Bukti Proses Review

Judul Karya Ilmiah	:	“Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control”
Penulis	:	**Ramadoni Syahputra** dan Indah Soesanti
Nama Jurnal	:	ENERGIES
Jenis Jurnal	:	Jurnal Internasional Bereputasi
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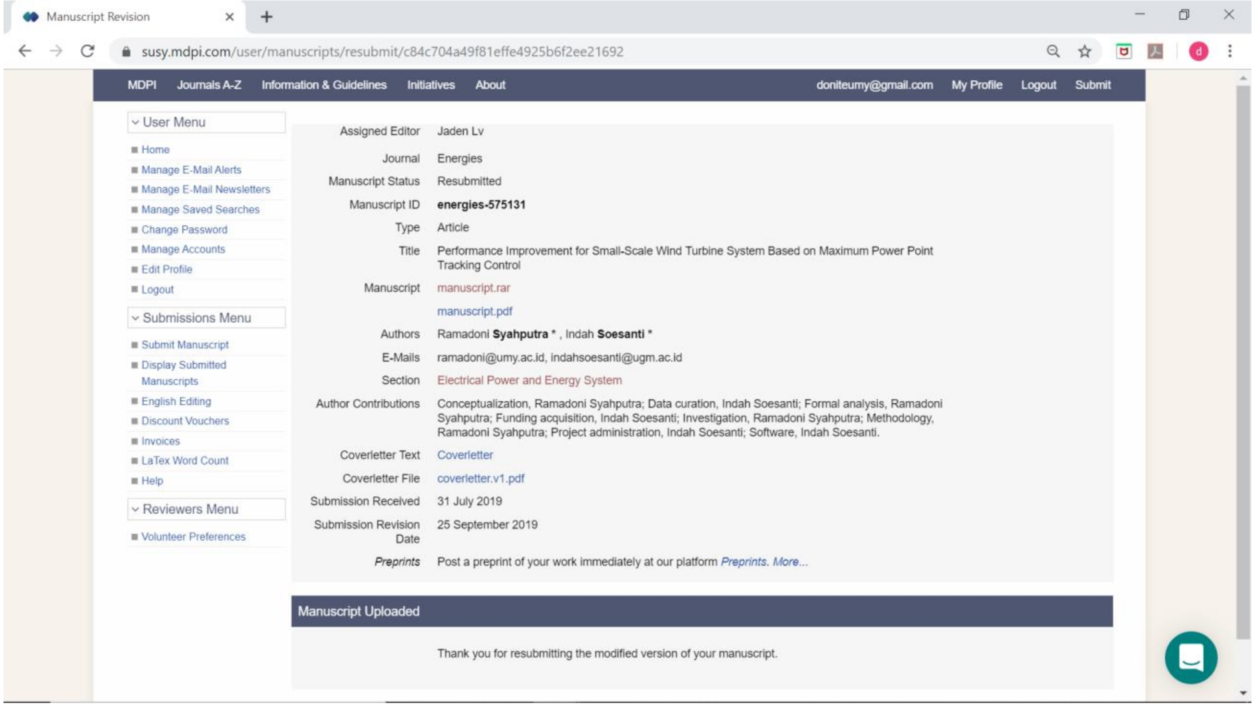
Tanggal	Kegiatan	Keterangan
31-Jul-2019	Penulis melakukan *submit* manuskrip ke editor jurnal ENERGIES via sistem online	Diberi nomor artikel: 575131 (Research Article)
19-Sep-2019	Notifikasi Round I dari Editor: Major Revisions Required	Rekomendasi Round I: Reviewer 1: Major revision Reviewer 2: Major revision
25-Sep-2019	Penulis melakukan *submit* hasil Revisi Round I, yang dilengkapi dengan tanggapan terhadap setiap saran perbaikan dari reviewer (*Response to Reviewers of Round I*)	*Response to Reviewers of Round I* terlampir
30-Sep-2019	Notifikasi Round II dari Editor: Minor Revisions Required	Rekomendasi Round II: Reviewer 1: Accepted Reviewer 2: Minor revision
2-Oct-2019	Penulis melakukan *submit* hasil Revisi Round II, yang dilengkapi dengan tanggapan terhadap setiap saran perbaikan dari reviewer (*Response to Reviewers of Round II*)	*Response to Reviewers of Round II* terlampir
14-Oct-2019	Notifikasi dari Editor: **Accepted for Publication**	Notifikasi “Accepted” via email kepada penulis
15-Oct-2019	Notifikasi dari Editor: Final Proofreading Before Publication	Penulis diminta untuk melakukan Final Proofreading Before Publication
17-Oct-2019	Notifikasi dari Editor: **Paper has been published**	Artikel telah terbit online di jurnal ENERGIES

31-Jul-2019; Submission the Manuscript



Assigned Editor	Jaden Lv
Journal	Energies
Manuscript Status	Resubmitted
Manuscript ID	**energies-575131**
Type	Article
Title	Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Manuscript	manuscript.rar manuscript.pdf
Authors	Ramadoni **Syahputra** * , Indah **Soesanti** *
E-Mails	ramadoni@umy.ac.id, indahsoesanti@ugm.ac.id
Section	Electrical Power and Energy System
Author Contributions	Conceptualization, Ramadoni Syahputra; Data curation, Indah Soesanti; Formal analysis, Ramadoni Syahputra; Funding acquisition, Indah Soesanti; Investigation, Ramadoni Syahputra; Methodology, Ramadoni Syahputra; Project administration, Indah Soesanti; Software, Indah Soesanti.
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Submission Received	31 July 2019
Submission Revision Date	25 September 2019
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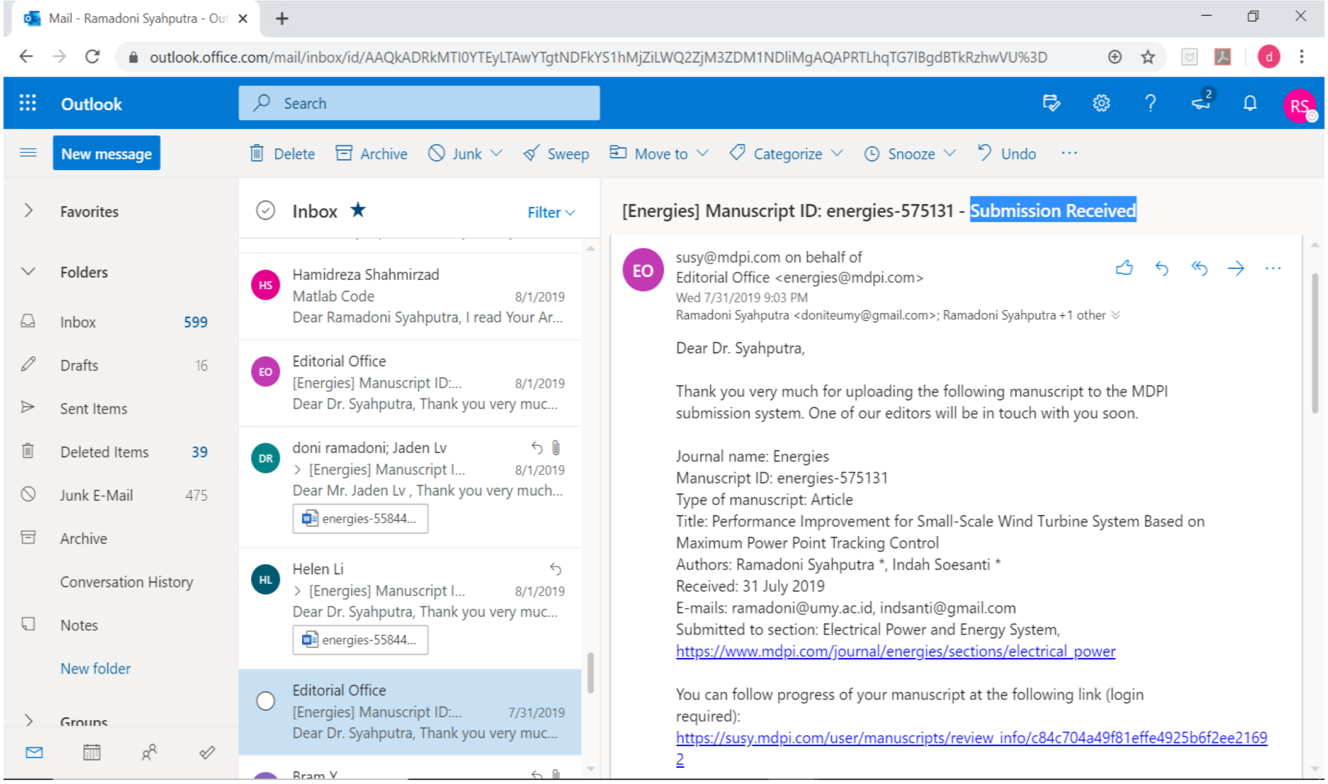

[Energies] Manuscript ID: energies-575131 - Submission Received

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Thank you very much for uploading the following manuscript to the MDPI submission system. One of our editors will be in touch with you soon.

Journal name: Energies
Manuscript ID: energies-575131
Type of manuscript: Article
Title: Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors: Ramadoni Syahputra *, Indah Soesanti *
Received: 31 July 2019
E-mails: ramadoni@umy.ac.id, indsanti@gmail.com
Submitted to section: Electrical Power and Energy System,
https://www.mdpi.com/journal/energies/sections/electrical_power

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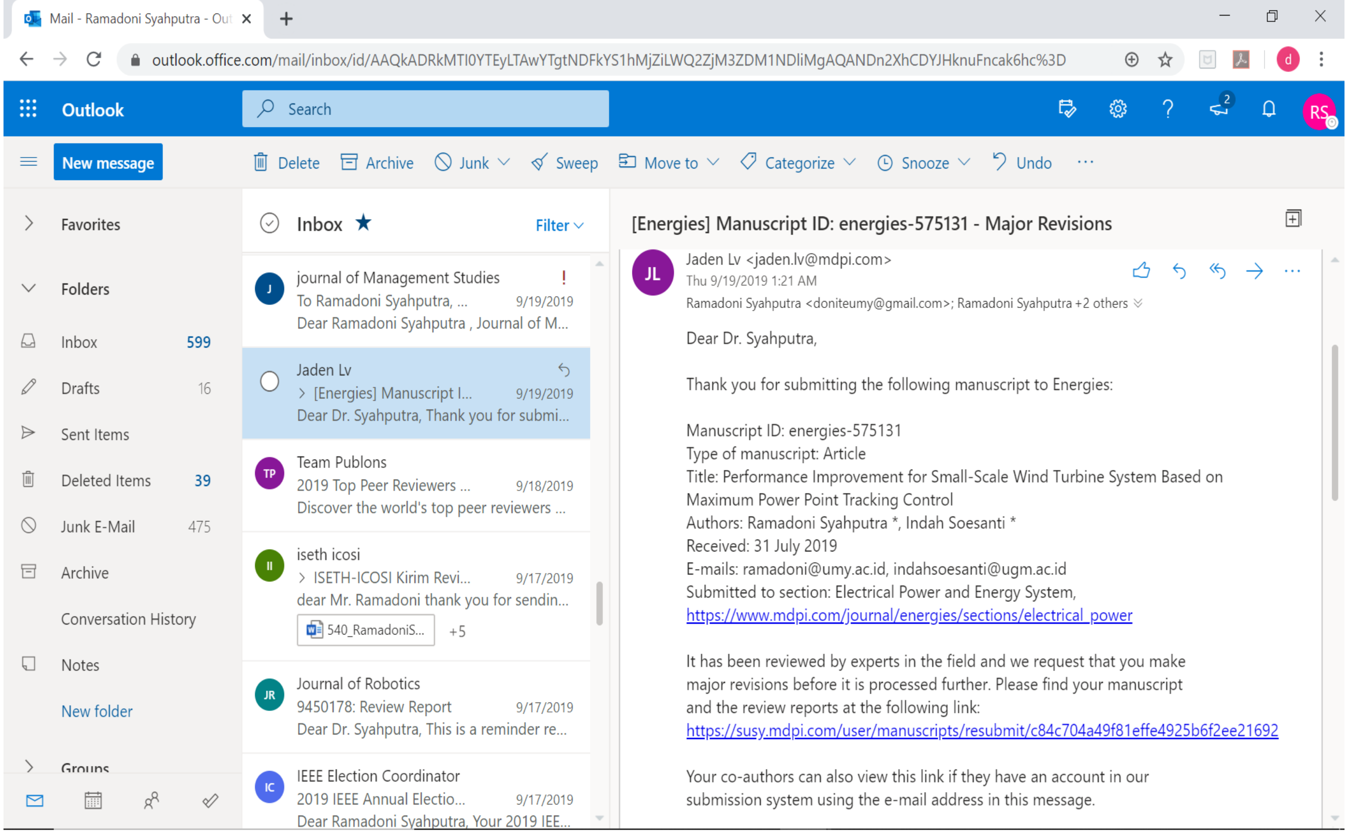
19-Sep-2019; Notifikasi Round I dari Editor: Major Revisions



[Energies] Manuscript ID: energies-575131 - Major Revisions

Jaden Lv <jaden.lv@mdpi.com>
Thu 9/19/2019 1:21 AM
Ramadoni Syahputra <doniteumy@gmail.com>; Ramadoni Syahputra +2 others

Dear Dr. Syahputra,

Thank you for submitting the following manuscript to Energies:

Manuscript ID: energies-575131
Type of manuscript: Article
Title: Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors: Ramadoni Syahputra *, Indah Soesanti *
Received: 31 July 2019
E-mails: ramadoni@umy.ac.id, indahsoesanti@ugm.ac.id
Submitted to section: Electrical Power and Energy System,
https://www.mdpi.com/journal/energies/sections/electrical_power

It has been reviewed by experts in the field and we request that you make major revisions before it is processed further. Please find your manuscript and the review reports at the following link:
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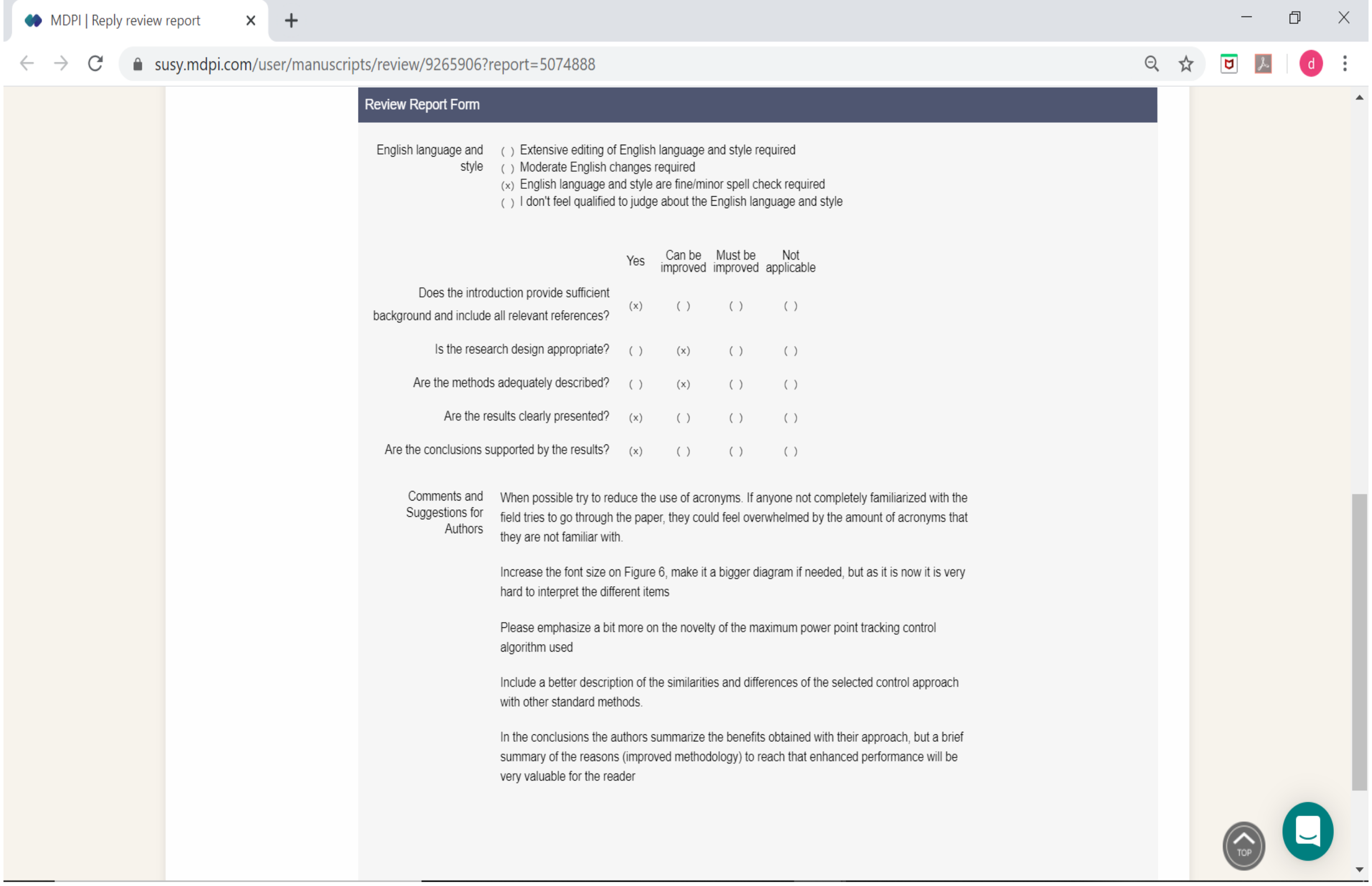
19-Sep-2019; Hasil Review Round I dari Reviewer 1



Review Report Form

English language and style
( ) Extensive editing of English language and style required
( ) Moderate English changes required
(x) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	(x)	( )	( )	( )
Is the research design appropriate?	( )	(x)	( )	( )
Are the methods adequately described?	( )	(x)	( )	( )
Are the results clearly presented?	(x)	( )	( )	( )
Are the conclusions supported by the results?	(x)	( )	( )	( )

Comments and Suggestions for Authors

When possible try to reduce the use of acronyms. If anyone not completely familiarized with the field tries to go through the paper, they could feel overwhelmed by the amount of acronyms that they are not familiar with.

