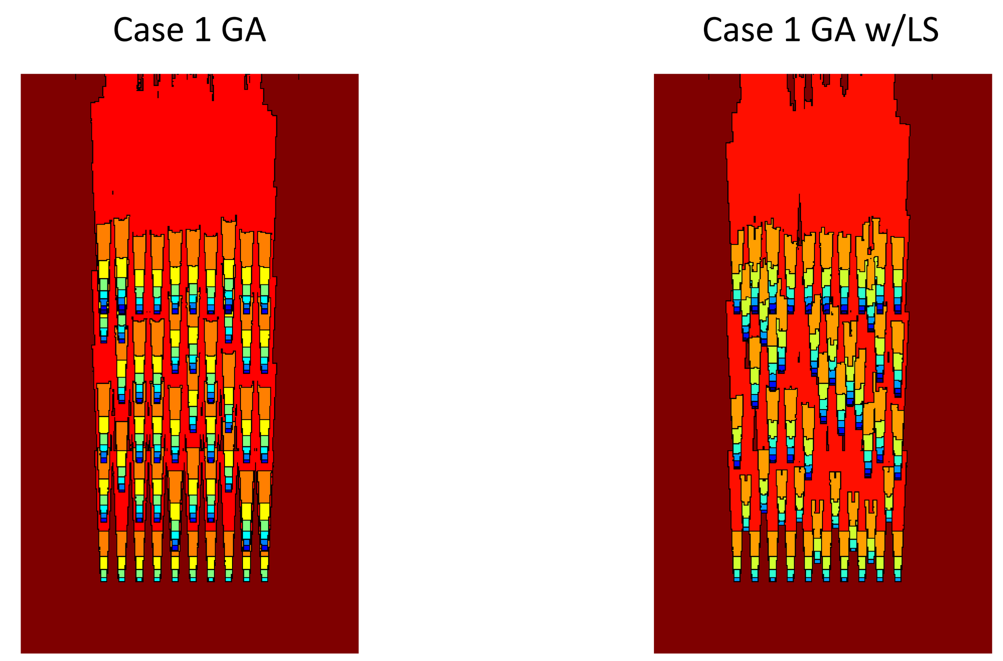

Figure 4: Velocity plots of the layouts obtained for flow Case 1 by GA before and after local search

Comparing the 2 layouts, it can be seen that the turbines have been shifted out of the wake of the most immediate upstream turbine. There are also regions within the farm where the velocity has almost recovered to the ambient velocity.

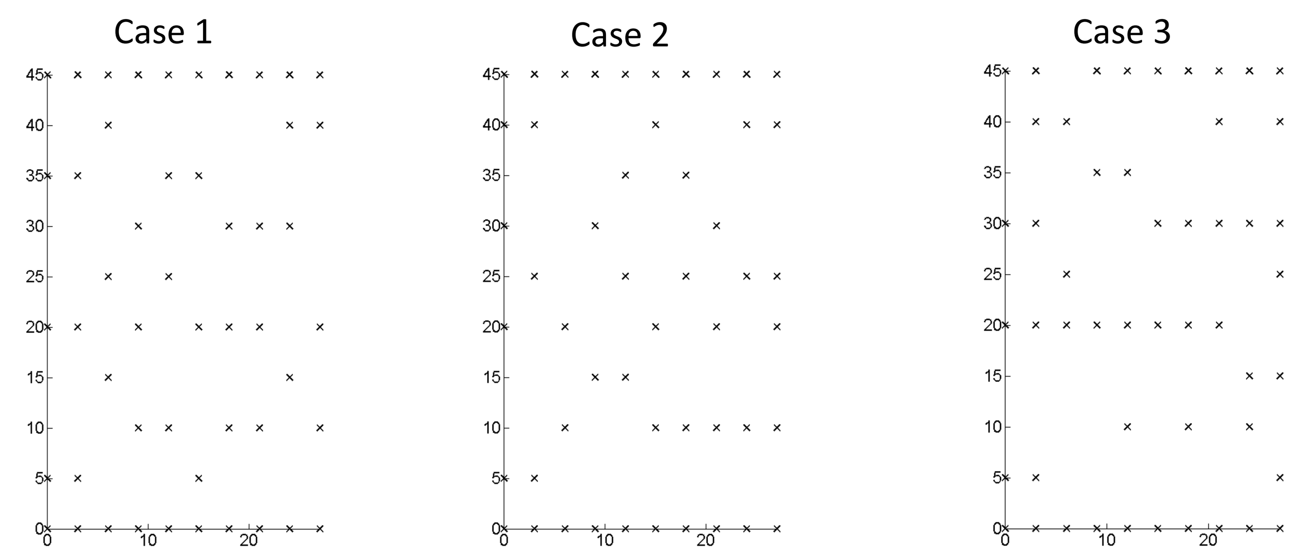

Figure 5: Illustration of the layouts obtained by GA for each of the flow case studied

Looking at the 3 GA derived layouts in Figure 5, one can also notice some similar features. The first and last row of the farm are filled with turbines as tightly as allowed by the program. This is in line with the advice to pack the 1st row as densely as possible to obtain the maximum energy [2].

Conclusion

GA on its own might not be able to produce the best layouts compared to the reference layouts. However, the performance of the layouts are able to be improved by a local search algorithm. As seen by the inclusion of the local search algorithm, farm efficiency is improved by avoiding the wakes of the upstream turbines as much as possible.

It can also be concluded that farm layout will be highly dependent on the flow characteristics of the site, as there is no one type fit all layout.

References

[1] Palm, M., Huijsmans, R., Pourquie, M., The Applicability of Semi-Empirical Wake Models for Tidal Farms, In: Proceedings of the 9th European Wave and Tidal Energy Conference, Southampton, UK, 2011.

[2] Vennell, R., Realizing the potential of tidal currents and the efficiency of turbine farms in a channel, Renewable Energy 2012; 47:95-102