The authors thank the reviewer for his/her comments. The thorough review and suggested edits have resulted in an improved manuscript. Responses to each comment are provided below and are formatted in the following manner: comments have been placed in italics, along with normal text for the response. If the changes have been made to the manuscript, these are included in bold thereafter.

Comment: The differences between the four cases are moderately interesting, but unfortunately the manuscript as it is currently written does not clearly define any unique contribution of this work to the literature.

Response: The author authors appreciate the interest of the reviewer, and want to clarify this point. this work focuses on the limited spacing for two reasons, first all the previous studies focus on the large spacing and the effect of the limited spacing is not clear, second the authors test this cases experimentally and we can not go with large spacing. This has been addressed directly in the manuscript by adding to the narrative in the introduction to frame the topic and the need for the study. The response to the following comment contains the added text.

Comment: Although it's clear that a lot of work went into this paper and the wind tunnel study behind it, substantial effort must be applied to it to make this manuscript suitable for publication. The scientific goal, or hypothesis, or driving question must be presented clearly (and it is not in the current form). The community understands the benefit of larger stream-wise spacing – is the goal here to assess the role of cross-stream spacing.

Response: The authors agree with the reviews about this point, The revised paper highlight the goal of this study in abstract, introduction and conclusion.

"**As wind farms become larger, the spacing between the turbines becomes a significant design element that can impose serious economic constraints. Therefore the investigation of the turbine spacing and its effect on the produced power and flow structure are crucial for future development of wind energy.**"

"As a result of wind farms becoming larger, the cost of the land-surface is considerable and becomes a critical factor in the overall value of the wind farm. The spacing between the turbines is an important design factor in terms of overall wind turbine performance and economic constraints. Therefore, the investigation of limited spacing is important as it affects the wind turbine-

generated wakes as well as the power production. The current work statistically compares the turbulent flow in various configurations of the array, where the streamwise and spanwise spacing are varied. The performance of the arrays is illustrated by analyzing the mean velocity, Reynolds shear stress, mean kinetic energy flux and power measurement. In addition, the proper orthogonal decomposition (POD) analysis is employed to identify the coherent structure of the turbulent wake associated with variation in spacing. The reconstruction algorithm of the POD is also applied to reconstruct the Reynolds shear stress and show the fast rebuilding based on the spacing variation."

"Insight into the behavior of the flow in a wind turbine array is useful in determining how to highlight the overall power extraction with the variation in spacing between the turbines. The main goal of the current study is to determine the effect of the tight spacings on the flow behavior and the findings of this study have a number of important implications, especially regarding the cost of a wind farm or when the large areas are not available. Stereographic PIV data are used to assess characteristic quantities of the flow field in a wind turbine array with varied streamwise and spanwise spacing. The flow fields are analyzed and compared statistically and by snapshot proper orthogonal decomposition."

Comment: Further, much text is devoted to describing the results of the POD and the differences between modes, but unfortunately it's not clear what new knowledge or insight is obtained from the POD analysis. What would a reader learn from this study that he/she did not know before.

Response: To clarify, previous studies used statistical analyses to highlight the optimal spacing and find the effect of the streamwise and spanwise spacing. In this study we try to find the effect of spacing variation in terms of the flow structures. Therefore, this study was the fist that quantify the spacing effect using the proper orthogonal decomposition. The authors highlight this intent in the revised paper.

Comment: Further, the authors should remember that one of their goals is to make their results as clear as possible to the reader. In its current form, the paper is very difficult to read and understand. The senior authors should provide a much more careful review of the writing style. Many sentences are confusing, even in the

abstract (which should provide a very clear and concise summary of the paper – no one will read the paper if the abstract is confusing). For example: "The region of interest downstream to the turbine confirms a notable influence of the streamwise spacing is shown when the spanwise spacing equals to 3D." What is the subject in this sentence? What is the verb? Please try to make the sentences as short and simple as possible to ensure they are more clear. Unless the writing is revised carefully, I cannot see that this paper would be appropriate for publication.

Response: The authors thank the reviewer for the detailed suggestions, including supporting the writing style and grammar. The revised version of the manuscript has been reviewed for clarity and readability.

Comment: Just as many individual sentences are very confusing, the overall structure of the paper is also confusing. For example, why does "Power Measurements" get a heading while everything else is folded into the "Results"? The power measurements should become part of the discussion of the streamwise velocity.