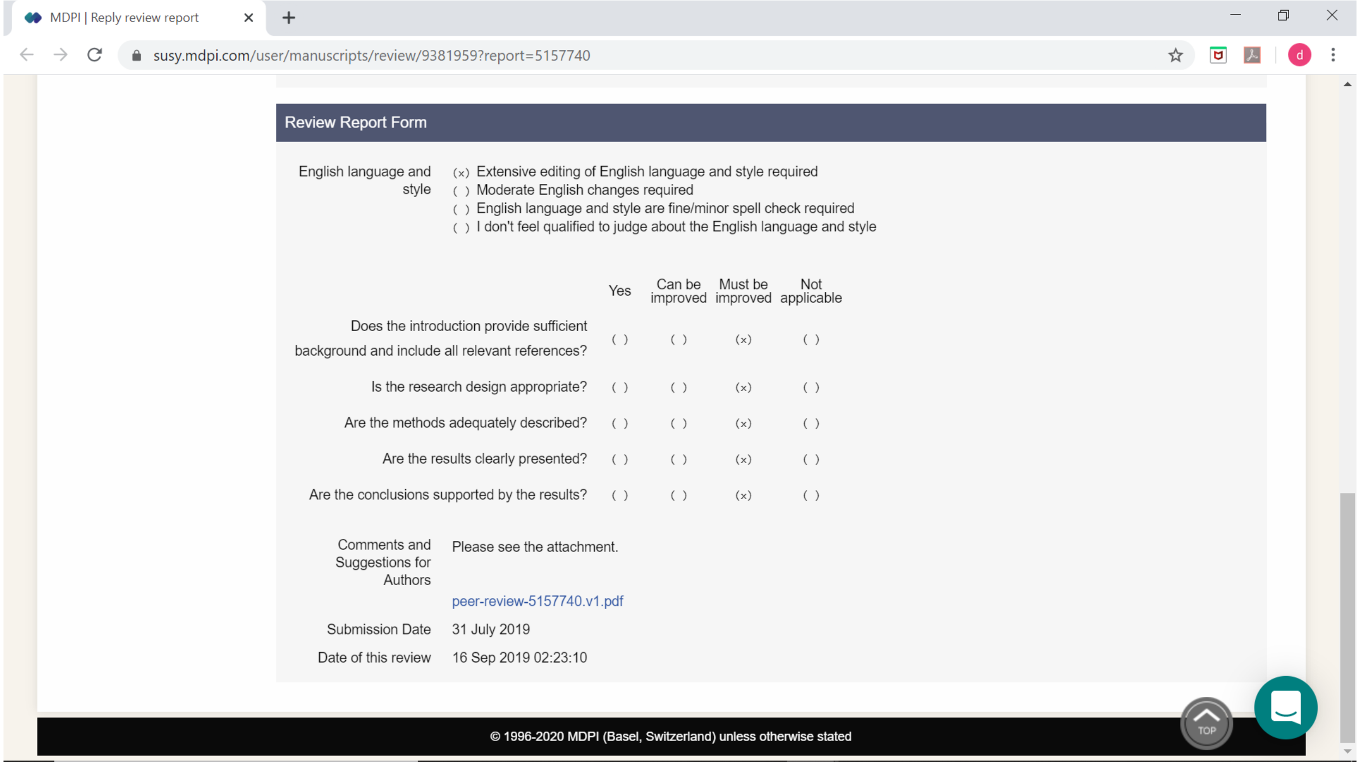
Increase the font size on Figure 6, make it a bigger diagram if needed, but as it is now it is very hard to interpret the different items

Please emphasize a bit more on the novelty of the maximum power point tracking control algorithm used

Include a better description of the similarities and differences of the selected control approach with other standard methods.

In the conclusions the authors summarize the benefits obtained with their approach, but a brief summary of the reasons (improved methodology) to reach that enhanced performance will be very valuable for the reader

19-Sep-2019; Hasil Review Round I dari Reviewer 2



Review Report Form

English language and style
(x) Extensive editing of English language and style required
( ) Moderate English changes required
( ) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	( )	( )	(x)	( )
Is the research design appropriate?	( )	( )	(x)	( )
Are the methods adequately described?	( )	( )	(x)	( )
Are the results clearly presented?	( )	( )	(x)	( )
Are the conclusions supported by the results?	( )	( )	(x)	( )

Comments and Suggestions for Authors: Please see the attachment.

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Submission Date: 31 July 2019

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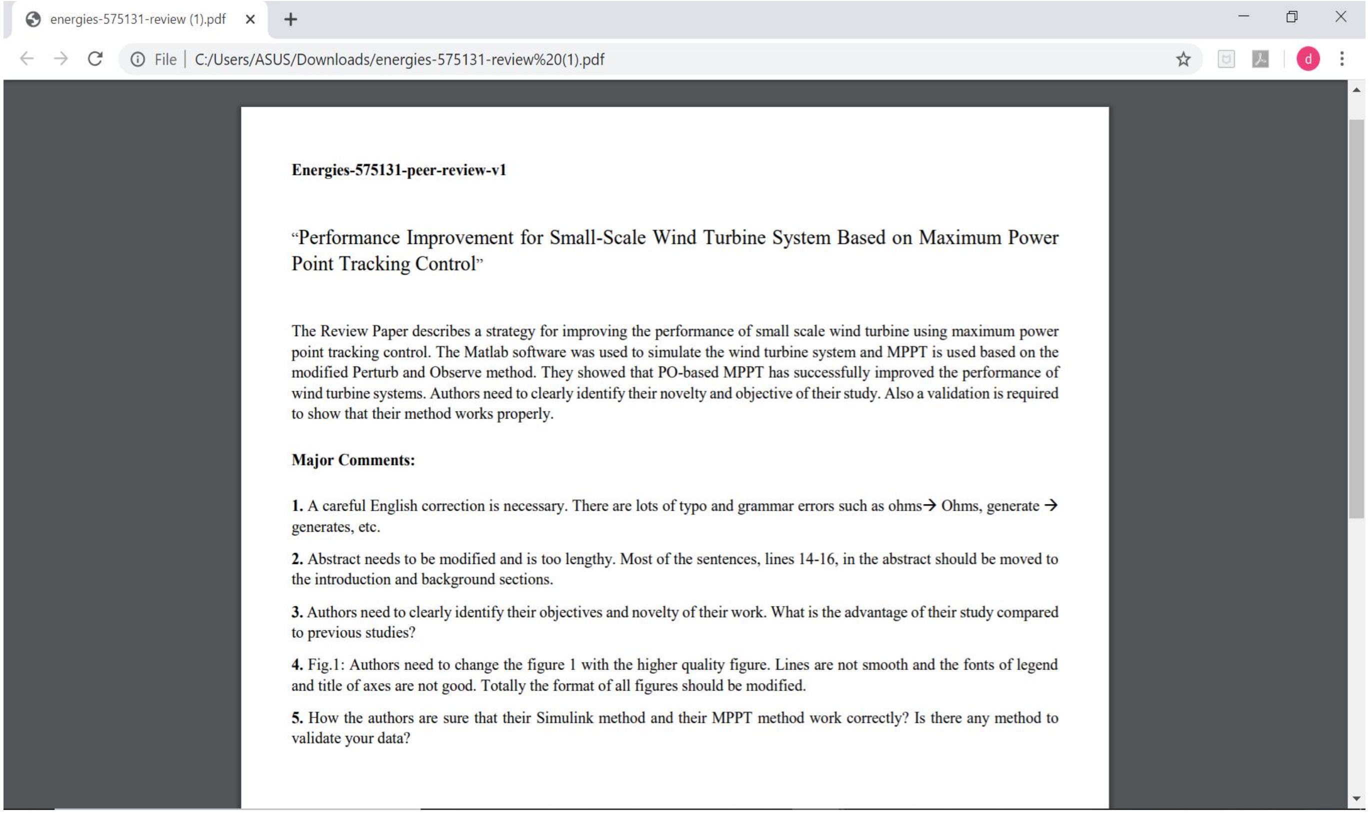


Energies-575131-peer-review-v1

"Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control"

The Review Paper describes a strategy for improving the performance of small scale wind turbine using maximum power point tracking control. The Matlab software was used to simulate the wind turbine system and MPPT is used based on the modified Perturb and Observe method. They showed that PO-based MPPT has successfully improved the performance of wind turbine systems. Authors need to clearly identify their novelty and objective of their study. Also a validation is required to show that their method works properly.

Major Comments:

1. A careful English correction is necessary. There are lots of typo and grammar errors such as ohms→ Ohms, generate → generates, etc.

2. Abstract needs to be modified and is too lengthy. Most of the sentences, lines 14-16, in the abstract should be moved to the introduction and background sections.

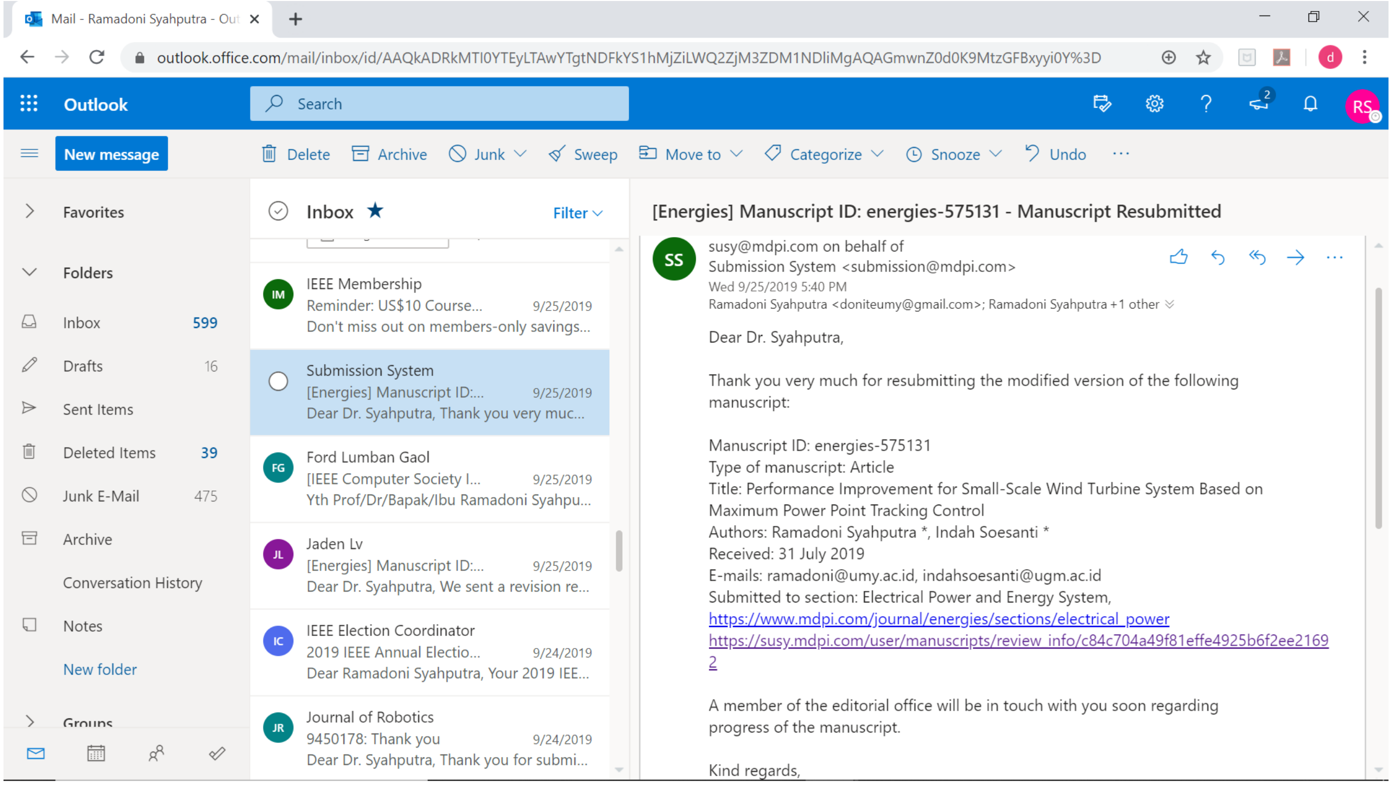
3. Authors need to clearly identify their objectives and novelty of their work. What is the advantage of their study compared to previous studies?

4. Fig.1: Authors need to change the figure 1 with the higher quality figure. Lines are not smooth and the fonts of legend and title of axes are not good. Totally the format of all figures should be modified.

5. How the authors are sure that their Simulink method and their MPPT method work correctly? Is there any method to validate your data?

Response to Reviewers of Round 1 by Authors

Manuscript Resubmitted on 25-Sep-2019



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Ramadoni Syahputra <doniteumy@gmail.com>; Ramadoni Syahputra +1 other

Dear Dr. Syahputra,

Thank you very much for resubmitting the modified version of the following manuscript:

Manuscript ID: energies-575131
Type of manuscript: Article
Title: Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors: Ramadoni Syahputra *, Indah Soesanti *
Received: 31 July 2019
E-mails: ramadoni@umy.ac.id, indahsoesanti@ugm.ac.id
Submitted to section: Electrical Power and Energy System,
https://www.mdpi.com/journal/energies/sections/electrical_power
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A member of the editorial office will be in touch with you soon regarding progress of the manuscript.

Kind regards,

Manuscript Details

Manuscript ID	: energies-575131
Type of manuscript	: Article
Title	: Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors	: Ramadoni Syahputra *, Indah Soesanti

Abstract: This paper proposes a strategy for performance improvement of small-scale wind turbine systems using maximum power point tracking control (MPPT). In this study, wind turbine systems which use permanent magnet synchronous generators and converter devices are modeled in Simulink-Matlab software. In order to increase the power generated, MPPT is used based on the extended Perturb and Observe (PO) method. This algorithm has the ability to improve the speed of the turbine without oscillation. To analyze the ability of the PO-based MPPT in maximizing output power, performance examination of wind turbine systems in Simulink-Matlab software were conducted. The study is carried out with a 3000W wind turbine device serving various electrical loads of 50Ω, 100Ω, 200Ω, and 300Ω, and each Ohm varies with a wind speed of 4, 5, 6.5, 7, 8.5, 9, and 10m/s. The overall turbine system performance found that the maximum increase in system output power occurs when it is loaded with 200Ω with a wind speed of 6.5m/s. During this combination of 200Ω and 6.5m/s, there are high increments of output power at 135.62%, caused by the installation of MPPT controllers, with an average output power increase of 50.77%. The results of this study proved that PO-based MPPT has successfully improved the performance of wind turbine systems.

Response to Reviewer 1 Comments

Dear Reviewers,

The authors would like to thank the reviewers for the careful reading of the paper and the constructive comments. In light of the reviewers’ observations, we have introduced some modifications to improve our paper in this round of revisions.

All changes in the body of the paper have been highlighted on yellow color.

Best regards,
Dr. Ramadoni Syahputra et al.

Response to Reviewer 1 Comments

Comments and Suggestions for Authors:

Point 1: **When possible try to reduce the use of acronyms. If anyone not completely familiarized with the field tries to go through the paper, they could feel overwhelmed by the amount of acronyms that they are not familiar with.**

Response 1 from Authors:

Dear reviewer, we want to thank you for taking your time to review our paper as well as for given us useful comments for improving its quality for a possible reconsideration in “Energies”.

Regarding the use of the acronym, we agree with the reviewer's suggestion. Indeed, in our article, some acronyms often appear, for example, MPPT, PO, and PMSG. Actually, at the beginning of the emergence of the acronyms are always accompanied by their meaning. Because in the beginning the meaning has been given, then the next is only an acronym. However, on the advice of this very valuable reviewer, we added the Abbreviations Lists table in the Appendix, as shown below.

Line 1217-1235:

Appendix

Table A1. Abbreviations Lists

Abbreviation	Meaning
AC	Alternating Current
DC	Direct Current
EMF	Electro-Motive Force
FLC	Fuzzy Logic Controller

GW	Giga Watts
MPPT	Maximum Power Point Tracking
PMSG	Permanent Magnet Synchronous Generator
PO	Perturb and Observe
PWM	Pulse Width Modulation
RC	Resistance-Capacitance
A	the area of cross-sectional coverage, in m^2
C_p	the coefficient of electric power of the wind turbine system
C_s	Snubber capacitance
I	electric currents, in amperes
P	the electric power of the wind turbine system, in watts
R_s	Snubber resistance
T	the torque of generator, in Nm
V	electric voltages, in volts
V_f	forward voltage, in volts
v	wind velocity, in m/s
ω	rotational speed of the rotor, in rad/s
λ	the ratio of tip speed
ρ	the mass density of the air type, in kg/m^3

Point 2: **Increase the font size on Figure 6, make it a bigger diagram if needed, but as it is now it is very hard to interpret the different items.**

Response 2 from Authors:

Thank you for the valuable comments.

Because of the addition of figures in Figure 4, the sequential numbers of the following pictures increase 1. Thus, the sequence number of Figure 6 changes to Figure 7.

We have revised Figure 7 so that it becomes more precise and more comfortable to read, The revised result of Figure 7 is shown below.

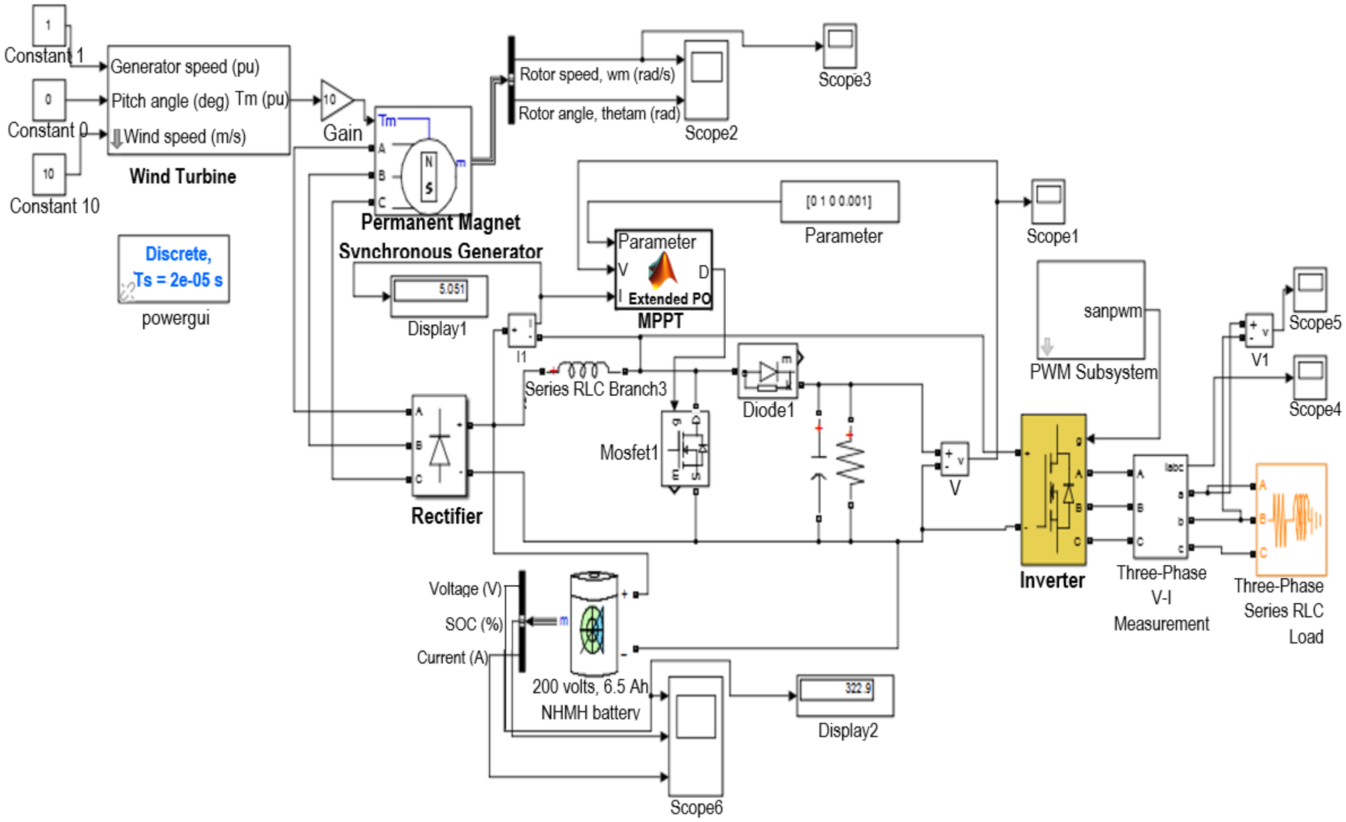

Figure 7. Wind turbine circuit diagram system with MPPT in the Simulink-Matlab software

We have also revised another Figures to make it easier for readers, as shown below.

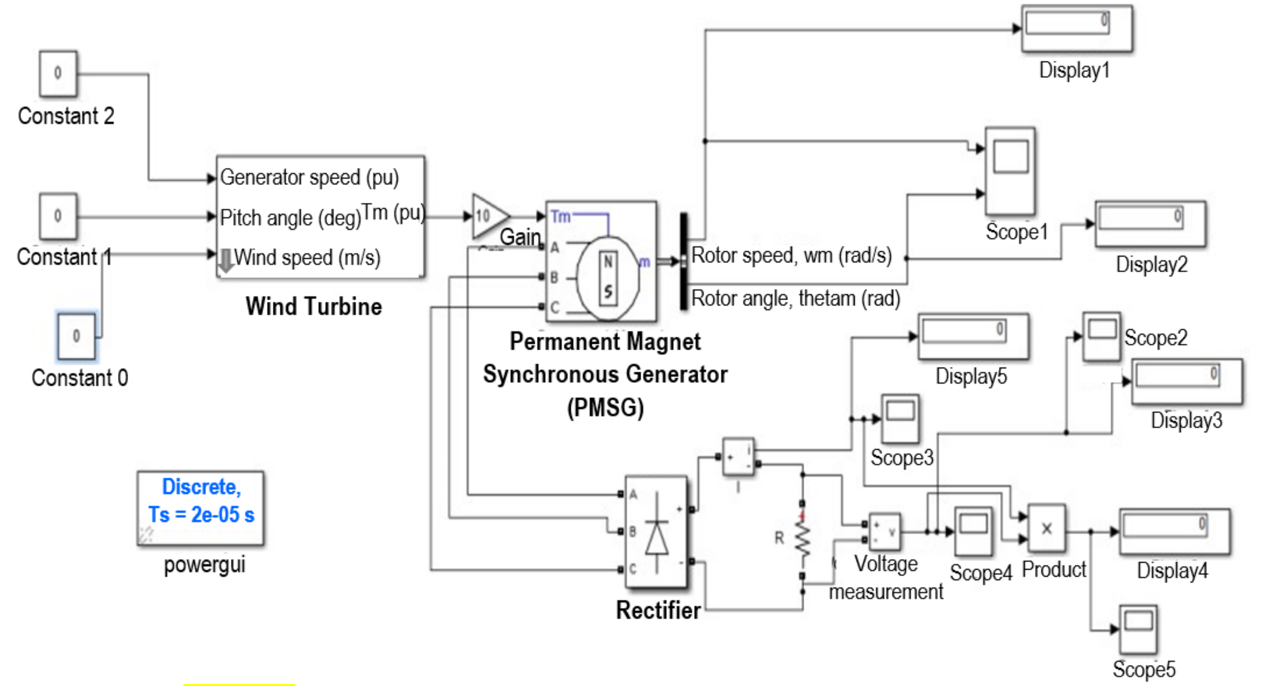

Figure 12. Wind turbine system without MPPT in Simulink-Matlab software

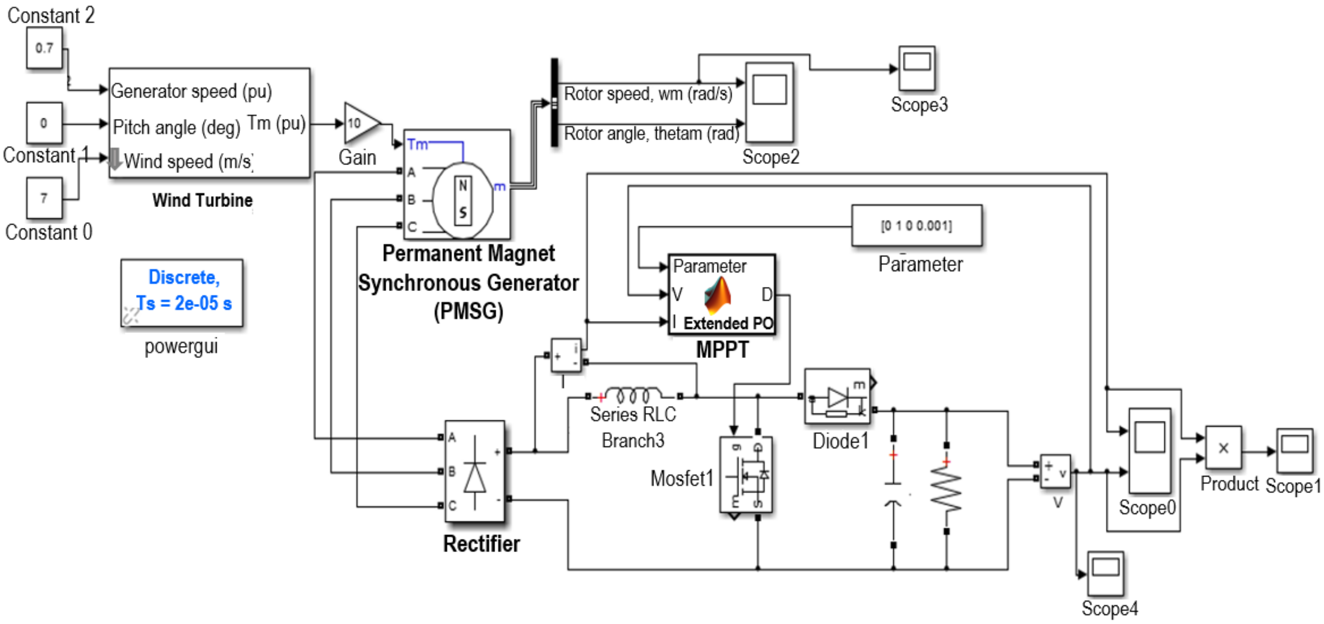

Figure 13. Wind turbine system with MPPT in Simulink-Matlab software

Point 3: **Please emphasize a bit more on the novelty of the maximum power point tracking control algorithm used.**

Response 3 from Authors:

Thank you for the valuable comments.

We have added the novelty of the maximum power point tracking control algorithm used in the Introduction section of the last paragraph, as shown below.

Line 102-118:

The objective of this study is to improve the performance of generators in wind power plants so that the power generated is always maximum. The technique used is the control strategy using the Maximum Power Point Tracking (MPPT) controller. In this MPPT, a control method is applied, namely the extended Perturb and Observe (PO) method. The Perturb and Observe (PO) based MPPT algorithm has been widely used in searching for maximum power values [17] due to its simplicity. Furthermore, the use of PO does not require wind speed information and turbine parameters, it is faster and more efficient in searching the maximum point of power. However, it has the disadvantage of producing oscillations under steady state conditions due to constant duty cycle changes. Therefore, modifications were made in the study, combining the PO and predictive method. Both methods work alternately according to current and voltage conditions on the input side of the converter. Predictive methods are used to determine the magnitude of step changes in the PO algorithm, the larger the voltage, the larger the step size used and vice versa. The combination of the PO and predictive method applied to the MPPT technique for optimizing the generator output power of wind power systems is the novelty of this research. The method used in the MPPT is the extended PO algorithm. The algorithm contains the foundations of standard PO, with changes to the step size value of each iteration according to the response of the system based on the predefined C constant. The modification of the method is resulting in faster convergence of the computation.

Point 4: **Include a better description of the similarities and differences of the selected control approach with other standard methods.**

Response 4 from Authors:

Thank you for the valuable comments.

We have added an explanation of the standard perturb and observe control algorithm. This explanation is complemented by a flowchart so that the similarities and differences in the extended perturb and observe methods used in this study can be seen (Figure 5), and the standard perturb and observe methods (Figure 4), as shown below.

Line 250-296:

The PO algorithm can be used to determine the optimum point of a system [17]. In this study, the optimum point is the maximum power value that a PMSG generator can achieve in a wind turbine system. The maximum power value is obtained by adjusting the dc voltage on the generator side converter, which in turn changes the output power. To monitor and manage these changes, a certain step-size (ΔD) and time needs to be specified: that is the output power generated compared to previous electrical power, so that the power changes (ΔP) and the next variable ΔD can be determined. If the generated power increases, then the variable ΔD will be fixed, if it decreases then the ΔD will change. The working principle of this extended PO algorithm can be seen in the flow chart in Figure 4 and Figure 5, with several parameters in the initial value to calculate the change of step size value in each iteration done. Furthermore, it is necessary to identify the limit duty cycle in running this algorithm to maintain the ability of the buck converter. Figure 4 shows the standard PO method, while Figure 5 shows the extended PO method used in this study.

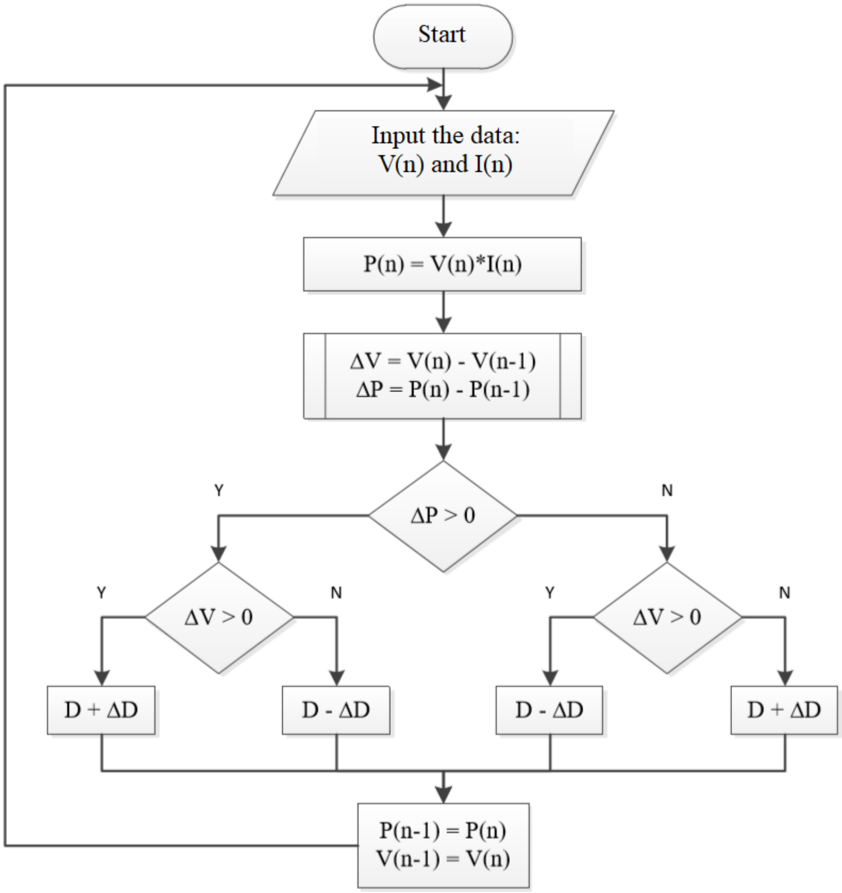

Figure 4. Flow chart of standard perturb and observe algorithm

Based on the analysis and literature study, the standard version of the PO algorithm (Figure 4) has disadvantages, including the time taken to reach a relatively slow convergence and high oscillation in maximum power search. However, this weakness can be overcome by changing the value of ΔD used to find the maximum point value of power generated, where the quantity of ΔD will be multiplied by a constant value of 0-1. When the system has reached the maximum power point then ΔD automatically decrease. The working principle of the extended PO algorithm can be seen in Figure 5.