Response: After revision, the reviewer will find that the structure of the paper is changed and that power measurements are included as the last part of the result because we discuss the connection between the power measurement and the averaged profile of the streamwise velocity.

Specific major comments:

1. *A clear hypothesis must be stated, and the value of the POD must be stated explicitly.*

Response: The authors agree that the hypothesis was not clearly stated. In the revised text, there is an addition reading,

" The current work compares the turbulent flow in various configurations of the array, where the streamwise and spanwise spacing are varied. The performance of the arrays is illustrated by analyzing the mean velocity, Reynolds shear stress, mean kinetic energy and power measurement. In addition, the proper orthogonal decomposition (POD) is employed to identify coherent structures of the turbulent wake associated with variation in spacing. The reconstruction algorithm of the POD is also applied to

reconstruct the Reynolds shear stress and show the fast rebuilding based on the spacing variation."

"Generally, faster reconstruction implies that the flow possesses coherent structures with a greater portion of the total turbulent kinetic energy. Consequently, the flow in the case C_{6x3} and $C_{6x1.5}$ is occupied by the coherent structures and is less energetic in cases C_{3x3} and $C_{3x1.5}$. Thus, the change in spanwise spacing does not show a significant effect on the coherent structure content when the streamwise spacing is 3D."

"To quantify the contribution of the moderate-scaled structures, Reynolds shear stress is reconstructed using the intermediate modes."

"The reconstructed profiles display the effect of the spacing and the variation between the wind array, where the array of large streamwise spacing exceeds and reconstruct faster than the other cases due to carrying more coherent structure within the flow."

2. The figures are not designed intuitively. Although four test cases are examined repeatedly, they are given names with no correlation to what they stand for. I understand the appeal of brief labels for the cases – it's more convenient for writing – but it's also more confusing for the reader. Perhaps labels like 6X3, 3X3, 3X1.5, 6X1.5 would facilitate the interpretation of the images? Similarly, wouldn't it be more intuitive to have top left 6X3, top right 3X3, bottom left 6X1.5, bottom right 3X1.5? In this fashion, the rows are organized according to the span-wise spacing and the columns are organized according to the stream-wise spacing, which makes it easier for the reader to do comparisons between the cases.

Response: The authors thank the reviewer about this suggestion and the Figures 4, 5 ,6, 9, 10 and 11 are rearranged as top left C_{6x3}, top right C_{3x3}, bottom left $C_{6x1.5}$, bottom right $C_{3x1.5}$.

3. Please try to start each paragraph with a topic sentence. For example, Line 16 jumps into a literature review, and the reader is not sure what the point is. Of the numerous wind tunnel studies and LES (many of which have been omitted from this literature review) studying wind farms, why are these studies the important ones in

reference of this particular study? This is just an example of many cases where paragraphs jump into a description of this or that figure without indicating to the reader what the point is of the discussion.

Response: The authors thank the reviewer that highlighted this point. The author modified the manuscript and added topic sentence in each paragraph in the paper.

"Although there are many studies dealing with the effect of the density of turbines on the wake recovery, it is still a debated question."

"Further investigation in array optimization is undertaken by changing the alignment of the wind farm often referred to as staggered wind farms."

"As a result of wind farms becoming larger, the cost of the land-surface is considerable and becomes a critical factor in the overall value of the wind farm. The spacing between the turbines is an important design factor in terms of overall wind turbine performance and economic constraints."

4. Speaking of the literature review, numerous other LES of wind farms (http://www.nrel.gov/docs/fy12osti/53554.pdf, among others) have been presented in the literature. What is the justification for omitting them?

Response: The reviewer is certainly correct that many other LES studies for wind turbine arrays exist. In recent years, a great many studies have been produced. The authors included only a few examples in the original manuscript, and excluded some only for brevity. The authors have included several other studies that fit the narrative of the paper.

"Yang et al used LES to study the influence of the streamwise and spanwise spacings on the power output in aligned wind farms under fully developed regime. Their result showed that when the streamwise spacing is larger the power output is higher, and the streamwise spacing shows more impact on the design of aligned wind farms than the spanwise spacing."