The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of ΔD, resulting in faster convergence of the computation.

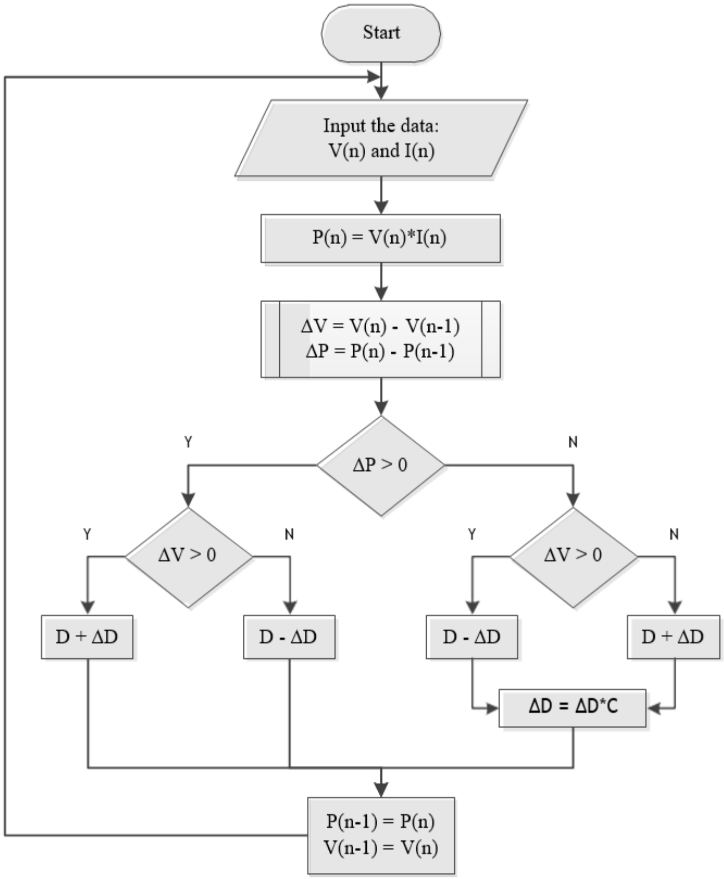

Figure 5. Flow chart of extended perturb and observe algorithm

Point 5: **In the conclusions the authors summarize the benefits obtained with their approach, but a brief summary of the reasons (improved methodology) to reach that enhanced performance will be very valuable for the reader.**

Response 5 from Authors:

Thank you for the valuable comments.

We have revised the Conclusions according to the reviewers' comments, as shown below.

Line 1001-1207:

In this study, the research of wind turbine system performance using an MPPT controller based on an extended PO algorithm was performed. This algorithm has the ability to calibrate without oscillation to determine the maximum power output. To analyze this, the Simulink-Matlab software was employed. The performance examination is carried out with a 3000W wind turbine system which served varying electrical loads of 50Ω, 100Ω, 200Ω, and 300Ω, respectively. In each of the variations, various wind speeds based on the prevailing wind conditions in Indonesia, i.e., 4, 5, 6.5, 7, 8.5, 9, and 10m/s, respectively, were performed. Based on the results of the overall wind turbine system performance examination, the largest increase in system output power occurs when the system is loaded with 200Ω with a wind speed of 6.5m/s.

Similarly, the installation of the MPPT controller increased the output power by 135.62%, with an average power increase of 50.77%. The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of ΔD, resulting in faster convergence of the computation. The results of this study have proven that extended PO-based MPPT, is capable of successfully enhancing the performance of wind turbine systems.

Manuscript Details

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Response to Reviewer 2 Comments

Dear Reviewers,

The authors would like to thank the reviewers for the careful reading of the paper and the constructive comments. In light of the reviewers' observations, we have introduced some modifications to improve our paper in this round of revisions.

All changes in the body of the paper have been highlighted on yellow color.

Best regards,
Dr. Ramadoni Syahputra et al.

Response to Reviewer 2 Comments

Comments and Suggestions for Authors:

Point 1: **A careful English correction is necessary. There are lots of typo and grammar errors such as ohms → Ohms, generate → generates, etc.**

Response 1 from Authors:

Dear reviewer, we want to thank you for taking your time to review our paper as well as for given us useful comments for improving its quality for a possible reconsideration in "Energies". We have made improvements in language quality and typo errors in our article. To improve language quality, we have used professional English editing services. We mark every change with the yellow highlight.

Point 2: **Abstract needs to be modified and is too lengthy. Most of the sentences, lines 14-16, in the abstract should be moved to the introduction and background sections.**

Response 2 from Authors:

Thank you for the valuable comments.
We have revised the Abstract. The sentences in lines 14-16 in the abstract have been moved to the Introduction and Background sections.

Revised the Abstract:

This paper proposes a strategy for performance improvement of small-scale wind turbine systems using maximum power point tracking control (MPPT). ~~Recently, the Indonesian government has encouraged the development of wind power technology in an effort to reduce carbon emissions. Wind turbine in~~

~~Indonesia, has become increasingly popular owing to the fact that the location has the wind potential.~~ In this study, wind turbine systems which use permanent magnet synchronous generators and converter devices are modeled in Simulink-Matlab software. In order to increase the power generated, MPPT is used based on the extended Perturb and Observe (PO) method. This algorithm has the ability to improve the speed of the turbine without oscillation. To analyze the ability of the PO-based MPPT in maximizing output power, performance examination of wind turbine systems in Simulink-Matlab software were conducted. The study is carried out with a 3000W wind turbine device serving various electrical loads of 50Ω, 100Ω, 200Ω, and 300Ω, and each Ohm varies with a wind speed of 4, 5, 6.5, 7, 8.5, 9, and 10m/s. The overall turbine system performance found that the maximum increase in system output power occurs when it is loaded with 200Ω with a wind speed of 6.5m/s. During this combination of 200Ω and 6.5m/s, there are high increments of output power at 135.62%, caused by the installation of MPPT controllers, with an average output power increase of 50.77%. The results of this study proved that PO-based MPPT has successfully improved the performance of wind turbine systems.

Revised the Introduction section (line 40-42):

Recently, the Indonesian government has encouraged the development of wind power technology in an effort to reduce carbon emissions. Wind turbine in Indonesia, has become increasingly popular owing to the fact that the location has the wind potential. Wind is one of the most readily available renewable energy sources in Indonesia, mostly prevalent on the southern coast of Java and Sumatra Island, and the east islands. Based on data from the National Energy Blueprint, Ministry of Energy and Mineral Resources of the Republic of Indonesia, the potential of wind energy is 9.29 GW, but the utilization is still around 0.5 GW, 5.38% of the existing potential [3, 4].

Revised the Background section: 2. Small-Scale Wind Turbine System (line 120-122):

The Indonesian government has encouraged the development of wind power technology in an effort to reduce carbon emissions. Wind turbine in Indonesia, has become increasingly popular owing to the fact that the location has the wind potential. Indonesia is located in a tropical climate area, with moderate wind potential at speeds ranging from 3 to 15 m/s [18]. Wind turbine systems are commonly used for smaller scales [19]. The turbine works to convert kinetic energy in the wind to mechanical via rotation by generating a torque. The magnitude of the kinetic energy depends on air density and wind speed [7]. Equation (1) expresses the electric power of the wind turbine system as follows:

Point 3: Authors need to clearly identify their objectives and novelty of their work. What is the advantage of their study compared to previous studies?

Response 3 from Authors:

Thank you for the valuable comments.

The objective of this study is to improve the performance of generators in wind power plants so that the power generated is always maximum. The technique used is the control strategy using the Maximum Power Point Tracking (MPPT) controller. In this MPPT, a control method is applied, namely the extended Perturb and Observe (PO) method.

The combination of the PO and predictive method applied to the MPPT technique for optimizing the generator output power of wind power systems is the novelty of this research.

We have added the objectives and novelty of this research in the introduction section of the last paragraph, as shown below.
Line 102-118:

> The objective of this study is to improve the performance of generators in wind power plants so that the power generated is always maximum. The technique used is the control strategy using the Maximum Power Point Tracking (MPPT) controller. In this MPPT, a control method is applied, namely the extended Perturb and Observe (PO) method. The Perturb and Observe (PO) based MPPT algorithm has been widely used in searching for maximum power values [17] due to its simplicity. Furthermore, the use of PO does not require wind speed information and turbine parameters, it is faster and more efficient in searching the maximum point of power. However, it has the disadvantage of producing oscillations under steady state conditions due to constant duty cycle changes. Therefore, modifications were made in the study, combining the PO and predictive method. Both methods work alternately according to current and voltage conditions on the input side of the converter. Predictive methods are used to determine the magnitude of step changes in the PO algorithm, the larger the voltage, the larger the step size used and vice versa. The combination of the PO and predictive method applied to the MPPT technique for optimizing the generator output power of wind power systems is the novelty of this research. The method used in the MPPT is the extended PO algorithm. The algorithm contains the foundations of standard PO, with changes to the step size value of each iteration according to the response of the system based on the predefined C constant. The modification of the method is resulting in faster convergence of the computation.

We have also added an explanation of the standard perturb and observe control algorithm. This explanation is complemented by a flowchart so that the extended PO methods used in this study can be seen (Figure 5), and the standard PO methods (Figure 4), as shown below. The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of ΔD, resulting in faster convergence of the computation.
Line 250-296:

> The PO algorithm can be used to determine the optimum point of a system [17]. In this study, the optimum point is the maximum power value that a PMSG generator can achieve in a wind turbine system. The maximum power value is obtained by adjusting the dc voltage on the generator side converter, which in turn changes the output power. To monitor and manage these changes, a certain step-size (ΔD) and time needs to be specified: that is the output power generated compared to previous electrical power, so that the power changes (ΔP) and the next variable ΔD can be determined. If the generated power increases, then the variable ΔD will be fixed, if it decreases then the ΔD will change. The working principle of this extended PO algorithm can be seen in the flow chart in Figure 4 and Figure 5, with several parameters in the initial value to calculate the change of step size value in each iteration done. Furthermore, it is necessary to identify the limit duty cycle in running this algorithm to maintain the ability of the buck converter. Figure 4 shows the standard PO method, while Figure 5 shows the extended PO method used in this study.

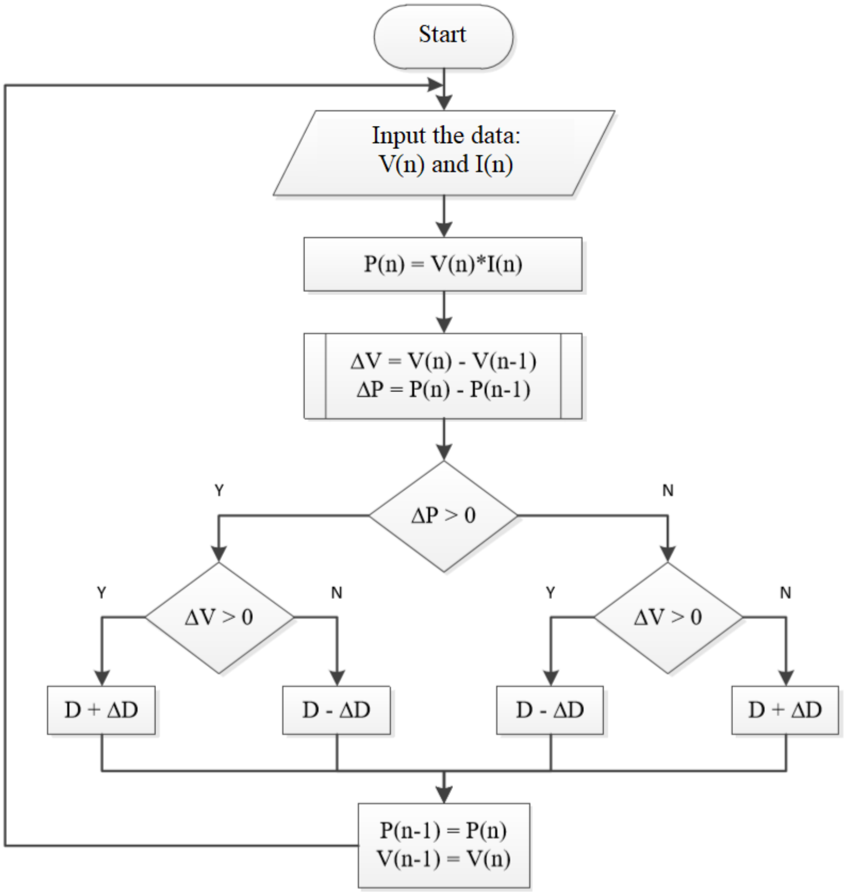

Figure 4. Flow chart of standard perturb and observe algorithm

Based on the analysis and literature study, the standard version of the PO algorithm (Figure 4) has disadvantages, including the time taken to reach a relatively slow convergence and high oscillation in maximum power search. However, this weakness can be overcome by changing the value of ΔD used to find the maximum point value of power generated, where the quantity of ΔD will be multiplied by a constant value of 0-1. When the system has reached the maximum power point then ΔD automatically decrease. The working principle of the extended PO algorithm can be seen in Figure 5.

The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of ΔD, resulting in faster convergence of the computation.

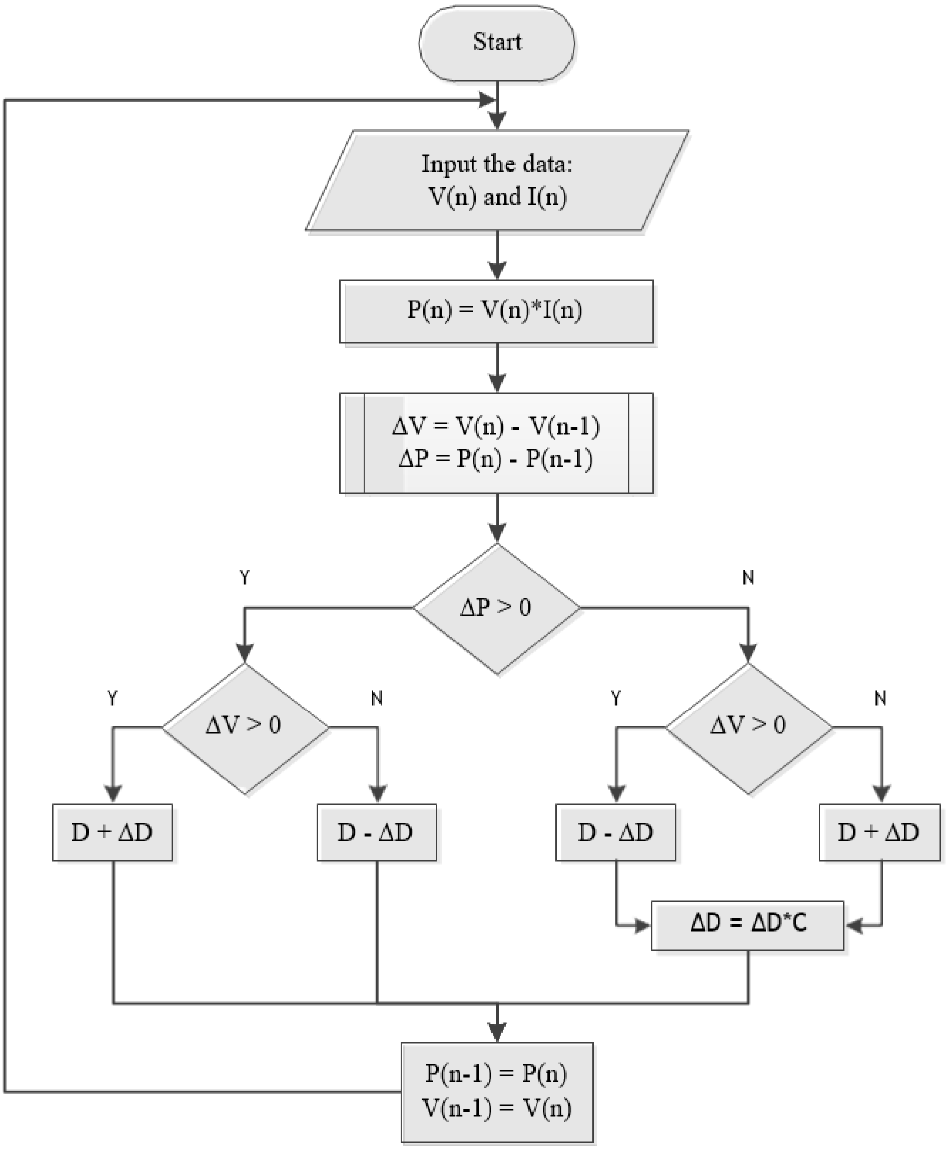

Figure 5. Flow chart of extended perturb and observe algorithm

Point 4: **Fig.1: Authors need to change the figure 1 with the higher quality figure. Lines are not smooth and the fonts of legend and title of axes are not good. Totally the format of all figures should be modified.**