"Calaf et al utilized LES to simulate infinite aligned wind farms of three different spacing ratio and five different turbine occupied areas to study the turbine spacing effects on the mean velocity profiles."

Nilsson et al. performed the large eddy simulations of the Lillgrund wind farm. They imposed pre-generated turbulence and wind shear in the computational domain to simulate realistic atmospheric conditions. The streamwise and spanwise spacing of the wind farm is 3.3D and 4.6D. In addition, a turbine located close to the center of the wind farm is not present, thus a limited spacing farm is accounted for as well as double its streamwise/ spanwise lengths are also represented. Consequently, their results are highly applicable in the current study, although the foci are on turbulence intensity effects as well as yaw angle.

"Wu and Port'e-Agel investigated turbulent flow within and above an aligned and a staggered wind farms under neutral conditions using validated LES framework. They showed the cumulative wakes are perceived to possess strong lateral interaction in the staggered case. In contrast, the lateral interaction between cumulated wakes is vulnerable in the aligned wind farm."

"Churchfield et al. applied a precursor LES of the atmospheric boundary layer to generate inflow conditions in the Lillgrund wind farm. simulated time-averaged power production for the aligned case strongly matches the field measurements up to the sixth turbine row."

"Archer et al. quantified the influence of wind farm layout on wind power production. They verified that the Increasing the turbine spacing in the predominant wind direction and staggering every second row improve wake recovery and maximize the power production."

5. Is there any thermal forcing in these cases? This should be mentioned.

Response: The flow under the neutral thermal stratification and the authors added to the manuscript as

"In this study, the flow field was sampled under neutral stratification in four configurations of a model-scale wind turbine array, classified as $C_{Sx,Sz}$, and considered in Table I. Permutations of streamwise spacing (S_x) of 6D and 3D, and spanwise spacing (S_z) of 3D and 1.5D are examined."

6. The upwind stream-wise velocity contours for cases 2 and 3 seem very surprising. If this decrease of velocity is due to an induction zone in front of the farm, shouldn't the lower velocities be closer to the turbines (ie at x=-1 D) rather than further away (at x=-1.8D)? The discussion in line 164 should explain this odd phenomena rather than just describe it.

Response: The authors disagree with the reviewer about this point. The measurements were taken at the fourth row, which means the upstream window of the fourth raw is the downstream of the third row. Therefore the velocity increase far away from the turbine of the third row.

7. All the velocities (Figure 4) should be normalized with respect to the desired inflow velocity at hub height.

Response: The velocities in figure 4 are normalized with the inflow velocity at hub height in the revised paper.

8. The motivation for the extensive POD discussion is never presented. What have we learned from the POD that we did not know before? It is not enough to state that "The findings of this study have a number of practical implications" without stating what those implications are directly.

Response: The authors added the motivation in the revised paper.

"Generally, faster reconstruction implies that the flow possesses coherent structures with a greater portion of the total kinetic energy. Consequently, the flow in the case C_{6x3} and $C_{6x1.5}$ is occupied by the coherent structures and is less energetic in cases C_{3x3} and $C_{3x1.5}$. Thus, the change in spanwise spacing does not show a significant effect on the coherent structure content when the streamwise spacing is 3D."

"The reconstructed profiles display the effect of the spacing and the variation between the wind array, where the array of large streamwise spacing exceeds and reconstruct faster than the other cases due to carrying more coherent structure within the flow."

Specific minor comments:

1. The abstract is organized in a confusing fashion: please put all the set-up information first, and then the results. Mixing them together ("Streamwise averaging: : :." appears after some of the results

Response. The structure of the abstract is changed in the revised paper to be more clear and organized.