Response 4 from Authors:

Thank you for the valuable comments.
We agree with the comment made by the reviewer.
We have replaced Figure 1 with the higher quality figure, as shown below.
Line 190-191:

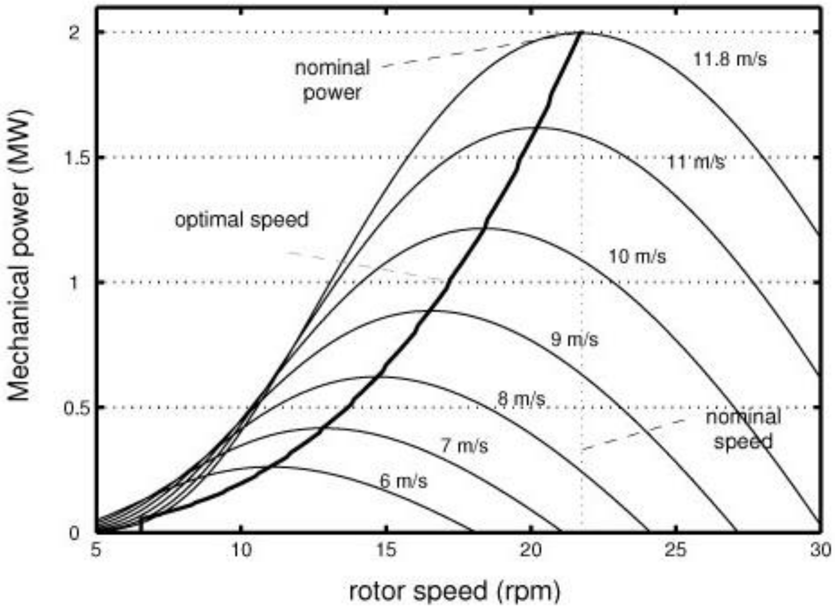

Figure 1. Wind turbine characteristics with pitch angle of 0°

Point 5: **How the authors are sure that their Simulink method and their MPPT method work correctly? Is there any method to validate your data?**

Response 5 from Authors:

Thank you for the valuable comments.

Simulink is not a method. Simulink is a software that is in the Matlab software environment. In our research, we applied MPPT control techniques to wind power generation systems. MPPT is Maximum Power Point Tracking, a technique to make the output power generated by wind power plants always maximum. To run the MPPT technique, a method is needed. In our study, the method applied to the MPPT was the extended Perturb and Observe (PO) method.

Regarding data validation in this study, we can explain as follows.

An explanation of validation test of the data and the PO method is described in section "*4.2. Evaluation of Perturb and Observe Algorithm*" (***lines 566-619***).

4.2. Evaluation of Perturb and Observe Algorithm

In the PO algorithm, the quantity of input is voltage, and the output is the current of PMSG generator. These voltages and currents are further utilized in order to obtain a more optimum output, as shown in Figure 7. The following stages are involved in the Perturb and Observe algorithm process.

1) Initial voltage measurement, is determined to study the exact value of the current PMSG generator output voltage.
2) The Power PMSG generator is measured to determine its current value.
3) The power difference is calculated to actuate the difference between the current and previously measured power.
4) The voltage and power is compared to figure out the process involved in the changes. From this comparison, the generator voltage will be larger or smaller depending on the generator power and measured voltage differences.
5) If the above stages turn out to be successful, step 1is repeated.

Table 6. Results of the PO algorithm validity test

Number of Experiments	Wind speed (m/s)	Turbine rotation (rpm)	Load resistance (Ω)	Output power (W)
1	10	508.06	200	2032
2	10	508.06	200	2032
3	10	508.06	200	2032
4	10	508.06	200	2032
5	10	508.06	200	2032
6	10	508.06	200	2032
Mean	10	508.06	200	2032
Standard deviation	0	0	0	0

After the PO algorithm is made on the wind turbine system, its validity and sensitivity is evaluated. In this study, the algorithm is valid if the standard value of deviation is less than 1% in 6 experiments. This is also similar to its sensitivity, which is also conducted by changing the wind speed.

A validity test is carried out to examine the results using the PO algorithm, and by conducting repetitive experiments for fixed parameters with a certain input, followed by an observation of mean and standard deviation from the experimental data. In this test, a wind rate of 10m/s is used as input with fixed turbine system parameters. The results of the algorithm validity test are shown in Table 6.

Table 7. Results of the PO algorithm sensitivity test

Wind speed (m/s)	**Generator Voltage (V)**	**Output Power (W)**
3	27.92	8.22
4	57.07	43.89
5	82.21	78.02
6	140.03	242.13
7	171.41	334.23
8	247.24	809.31
9	316.90	1201.18
10	348.62	1472.34

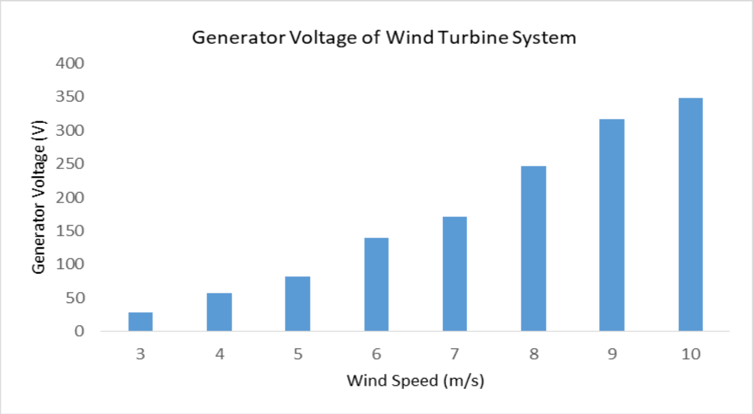

Figure 10. Generator voltage of wind turbine system

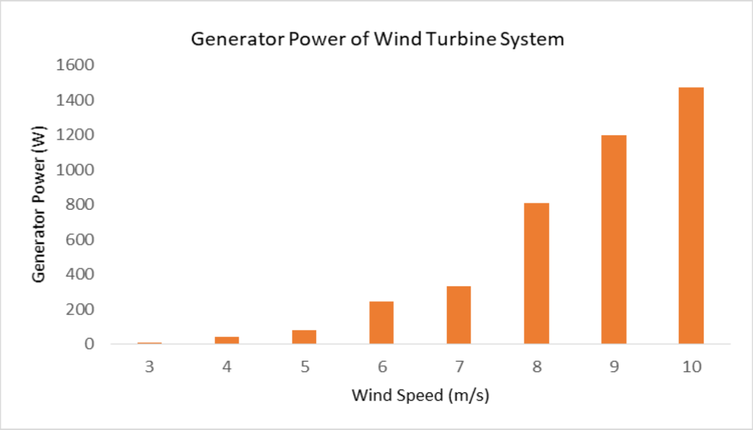

Figure 11. Generator output power of wind turbine system

The test resulted to a standard deviation value of 0, which means that the optimization procedure produced the same value in each experiment; hence, the output power of the wind turbine system can be categorized as valid.

In order to determine the effect of the changes associated with the parameter values, a sensitivity analysis of the PO algorithm is tested by varying the value of the wind speed between 3 to 10m/s with a fixed power generator value of 3000W. In this experiment, 100Ω resistance was used, and results obtained are shown in Table 7 and Figure 10. From the experimental results, it can be seen that the higher the wind speeds the greater the voltage and power of the generator. This is because the rotor speed increases with a rise in wind speed, which also affects the power generated. The results of experiments in Table 7 and Figure 11 also prove that same.

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Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control

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Received: date; Accepted: date; Published: date

Abstract: This paper proposes a strategy for performance improvement of small-scale wind turbine systems using maximum power point tracking control (MPPT). ~~Recently, the Indonesian government has encouraged the development of wind power technology in an effort to reduce carbon emissions. Wind turbine in Indonesia, has become increasingly popular owing to the fact that the location has the wind potential.~~ In this study, wind turbine systems which use permanent magnet synchronous generators and converter devices are modeled in Simulink-Matlab software. In order to increase the power generated, MPPT is used based on the extended Perturb and Observe (PO) method. This algorithm has the ability to improve the speed of the turbine without oscillation. To analyze the ability of the PO-based MPPT in maximizing output power, performance examination of wind turbine systems in Simulink-Matlab software were conducted. The study is carried out with a 3000W wind turbine device serving various electrical loads of 50Ω, 100Ω, 200Ω, and 300Ω, and each Ohm varies with a wind speed of 4, 5, 6.5, 7, 8.5, 9, and 10m/s. The overall turbine system performance found that the maximum increase in system output power occurs when it is loaded with 200Ω with a wind speed of 6.5m/s. During this combination of 200Ω and 6.5m/s, there are high increments of output power at 135.62%, caused by the installation of MPPT controllers, with an average output power increase of 50.77%. The results of this study proved that PO-based MPPT has successfully improved the performance of wind turbine systems.

Keywords: Small-scale wind turbine system; MPPT; Extended perturb and observe method; Renewable energy

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1. Introduction

Due to energy issues related to potential, inventory, technology, and environmental impact, the necessity for renewable energy has become increasingly urgent. This fact is attributed to the easy availability of fossil energy and its proven negative impact on the environment [1]. People are realizing the importance of renewable energy as a source of electricity to power our world. Indonesia, as a tropical country, has also paid serious attention to renewable energy [2], the government creating a goal of deriving 23% of national electricity from renewable energy sources by 2025. This contribution will be increased to 31% by 2050.

Recently, the Indonesian government has encouraged the development of wind power technology in an effort to reduce carbon emissions. A wind turbine in Indonesia has become increasingly popular owing to the fact that the location has the wind potential. The wind is one of the most readily available renewable energy sources in Indonesia, most prevalent on the southern coast

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of Java and Sumatra Island, and the eastern islands. Based on data from the National Energy Blueprint, Ministry of Energy and Mineral Resources of the Republic of Indonesia, the potential of wind energy is 9.29 GW, but the utilization is still around 0.5 GW, 5.38% of the existing potential [3, 4].

Wind generates electrical energy through the turbines, which are characterized by the various types according to shapes and shafts. The wind turbine is connected with a generator that converts kinetic into electricity. Generators commonly used in conjunction with low to medium scale wind turbines are called Permanent Magnet Synchronous Generator (PMSG) [5, 6]. The output of power generated by PMSG varies depending on wind speed [7]. In order to maximize the output power of the generator, the Maximum Power Point Tracking (MPPT) controller is used to stabilize the maximum power [8, 9].

The methods for MPPT are commonly used, including gradient approximation, artificial neural network method, fuzzy logic, particle swarm optimization, ant colony optimization, and Perturb and Observe methods [10 - 14]. In the study of [15], stand-alone wind turbines and MPPT using the gradient approximation method is carried out. It works by measuring the voltage and current, then changing the duty cycle in the DC-DC converter to obtain the maximum power. The AC output voltage used single phase full bridge inverter. Simulation results show that the maximum power ratio without MPPT is 79.41%, while with it, the maximum power is 94.51%. The results of this study indicate that wind turbines have a higher average power when using MPPT.

Furthermore, research [16] shows that MPPT technology is used to regulate the output voltage of the generator through a DC-DC Converter circuit, where the switching technique uses Pulse Width Modulation (PWM) by adjusting the duty cycle. The change of the duty cycle value depends on the wind speed. Therefore, a Fuzzy Logic Controller (FLC) algorithm is used to set the cost as well as accelerate the PWM control switching response. The results showed that with FLC-based MPPT technology, the efficiency of power output is increased from 45.5% to 87%.

The objective of this study is to improve the performance of generators in wind power plants so that the power generated is always maximum. The technique used is the control strategy using the Maximum Power Point Tracking (MPPT) controller. In this MPPT, a control method is applied, namely the extended Perturb and Observe (PO) method. The Perturb and Observe (PO) based MPPT algorithm has been widely used in searching for maximum power values [17] due to its simplicity. Furthermore, the use of the PO does not require wind speed information and turbine parameters, and it is faster and more efficient in searching the maximum point of power. However, it has the disadvantage of producing oscillations under steady-state conditions due to constant duty cycle changes. Therefore, modifications were made in the study, combining the PO and predictive method. Both methods work alternately according to current and voltage conditions on the input side of the converter. Predictive methods are used to determine the magnitude of step changes in the PO algorithm, the larger the voltage, the larger the step size used, and vice versa. The combination of the PO and predictive method applied to the MPPT technique for optimizing the generator output power of wind power systems is the novelty of this research. The technique used in the MPPT is the extended PO algorithm. The algorithm contains the foundations of standard PO, with changes to the step size value of each iteration according to the response of the system based on the predefined C constant. The modification of the method is resulting in faster convergence of the computation.

2. Small-Scale Wind Turbine System

The Indonesian government has encouraged the development of wind power technology in an effort to reduce carbon emissions. The wind turbine in Indonesia has become increasingly popular owing to the fact that the location has the wind potential. Indonesia is located in a tropical climate area, with moderate wind potential at speeds ranging from 3m/s to 15m/s [18]. Wind turbine systems are commonly used for smaller scales [19]. The turbine works to convert the kinetic energy in the wind to mechanical via rotation by generating a torque. The magnitude of the kinetic energy depends on air density and wind speed [7]. Equation (1) expresses the electric power of the wind turbine system as follows:

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$$P = 0.5\ C_p\ \rho A\ v^3 \quad (1)$$

As can be seen in equation (1), the coefficient of C_p generates a fraction of the kinetic energy converted into mechanical energy caused by the wind turbine. Some factors contribute to determining the wind turbine power, such as the ratio of tip speed λ. This wind speed ratio depends on the angle of the pitch blade for the turbine controlled by the pitch. The speed ratio can be defined as a correlation between the linear speed of the turbine blade and the wind velocity, which can be expressed by the following equation (2).

$$\lambda = r\ \omega / v \quad (2)$$

Substituting equation (2) in (1), the electric power that a wind turbine system is as follows,

$$P = 0.5\ C_p\ \lambda\ \rho A\ (r/\lambda)^3(\omega)^3 \quad (3)$$

Further torque can be calculated using the following equation (4).

$$P = 0.5\ C_p\ \rho A\ (v/\lambda) \quad (4)$$

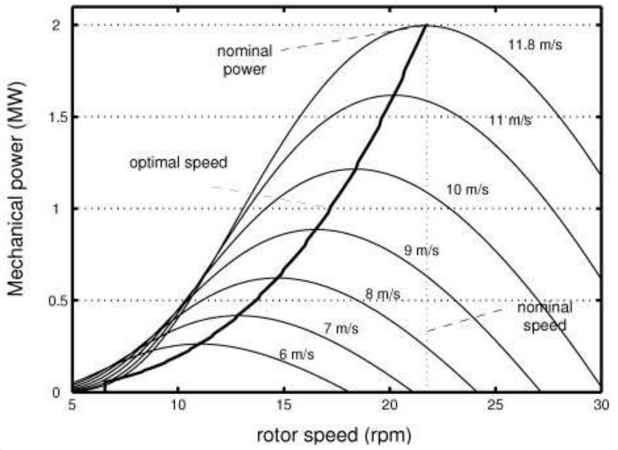

Figure 1. Wind turbine characteristics with pitch angle of 0°

Based on (4), it can be concluded that the value of the ratio of speed at which the coefficient of power reaches a maximum is possible. Wind turbines can generate maximum electrical energy by optimizing the tip speed ratio λ, achieved by adjusting the pace of the blade according to the wind speed. Figure 1 shows the power generated at different winds with a pitch angle of 0^0, indicating divergent speeds lead to a difference in output power. The mechanical power is dependent on the rotation speed, as shown by the winds ranging from 4m/s to 10m/s. Based on this example, the nominal wind speed that produces nominal mechanical power (1 p.u. = 3 MW) is 9m/s. A complete list of quantity symbols is presented in Table A1 in the Appendix.

3. MPPT Control Using Extended Perturb and Observe Algorithm

3.1. MPPT Control for Small-Scale Wind Turbine System

Figure 2 shows the typical diagram of a wind turbine system, composed of a turbine and PMSG generator that both serve to convert wind into mechanical energy, a generator-side converter that

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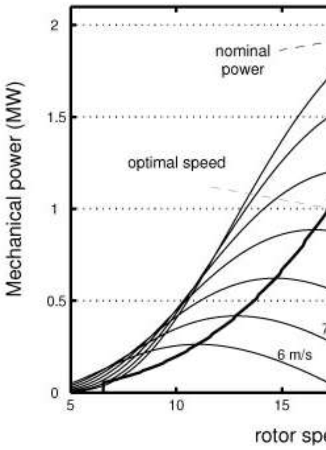

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rectifies the 3 phase ac electrical voltage into dc, and a boost converter. There is also an MPPT Controller which maximizes the output power, and a grid-side converter that turns dc electrical voltage into ac [20]. Furthermore, the output from the inverter can be integrated into the grid of the distribution system.

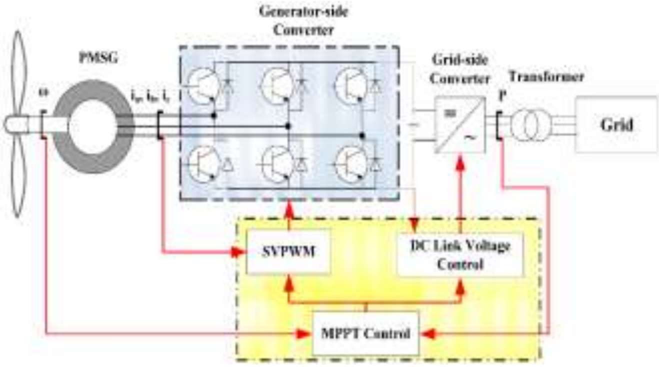

Figure 2. Typical diagram of wind turbine system

A wind turbine is a piece of equipment for converting wind energy into mechanical energy. As expressed in equation (4) that the power produced by the wind turbine (*P*) is the result of a process of half the mass density of the air type (*ρ*) with the area of cross-sectional coverage (*A*) and the power of the wind velocity (v^3). Wind energy drives the turbine rotor connected to the generator to create electrical energy. The maximum output power of the wind turbine is limited to the power coefficient (C_p), a function of tip speed ratio *λ*, rated from 25% to 45%. Based on the experimental results, this value will not exceed 59.3%. A generator is a tool to convert mechanical energy into electricity, changing the torque (*T*) and rotational speed of the rotor (*ω*) it receives from the blade into voltage (*V*) and current (*I*) values. The output of this generator is 3-phase AC voltage.

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The Permanent Magnet Synchronous Generator (PMSG) does not require an excitation system because its source is provided by a permanent magnet on the rotor [7], therefore eliminating the need for voltage control, simplifying the overall system. PMSG is usually used to generate electrical energy in wind turbines with low to medium power capacity. It is suitable for small scale power generators, hence useful in the Indonesian region where wind speeds are not too high. The advantage of using a PMSG is the low cost, durability, simplicity, and more straightforward clutch grid, however, a significant disadvantage is its need for smaller power factor and efficiency compensators [21].

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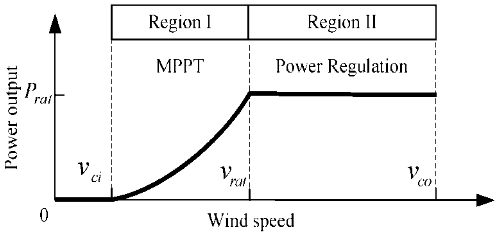

Figure 3. Ideal power curve in wind turbines with varying wind speeds

The wind energy system extracts the wind energy and converts it to electrical energy. The output power of the wind energy system varies depending on the wind speed [22]-[23]. When wind speed

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is below the expected value, MPPT is required to produce maximum power. The generator load is adjusted when the turbine ratings are smaller than the wind speeds. Figure 3 shows the ideal power curve in turbines with varying wind speeds. Region I illustrates areas where MPPT maximizes turbine power, while Region II portrays its regulation.

MPPT is the method of tracking the maximum power value of a power plant system [16], in order to produce higher levels of efficiency. The working principle is to increase and decrease the voltage by adjusting the duty cycle on the power side converter. However, with MPPT, the maximum power output from the generator can be optimized. The methods used in MPPT vary according to the algorithm used; this study used an extended PO.

3.2. Extended Perturb and Observe Algorithm

The PO algorithm can be used to determine the optimum point of a system [17]. In this study, the optimum point is the maximum power value that a PMSG generator can achieve in a wind turbine system. The maximum power value is obtained by adjusting the dc voltage on the generator side converter, which in turn changes the output power. To monitor and manage these changes, a certain step-size (ΔD) and time need to be specified: that is the output power generated compared to previous electrical power, so that the power changes (ΔP) and the next variable ΔD can be determined. If the generated power increases, then the variable ΔD will be fixed, if it decreases, then the ΔD will change. The working principle of this extended PO algorithm can be seen in the flow chart in Figure 4 and Figure 5, with several parameters in the initial value to calculate the change of step size value in each iteration done. Furthermore, it is necessary to identify the limit duty cycle in running this algorithm to maintain the ability of the buck converter. Figure 4 shows the standard PO method, while Figure 5 shows the extended PO method used in this study.

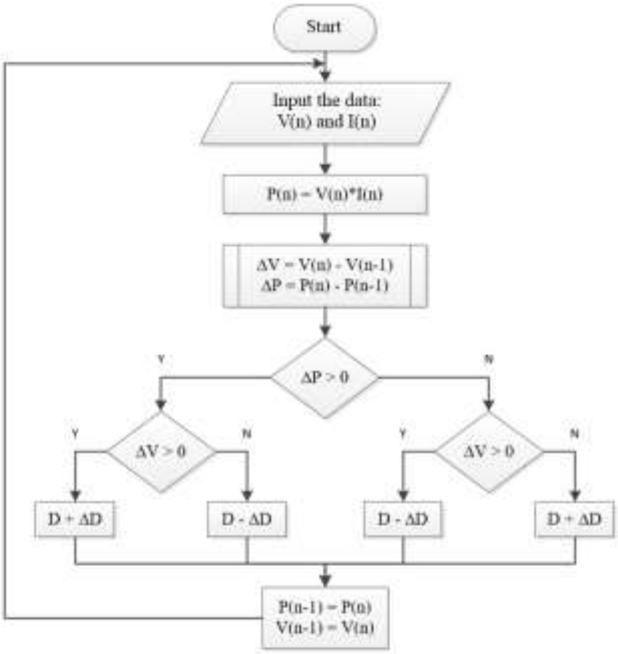

Figure 4. Flow chart of the standard perturb and observe algorithm

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The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of ΔD, resulting in faster convergence of the computation. ¶

Based on the analysis and literature study, the standard version of the PO algorithm (Figure 4) has disadvantages, including the time taken to reach a relatively slow convergence and high oscillation in maximum power search. However, this weakness can be overcome by changing the value of ΔD used to find the maximum point value of power generated, where the quantity of ΔD will be multiplied by a constant value of 0-1. When the system has reached the maximum power point then ΔD automatically decrease. The working principle of the extended PO algorithm can be seen in Figure 5.

The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of ΔD, resulting in faster convergence of the computation.

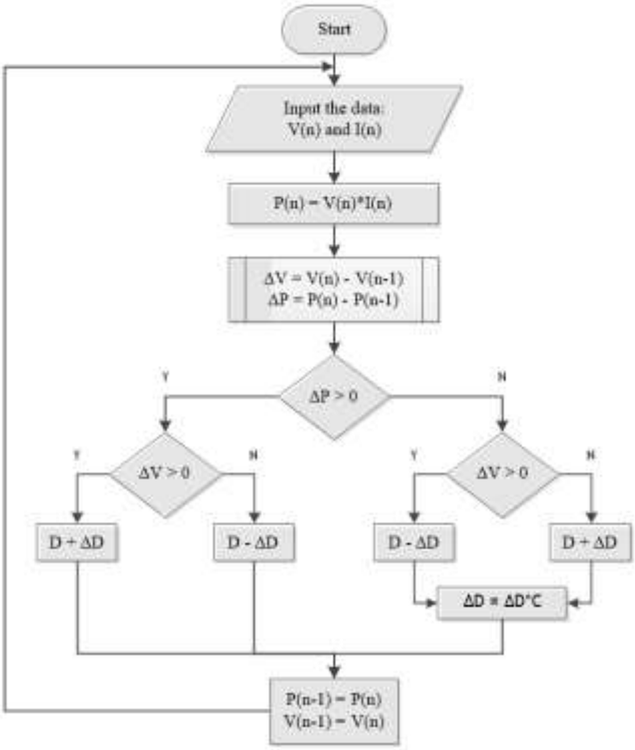

Figure 5. Flow chart of the extended perturb and observe algorithm

This extended PO algorithm contains the foundations of the original, with changes to the value of the step size of each iteration according to the response of the system based on the predefined *C* constant. The duty cycle value limit is also specified in order to keep the system working in accordance with the capabilities of the buck converter. Time delay running the program in a one-time iteration is to respond due to changes in the given duty cycle.

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4. Results and Discussion

4.1. Model of Wind Turbine System

This study analyzes the wind turbine system modelled by the Simulink-Matlab software. The system comprises a wind turbine, PMSG, a rectifier, MPPT, and an inverter. The turbine converts wind into mechanical energy, the PMSG transforms the mechanical energy into electricity, and the rectifier ensures that the ac electrical voltage is transformed into dc electrical current. Furthermore, the MPPT maximizes the output power of the wind turbine system, and the inverter converts the dc into ac voltage. The block diagram of the wind turbine system with MPPT and circuit diagram are shown in Figure 6 and Figure 7.

Table 1. Parameters of wind turbine in this study

Parameters	**Quantities and Units**
Nominal mechanical output power	3000W
Base power of the electrical generator	3000/0.9VA
Base wind speed	12m/s
Maximum power at base wind speed of nominal mechanical power	0.73p.u.
Base rotational speed of base generator speed	1.2p.u.
Pitch angle beta to display wind turbine power characteristics	0

The parameters used in this study are shown in Table 1, where the mechanical output of power is 3000W. It has a base electrical generator power of 1,111.11VA and a base wind speed of 12m/s. The maximum power at base wind speed is 0.73 p.u, while the base rotational speed of the generator is 1.2 p.u. The pitch angle employed is 0^0.

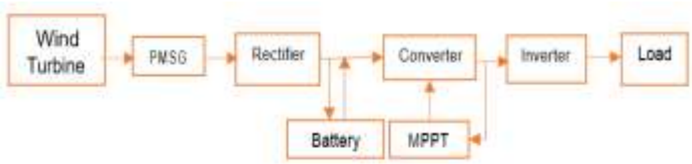

Figure 6. Block diagram of the wind turbine system with MPPT

Table 2. Parameters of PMSG

Parameters	**Quantities and Units**
Back EMF waveform	Sinusoidal
Rotor type	Salient pole
Mechanical input	Torque (Tm)
Stator phase resistance	0.00867Ω

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Inductances (L_d)	0.00286H
Inductances (L_q)	0.00344H
Flux linkage	0.175V.s.
Voltage constant	126.966Ω
Torque constant	1.05N.m.

Wind turbine circuit diagram system with MPPT in the Simulink software, as shown in Figure 7 is an implementation of a block diagram of the wind turbine system with MPPT, as shown in Figure 6. The wind turbine model in Simulink-Matlab software is presented in Figure 8.

There are three inputs and one output of the system, as shown in Figure 8. The first input is the speed of the generator from the rotor. There is a pitch angle measured in degrees, and in this study, we use 0^0. The third input is the wind speed in m/s, adjusted for the simulated conditions, namely both are constant and changing. The output of the turbine is the mechanical torque of the rotation. The turbine is then connected to the PMSG generator.

This wind turbine system is adapted to speeds ranging from 3 to 15m/s, with optimal occurrence between 11:00 AM to 02:00 PM. Along with this condition, the off-grid system is required to store the electrical energy produced. In this study, the generator used is a 3-phase PMSG type, as shown in Table 2. The 3-phase power voltage generated uses a rectifier to achieve a 48V dc voltage, which can be connected to the battery, a converter, and an inverter to serve electric loads. As shown in Figures 1 and 2, MPPT is used to optimize generator voltage through rectifiers at boost converter locations. Furthermore, rectifier parameters are used in this study, as shown in Table 3. The power used is a bridge-type, where the RC snubber circuits are connected to each switch device in parallel form.

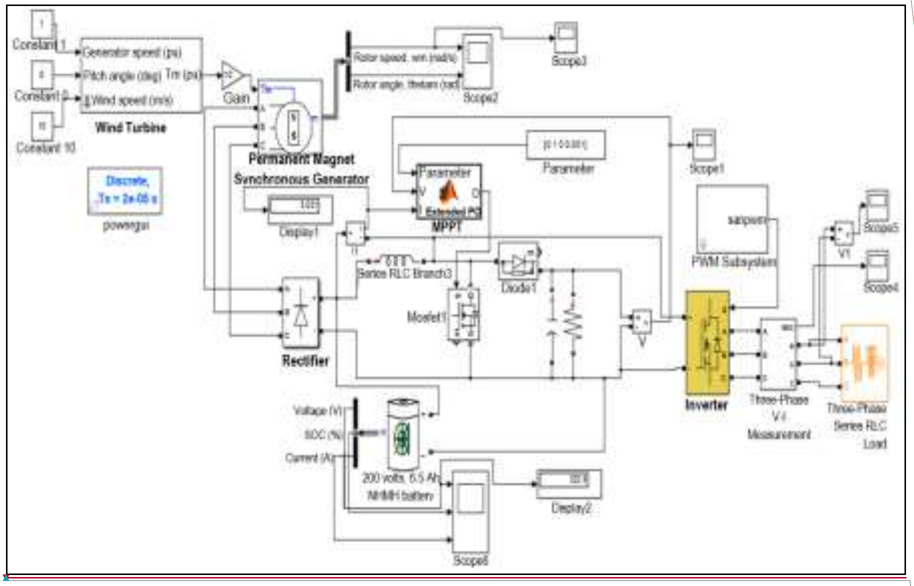

Figure 7. Wind turbine circuit diagram system with MPPT in the Simulink-Matlab software

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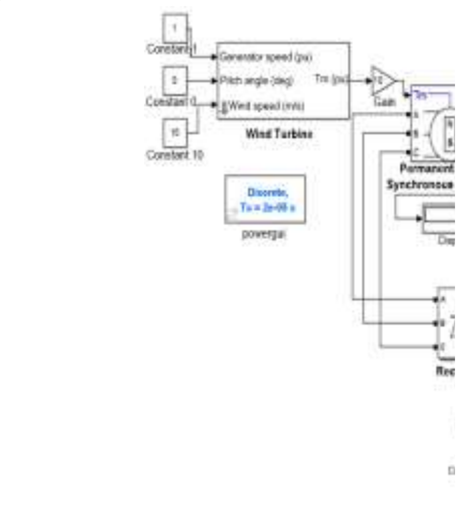

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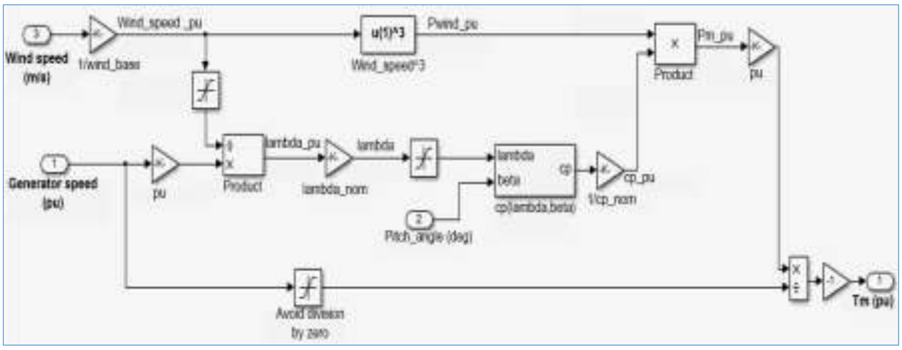

Figure 8. Wind turbine model in Simulink-Matlab software

Figure 9 shows the model of the boost converter circuit in Simulink-Matlab. The parameters in the boost converter are shown in Table 4. In order to determine the boost converter circuit, an input voltage (V_{in}) of 100V, is used to test the system, as shown in Figure 10. Results obtained prove that the model is able to produce the required voltage. Table 4 shows battery parameters, while the inverter, which is a bridge of selected power electronic devices consisting of RC snubber circuits connected in parallel with each switch device is shown in Table 5.