"As wind farms become larger, the spacing between the turbines becomes a significant design element that can impose serious economic constraints. Therefore the investigation of the turbine spacing and its effect on the produced power and flow structure are crucial for future development of wind energy. A 4 x 3 array of wind turbines was assembled in a wind tunnel with four cases to study the influence based on streamwise and spanwise spacings. The four cases are chosen with a spacing of 6D and 3D in the streamwise, and 3D and 1.5D in the spanwise direction. Data are extracted experimentally using stereo particle-image velocimetry and analyzed statistically. The maximum mean velocity is displayed at the upstream of the turbine with the spacing of $6D$ and $3D$, in the streamwise and spanwise direction, respectively. Downstream the turbines confirms a notable influence of the streamwise spacing is shown when the spanwise spacing equals to 3D. Streamwise averaging is performed after shifting the upstream windows toward the downstream flow to quantify wake statistics independent of differences in spacing. The largest and smallest averaged Reynolds stress, and flux locates at cases 3D x 3D and 6D x 1.5D, respectively. Snapshot proper orthogonal decomposition is employed to identify the flow structures based on the turbulent kinetic energy content. The case of spacing 6D x 1.5D possesses the maximum turbulent kinetic energy content in the first mode compared with other cases. Thus, the upstream flow of each of the four cases converges faster than the flow downstream of the wind turbine in terms of the represented cumulative turbulent kinetic energy. The streamwise averaged profile of the Reynolds stress is reconstructed using a specific number of modes for each case; the case of 6D x 1.5D spacing displays the fastest reconstruction. Intermediate modes are also used to reconstruct the averaged profile and show that the intermediate scales are responsible for taking the shape of the original profile. The impact of the streamwise and spanwise spacings in power produced is quantified, where the maximum power produced corresponds with the case of greatest turbine spacing."

2. Line 36: "optimal" is not the appropriate word here. "actual" makes more sense– the wind farm designers were considering many variables when constructing those wind farms.

Response: The word is changed in the revised paper. Thanks

3. lines 35-62: please break up this paragraph: the first idea is about density for aligned wind farms, then at some point staggered design is introduced. That should get its own paragraph (if it is important).

Response: The authors separate the paragraph regarding the staggered and aligned wind farm in the revised paper.

"Further investigation in array optimization is undertaken by changing the alignment of the wind farm often referred to as staggered wind farms. Meyers and Meneveau compared aligned versus staggered wind farms; the latter yielding a 5% increase in extracted power. Stevens et al. used LES model to investigate the power output and wake effects in aligned and staggered wind farms with different streamwise and spanwise turbine spacing. In the staggered configuration, power output in fully developed flow depends mainly on the spanwise and streamwise spacings, whereas in the aligned configuration, power strongly depends on the streamwise spacing. Recently, Hamilton et al. investigated the effect of wind turbine configuration on the wake interaction and canopy layer. They considered standard Cartesian and row-offset configurations. The results showed that the maximum flux of kinetic energy increases about 7.5% in the exit row of offset configuration compared with the Cartesian arrangement."

4. lines 63-66. Very abrupt transition to POD. It, and its use in wind energy research, should be introduced.

Response: The authors prefer to introduce the POD in the theory part to keep the introduction only for the spacing effect.

5. lines 63-66: Please provide a few sentences outlining the structure of the paper.

Response: The author added paper outline in the revised paper.

"**This paper is organized as follows. In Section II the mathematical formulation for the proper orthogonal decomposition is stated, and experimental design including the wind turbine mode, experimental setup and measurements are introduced in Section III. In Section IV, results are presented. First, the statistical analysis, averaged profile and then POD analysis in subsection A-C. Subsequently, in subsection D, the results for Reconstruction averaged profile using a multiple POD modes are discussed. In section V the power measurements are identified and finally, conclusions are presented in Section VI.**"

6. line 79: isn't POD widely used in wind energy? Shouldn't some of those papers be cited here? (I see now that I have read down to 97 that a short review is presented there, but it should come earlier in the paper.)

Response: The author moved the POD review to the beginning of the POD part.

7. Figure 1: has the publishing company of Hamilton et al. given permission for the figure to be reproduced here?

Response: The authors make a new figure to use in the revised manuscript.

8. line 145-146: how were erroneous field identified? How many were there? Does this undermine the reader's confidence in the measurements?

Response: The author used a standard approach. If the magnitude of a vector is more than five times the rms value of the neighboring vectors, it is replaced with a Gaussian interpolation. Erroneous vectors were on the order of **1**% of the total calculated vectors.

9. Somewhere in the discussion of Table 1 it should be pointed out that no staggered grids were considered.

Response: The authors added sentence that clarify this point.

10. Table 1/Figure 3/Figure 7: I understand why you might want to use brief labels for the cases, but can you choose labels somewhat more clear, like 6X3, 3X3, 3X1.5, 6X1.5 to facilitate the interpretation of the images?

Response: The author changed the label to C_{6x3} , $C_{6x1.5}$, C_{3x3} and $C_{3x1.5}$

11. Figure 4, 5, 6: Please use small letters to clearly define what each panel is showing. (Thank you for using a clear color table.) Wouldn't it be more intuitive to have top left 6X3, top right 3X3, bottom left 6X1.5, bottom right 3X1.5? Also consider overlaying a contour level at some important threshold.

Response: The author added small letter to define figures 4 , 5 and 6 in the revised manuscript.

12. line 174: please summarize, providing a ranking of the cases corresponding to their spacings

Response: The author added the summery in the conclusion section in the revised paper.

13. In the conclusion, please first redefine the cases before describing their results. Particularly confusing sentences: Please review the entire manuscript carefully to ensure coherency and correct English grammar. In many places the intent of the writing is muddied by the composition of the sentences.

Response: The author rewrite the conclusion to be more clear and the cases define first before describing the results.

Some of these are noted below, but the entire manuscript should be reviewed.
1. abstract: "The region of interest downstream: : :."

Response: The sentence is changed as

"Downstream the turbines confirms confirms a notable influence of the streamwise spacing is shown when the spanwise spacing equals to 3D."

2. abstract: "The impact of the streamwise: : :.in power produce: : :" should be produced
perhaps?

Response: The sentence is changed as

The impact of the streamwise and spanwise spacings in power produced is quantified,"

3. line 9: coalesce?

Response : The word is changed to

"accumulated"

4. line 10-13: where is the verb?

Response: The sentence has two verbs as highlighted in the following sentence

"Extensive experimental and numerical studies **focus** on the wake properties in terms of mean flow characteristics and **used** to obtain estimates of power production"

5. many between 13 and 65 ….

Response: The introduction has been revised for grammar and clarity.

6. line 65: missing a word

Response: The authors clarified the sentence,

“streamwise and spanwise spacing”

7. line 68: “Balancing” should be “The balance”

Response: The sentence is changed although the balancing word is kept

“The balance of gains and losses of energy can be quantified through the mean kinetic energy budget”

8. line 71: “center” ?

Response: The sentence is revised as

“The Reynolds shear stress is responsible for the mean kinetic energy flux.”

9. line 76: misspelling of Lumley. Using bibliographic software can reduce errors like this.

Response: The Lumley name is corrected in the revised paper. Thanks

10. line 89

Response: The sentence is revised as

“The eigenfunctions are orthogonal and the corresponding eigenvalues are positive and real and organized in descending order.”

11. line 118

Response: The sentence is revised as,

“Nine vertical Plexiglas strakes located at 0.25 m downstream of the passive grid and 2.15 m upstream of the first row of the wind turbine were used to modify the inflow.”

12. line 122

Response: The sentence is revised as,

“Sheet steel of 0.0005 m thick was used to construct the 3 bladed wind turbine rotors.”

14. line 137-140

Response: The sentence is revised as

“SPIV equipment is LaVision and consist of a Nd:Yag (532nm, 1200mJ, 4ns duration) double-pulsed laser and four 4 MP ImagerProX CCD cameras positioned at the upstream and downstream of the wind turbine.”

15. Table I: is “spacing area” the correct term for this?

Response: The spacing area is changed to occupied area

16. line 155: majority? Do you mean maximum?

Response: The author is correct about the authors' original intent. The word choice has been changed in the revised manuscript.

17. 159-160

Response: The sentence is revised as

“Herein, characterization of the wind turbine wake flow is presented by the streamwise mean velocity, Reynolds shear stress, and energy flux, with the aim to comprehend the influence of turbine- to-turbine spacing.”

18. 173-174

Response: The sentence is revised as,

"The comparison between case $C_{3x1.5}$ and case $C_{6x1.5}$ shows a resemblance in velocity distribution with the exception at region x=D < 0:8, where case $C_{6x1.5}$ displays the most significant velocity deficit."

19. 178-179

Response: The sentence is revised as,

"The differences are clear at 0.5 < y=D < 1, where case $C_{3x1.5}$ exhibits heightened magnitudes of - <uv>"

20. please carefully review the rest of the manuscript

Response: The paper has been revised to remove ambiguities and to add clarity in the writing style and grammar. The authors thank the reviewer for the thorough and thoughtful comments.