Table 3. Parameters of rectifier

Parameters	Quantities and Units
Number of bridge arms	3
Snubber resistance (R_s)	100Ω
Snubber capacitance (C_s)	0.1μF
Power electronic device	diodes
Forward voltage (V_f)	0.8V

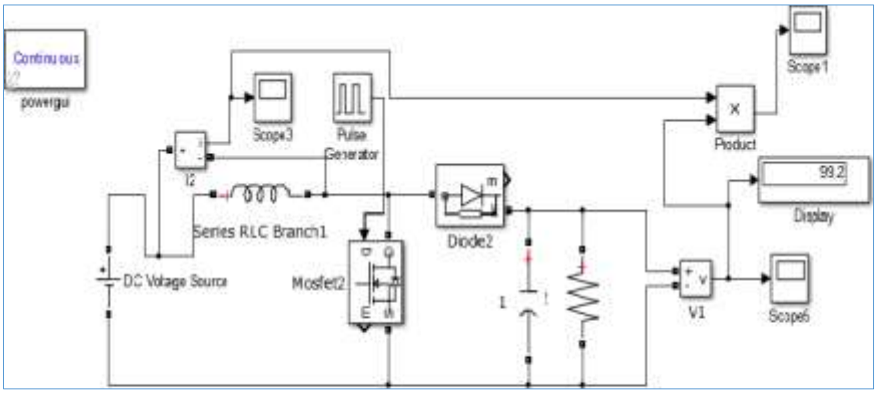

Figure 9. Boost converter model in Simulink-Matlab software

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Table 4. Parameters of battery

Parameters	Quantities and Units
Nominal voltage	300V
Rated capacity	6.5Ah
Initial state of charge	60%
Maximum capacity	7Ah
Fully charged voltage	353.39V
Nominal discharge current	1.3A
Internal resistance	0.4615Ω
Capacity at nominal voltage	6.25Ah
Exponential zone	325.42V, 1.3Ah

Table 5. Parameters of inverter

Parameters	Quantities and Units
Snubber resistance	100kΩ
Snubber capacitance	Infinite
Power electronic device	Mosfet, diodes
Internal resistance	0.001Ω

4.2. Evaluation of Perturb and Observe Algorithm

In the PO algorithm, the quantity of input is voltage, and the output is the current of PMSG generator. These voltages and currents are further utilized in order to obtain a more optimum output, as shown in Figure 7. The following stages are involved in the Perturb and Observe algorithm process.

1) Initial voltage measurement is determined to study the exact value of the current PMSG generator output voltage.
2) The Power PMSG generator is measured to determine its current value.
3) The power difference is calculated to actuate the difference between the present and the previously measured power.
4) The voltage and power are compared to figure out the process involved in the changes. From this comparison, the generator voltage will be larger or smaller, depending on the generator power and measured voltage differences.
5) If the above stages turn out to be successful, step 1is repeated.

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Table 6. Results of the PO algorithm validity test

Number of Experiments	Wind speed (m/s)	Turbine rotation (rpm)	Load resistance (Ω)	Output power (W)
1	10	508.06	200	2032
2	10	508.06	200	2032
3	10	508.06	200	2032
4	10	508.06	200	2032
5	10	508.06	200	2032
6	10	508.06	200	2032
Mean	10	508.06	200	2032
Standard deviation	0	0	0	0

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After the PO algorithm is made on the wind turbine system, its validity and sensitivity are evaluated. In this study, the algorithm is valid if the standard value of deviation is less than 1% in 6 experiments. This fact is also similar to its sensitivity, which is also conducted by changing the wind speed.

A validity test is carried out to examine the results using the PO algorithm, and by conducting repetitive experiments for fixed parameters with a particular input, followed by an observation of mean and standard deviation from the experimental data. In this test, a winding rate of 10m/s is used as an input with fixed turbine system parameters. The results of the algorithm validity test are shown in Table 6.

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Table 7. Results of the PO algorithm sensitivity test

Wind speed (m/s)	Generator Voltage (V)	Output Power (W)
3	27.92	8.22
4	57.07	43.89
5	82.21	78.02
6	140.03	242.13
7	171.41	334.23
8	247.24	809.31
9	316.90	1201.18
10	348.62	1472.34

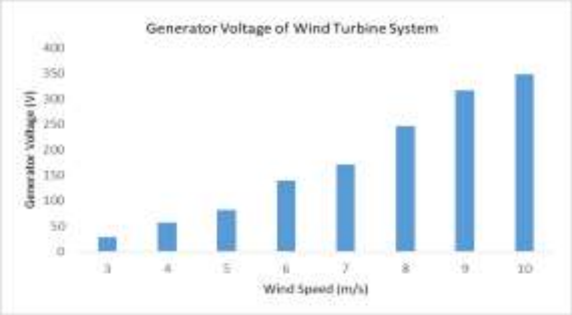

Figure 10. Generator voltage of wind turbine system

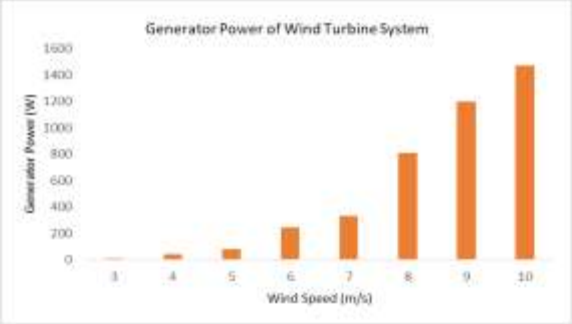

Figure 11. Generator output power of wind turbine system

The test resulted to a standard deviation value of 0, which means that the optimization procedure produced the same value in each experiment; hence, the output power of the wind turbine system can be categorized as valid.

In order to determine the effect of the changes associated with the parameter values, a sensitivity analysis of the PO algorithm is tested by varying the value of the wind speed between 3 to 10m/s with a fixed power generator value of 3000W. In this experiment, 100Ω resistance was used, and results obtained are shown in Table 7 and Figure 10. From the experimental results, it can be seen that the higher the wind speeds the more significant the voltage and power of the generator. This fact is because the rotor speed increases with a rise in wind speed, which also affects the power generated. The results of experiments in Table 7 and Figure 11 also prove that same.

4.3. Performance Test of Wind Turbine System

In this section, a test is conducted on the wind turbine systems in order to improve the performance. Figure 12 and Figure 13 are used to test the Simulink Matlab performance with the installation of MPPT controllers. Test results of the system performance with and without the MPPT controller are shown in Table 8.

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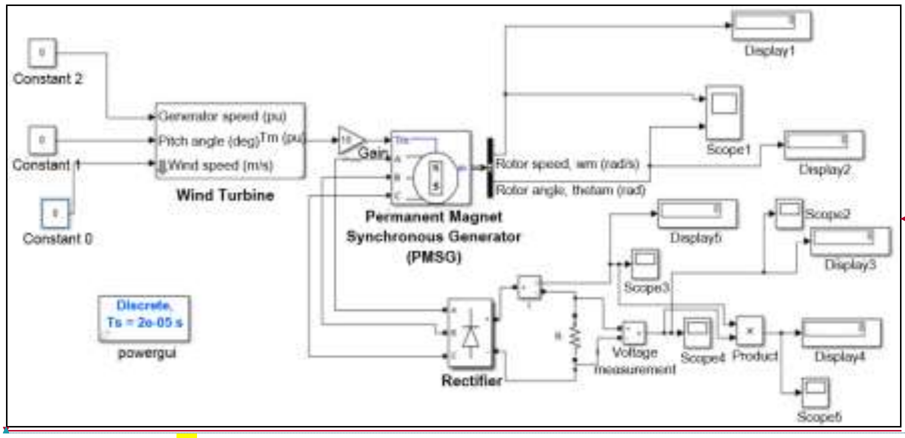


Figure 12. Wind turbine system without MPPT in Simulink-Matlab software

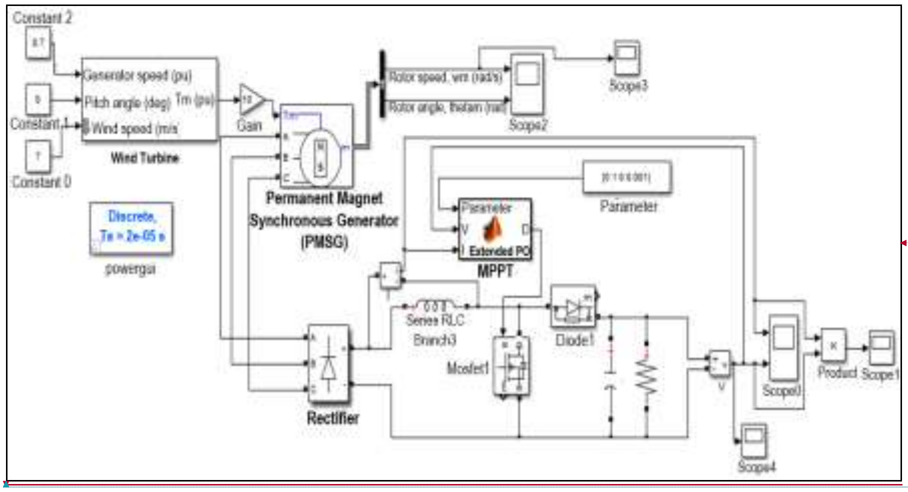
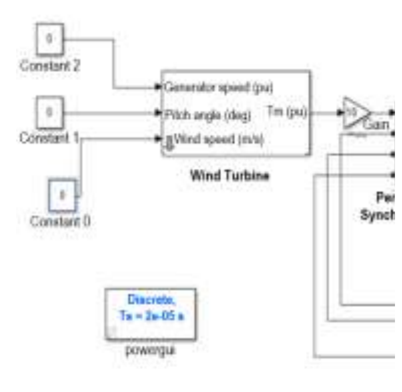


Figure 13. Wind turbine system with MPPT in Simulink-Matlab software

Table 8. Results of performance test of wind turbine system

Load resistance (Ω)	Wind speed (m/s)	Performance test variables of wind turbine system						
		Without MPPT			With MPPT			Power increasing (%)
		Output voltage (V)	Electric Current (A)	Output power (W)	Output voltage (V)	Electric Current (A)	Output power (W)	
50	4	33.76	0.67	22.62	33.83	0.69	23.34	3.20
	5	54.09	1.08	58.42	60.05	1.15	69.06	18.21
	6.5	71.51	1.43	102.26	73.21	1.53	112.01	9.54
	7	83.03	1.66	137.83	85.92	1.81	155.52	12.83



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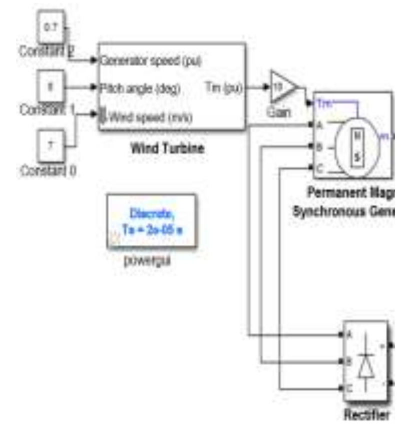

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	8.5	124.24	2.42	300.66	130.54	2.77	361.60	20.27
	9	140.41	2.81	394.55	147.52	3.14	463.21	17.40
	10	174.35	3.49	608.48	183.81	3.95	726.05	19.32
100	4	62.63	0.62	38.83	66.24	0.75	49.68	27.94
	5	95.09	1.09	103.65	119.12	1.12	133.41	28.72
	6.5	137.64	1.38	189.94	149.02	1.81	269.73	42.00
	7	160.12	1.62	259.39	171.41	2.05	351.39	35.47
	8.5	238.23	2.35	559.84	265.5	3.62	961.11	71.68
	9	269.32	2.69	724.47	296.04	4.07	1204.88	66.31
	10	335.09	3.35	1122.55	348.61	4.45	1551.31	38.20
200	4	116.51	0.58	67.58	134.81	1.14	153.68	127.42
	5	189.89	0.89	169.00	215.66	1.65	355.84	110.55
	6.5	240.64	1.23	295.99	280.08	2.49	697.40	135.62
	7	299.11	1.49	445.67	315.31	2.65	835.57	87.48
	8.5	376.07	1.88	707.01	431.62	2.92	1260.33	78.26
	9	438.01	2.51	1099.41	485.41	3.26	1582.44	43.94
	10	547.11	2.73	1493.61	586.44	3.53	2070.13	38.60
300	4	166.03	0.55	91.32	184.25	1.03	189.78	107.82
	5	234.09	0.89	208.34	256.05	1.35	345.67	65.92
	6.5	354.81	1.18	418.68	360.26	1.93	695.30	66.07
	7	426.22	1.44	613.76	412.06	2.07	852.96	38.97
	8.5	574.05	1.93	1107.92	589.92	2.48	1463.00	32.05
	9	483.15	2.18	1053.27	658.09	2.69	1770.26	68.07
	10	902.72	3.04	2734.67	817.71	3.72	2999.88	9.63
Average of power increasing (%)								50.77

Table 8 shows the results of the wind turbine system performance test from simulations in Figure 12 and Figure 13. The performance test is carried out with a 3000W wind turbine with electrical loads of 50Ω, 100Ω, 200Ω, and 300Ω, respectively in order to assess the performance of the turbine while serving the increased load with and without the MPPT controller.

As seen in Table 8, the greater the electrical load served, the higher the output power of the PMSG generator from the wind turbine. The most considerable output power is obtained when the system serves the highest electrical load of 300Ω. Furthermore, the electrical load, and wind speed variation, on the prevailing wind conditions in Indonesia (i.e., 4, 5, 6.5, 7, 8.5, 9, and 10m/s), is examined. Overall, the MPPT controller is able to increase the wind turbine system's power output significantly. The average power increase after installing the MPPT controller using the PO algorithm is 50.77%. The results are presented in graphical form to clearly analyze the effect of MPPT controller on various wind speed variations, as shown in Figures 14, 15, 16, and 17.

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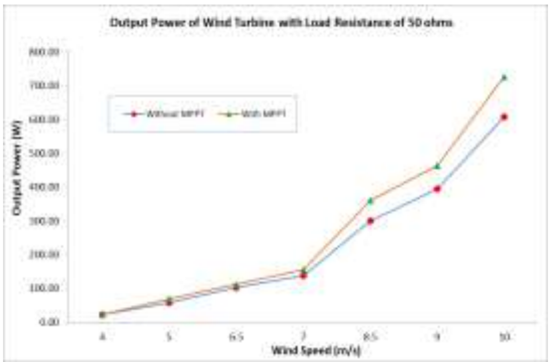

Figure 14. Output power of wind turbine system with load resistance of 50Ω.

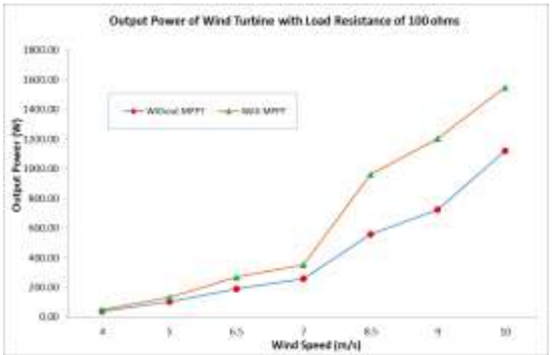

Figure 15. Output power of wind turbine system with load resistance of 100Ω.

Figure 14 shows the output power of the wind turbine system with a load resistance of 50Ω. At wind speeds of 4m/s, the turbine system without MPPT produces 33.76V, and at an electrical current of 0.67A, the output power of the turbine is 22.62W. The application of an MPPT controller on the PMSG generator side converter generated both voltage and current of 33.83V and 0.69A, respectively, resulting in output power of 23.34W. In this case, the system output power is increased by 3.20% before implementing the MPPT controller. Furthermore, the system performance test with wind speeds of 5, 6.5, 7, 8.5, 9, and 10m/s, respectively, were examined. Based on the graph in Figure 14, it can be concluded that the higher the wind speed that hits the turbine, the greater the voltage, current, and output power with the best output recorded at 10m/s. The condition without MPPT produced a voltage of 174.35V with a load current of 3.49A, thereby, generating power of 608.48W.

Furthermore, with the application of the MPPT controller, there is an increase in voltage, load current, and system output power of 183.81V, 3.95A, and 726.05W, respectively. When compared to the condition before the application, an increase in system output power by 19.32% is displayed. Based on the graph in Figure 14, the best performance of the MPPT controller in increasing the output power occurs precisely at wind speeds of 8.5m/s, where the percentage increase in output power is 20.27%. Overall, it can be seen that the MPPT controller using the PO algorithm has successfully improved the performance of wind turbine systems.

The output power of the wind turbine system with a load resistance of 100Ω is shown in Figure 15. At a wind speed of 4m/s, and without MPPT, the system produces a voltage of 62.63V and an electric current of 0.62A to serve the load resistance of 100Ω, with an output turbine power of 38.83W. Furthermore, the application of the MPPT controller on the PMSG generator side converter, as well as the voltage and current generated was 66.24V and 0.75A, respectively, resulting in output power

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of 49.68W. This result means that the system output power is increased by 27.94% compared to when the MPPT controller wasn't implemented. Furthermore, the system performance test with a wind speed of 5, 6.5, 7, 8.5, 9, and 10m/s, was examined. Based on the graph in Figure 15, it can be seen that the higher the wind speed, the greater the voltage, current, and output power of the system. The results show that the best output is produced with a wind speed of 10m/s. Without applying the MPPT, the voltage produced was 335.09V with a load current of 3.35A, and power of 1,122.55W.

Furthermore, with the application of the MPPT, there is an increase in voltage, load current, and system output power of 348.61V, 4.45A, and 1,151.3W, respectively. When compared to the condition before the application of the MPPT, an increase in system output power by 38.20% is noticed. Based on the graph in Figure 15, it can also be seen that the best performance of the MPPT controller in increasing the output power of the system occurs precisely at the of 8.5m/s wind speed, where the percentage increase in output power is 71.68%. Overall, it can be seen that the MPPT controller using the extended PO algorithm has successfully improved the performance of wind turbine systems.

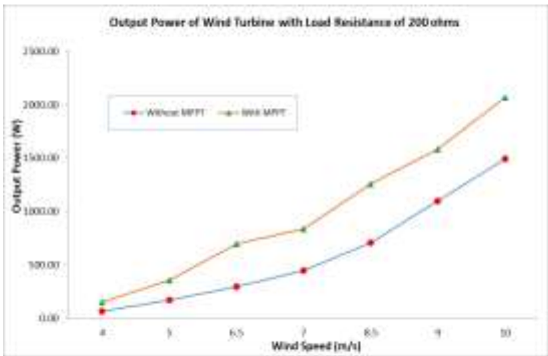

Figure 16. Output power of wind turbine system with load resistance of 200Ω.

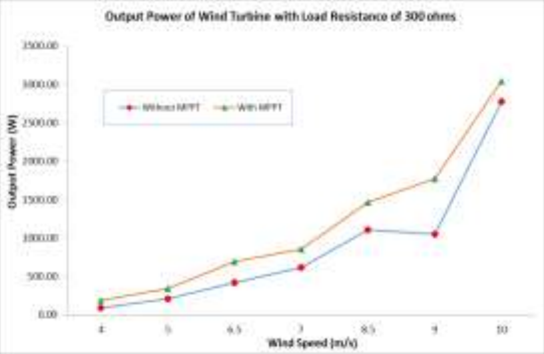

Figure 17. Output power of wind turbine system with load resistance of 300Ω.

Figure 16 shows the output power of the turbine system with a load resistance of 200Ω. At a wind speed of 4m/s, and without implementing the MPPT, it produces a voltage of 116.51V and electric current of 0.58A to serve the load resistance of 200Ω with an output power of 67.58W. Along with the application of the MPPT controller on the PMSG generator, both voltage and current of 134.81V and 1.14A were generated, which resulted in output power of 153.68W. Furthermore, the system performance test with wind speeds of 5, 6.5, 7, 8.5, 9, and 10m/s, respectively, was examined. Based on the graph in Figure 16, it can be seen that the higher the wind speed, the greater the voltage,

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current, and output power of the wind turbine system. The results show that at a wind speed of 10m/s, the system produces the optimal output.

Similarly, without implementing the MPPT, 547.11V with a load current of 2.73A were produced, which generated a total power of 1493.61W. However, with the application of the MPPT controller, an increase in voltage, load current, and system output power of 586.44V, 3.53A, and 2070.13W, respectively, was recorded. When compared to the condition before the application of the MPPT, the system output power is increased by 38.60%. Based on the graph in Figure 16, it can also be seen that the best performance of the MPPT controller in increasing the output power of the system occurs precisely when the wind speed is 6.5m/s, with an output percentage power output of 135.62%. Overall, implementing the MPPT controller using the extended PO algorithm has successfully enhanced the performance of wind turbine systems.

The output power of the wind turbine system with a load resistance of 300Ω is shown in Figure 17. At wind speeds of 4m/s, the system without MPPT produces a voltage of 166.03V and electric current of 0.55A which is used to serve the load resistance of 300Ω with an overall output power of 91.32W. The application of the MPPT controller on the PMSG generator produced a voltage and current of 184.25V and 1.03A, respectively, with an overall power output of 189.78W. In this case, the system output power increased by 107.82% compared to when the MPPT controller wasn't implemented. Furthermore, the system performance test with wind speeds of 5, 6.5, 7, 8.5, 9, and 10m/s, respectively, was examined.

Based on the graph in Figure 17, the higher the wind speed, the greater the voltage, current, and output power of the wind turbine system. The results show that the system produces an outstanding wind speed of 10m/s. Without the implementation of the MPPT, the generated voltage is 902.72V with a load current of 3.04A, thus creating a power of 2,734.67W. Furthermore, with the application of the MPPT controller, there is an increase in voltage, load current, and system output power of 817.71V, 3.72A, and 2,999.88W, respectively. When compared to the initial condition, an increase in system output power by 9.63% can be detected. Based on the graph in Figure 17, the best performance of MPPT controller in increasing the output power of the system occurs when the wind speed is 4m/s, with a percentage increase in output power of 107.82%.

Based on the results of the overall wind turbine system performance test, the most significant increase in system output power occurs when the system is loaded with 200Ω, with a wind speed of 6.5m/s. In this condition, there has been a high increase of output power by135.62%, caused by the installation of the MPPT controller in the wind turbine system, while the average growth of output power is only 50.77%. Thus, it can be concluded that MPPT uses the extended PO method in this study has been proven to be able to increase the performance of wind turbine systems.

5. Conclusions

In this study, the research of wind turbine system performance using an MPPT controller based on an extended PO algorithm was performed. This algorithm can calibrate without oscillation to determine the maximum power output. To analyze the performance, the Simulink-Matlab software was employed. The performance examination is carried out with a 3000W wind turbine system which served varying electrical loads of 50Ω, 100Ω, 200Ω, and 300Ω, respectively. In each of the variations, various wind speeds based on the prevailing wind conditions in Indonesia, i.e., 4, 5, 6.5, 7, 8.5, 9, and 10m/s, respectively, were performed. Based on the results of the overall wind turbine system performance examination, the most significant increase in system output power occurs when the system is loaded with 200Ω with a wind speed of 6.5m/s. Similarly, the installation of the MPPT controller increased the output power by 135.62%, with an average power increase of 50.77%. The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of *ΔD*, resulting in faster convergence of the computation. The results of this study have proven that extended PO-based MPPT, is capable of successfully enhancing the performance of wind turbine systems.

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Funding: This research received funding from the Directorate General of Development and Research Enhancement, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia, under Research Grant.

Acknowledgments: The authors gratefully acknowledge the contributions of the Directorate General of Development and Research Enhancement, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia, for funding this research.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix

Table A1. Abbreviations Lists

Abbreviation	Meaning
AC	Alternating Current
DC	Direct Current
EMF	Electro-Motive Force
FLC	Fuzzy Logic Controller
GW	Giga Watts
MPPT	Maximum Power Point Tracking
PMSG	Permanent Magnet Synchronous Generator
PO	Perturb and Observe
PWM	Pulse Width Modulation
RC	Resistance-Capacitance
A	the area of cross-sectional coverage, in m^2
C_p	the coefficient of electric power of the wind turbine system
C_s	Snubber capacitance
I	electric currents, in amperes
P	the electric power of the wind turbine system, in watts
R_s	Snubber resistance
T	the torque of generator, in Nm
V	electric voltages, in volts
V_f	forward voltage, in volts
v	wind velocity, in m/s
ω	rotational speed of the rotor, in rad/s
λ	the ratio of tip speed
ρ	the mass density of the air type, in kg/m^3

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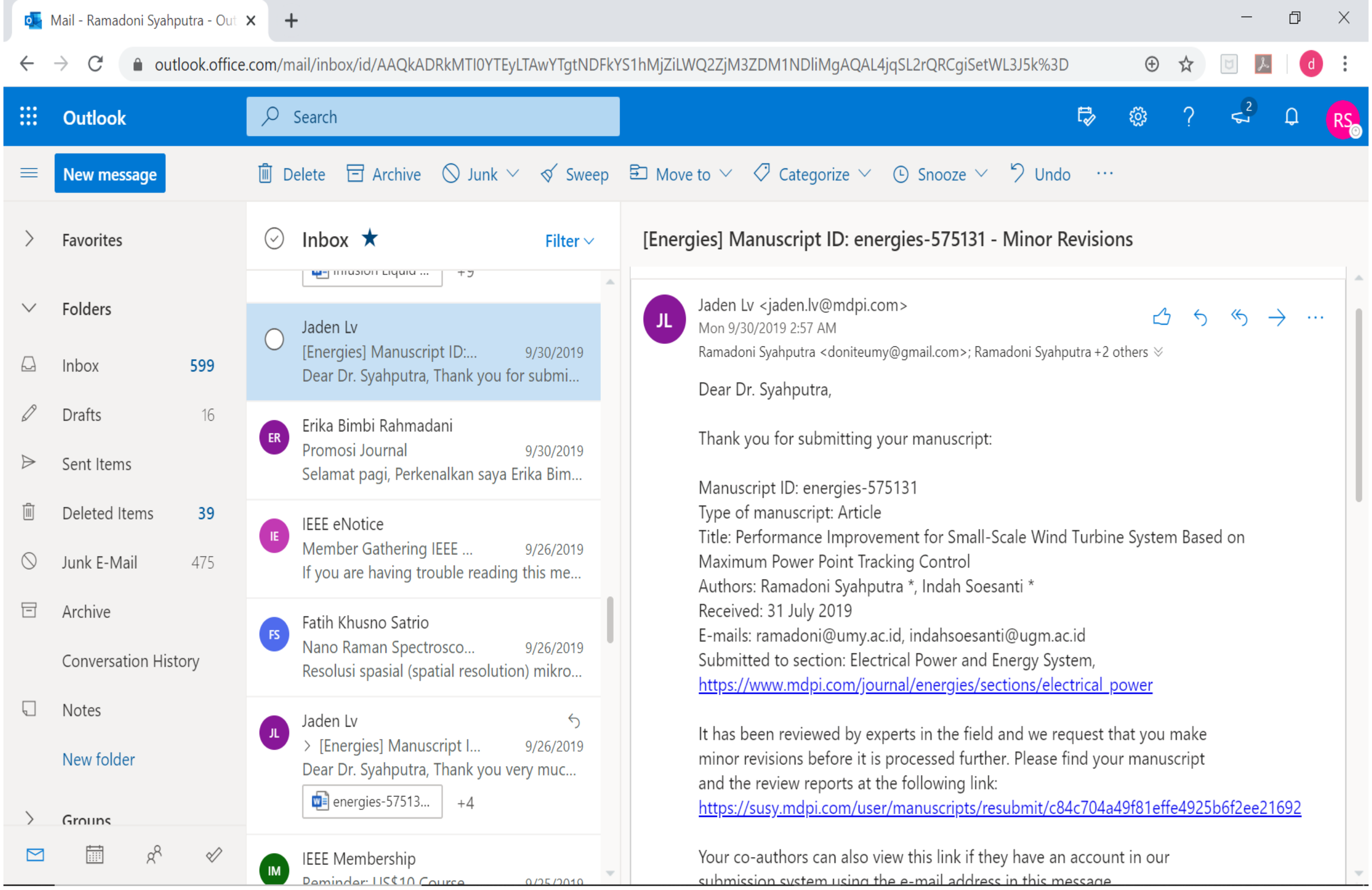
30-Sep-2019; Notifikasi Round II dari Editor: Minor Revisions



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Jaden Lv <jaden.lv@mdpi.com>
Mon 9/30/2019 2:57 AM
Ramadoni Syahputra <doniteumy@gmail.com>; Ramadoni Syahputra +2 others

Dear Dr. Syahputra,

Thank you for submitting your manuscript:

Manuscript ID: energies-575131
Type of manuscript: Article
Title: Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors: Ramadoni Syahputra *, Indah Soesanti *
Received: 31 July 2019
E-mails: ramadoni@umy.ac.id, indahsoesanti@ugm.ac.id
Submitted to section: Electrical Power and Energy System,
https://www.mdpi.com/journal/energies/sections/electrical_power

It has been reviewed by experts in the field and we request that you make minor revisions before it is processed further. Please find your manuscript and the review reports at the following link:
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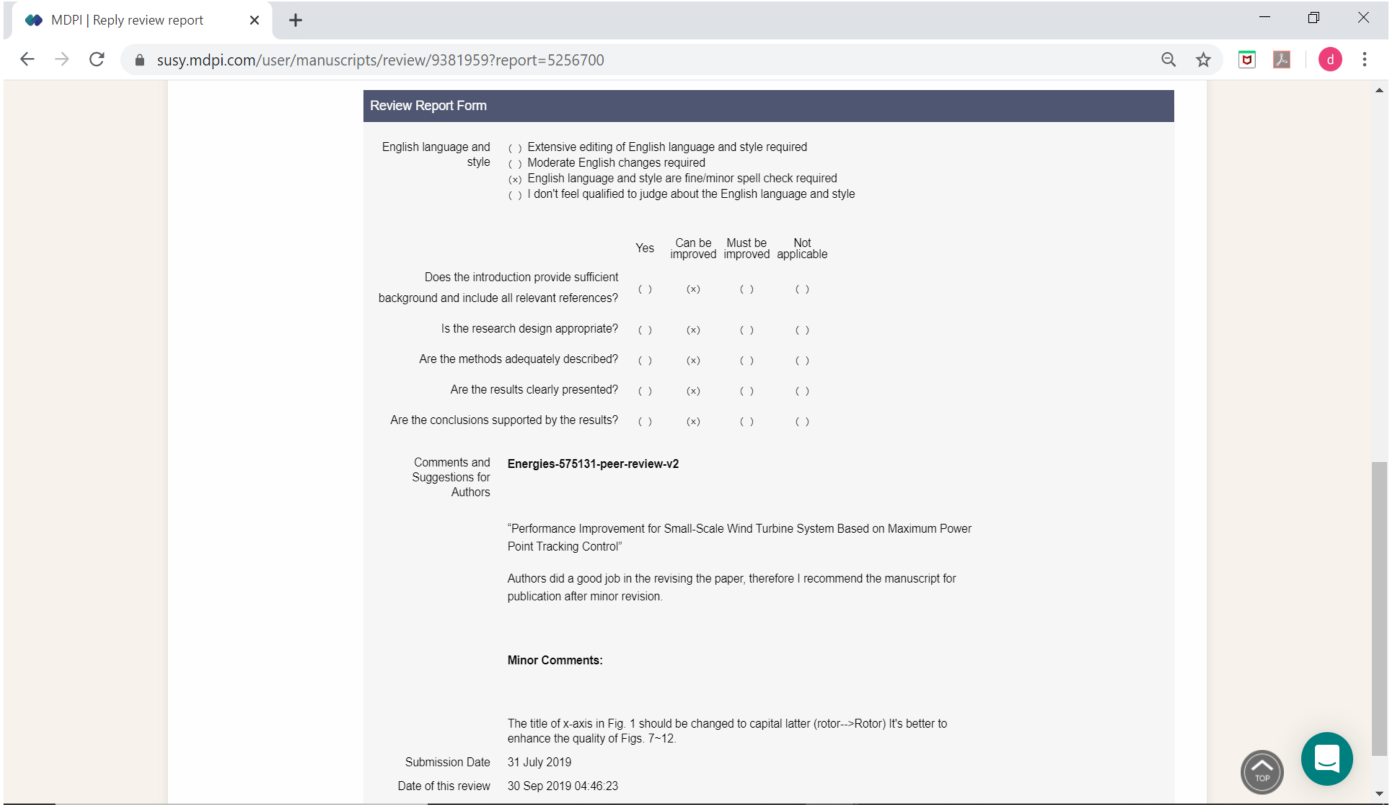


Review Report Form

English language and style
( ) Extensive editing of English language and style required
( ) Moderate English changes required
(x) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	( )	(x)	( )	( )
Is the research design appropriate?	( )	(x)	( )	( )
Are the methods adequately described?	( )	(x)	( )	( )
Are the results clearly presented?	( )	(x)	( )	( )
Are the conclusions supported by the results?	( )	(x)	( )	( )

Comments and Suggestions for Authors

Energies-575131-peer-review-v2

"Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control"

Authors did a good job in the revising the paper, therefore I recommend the manuscript for publication after minor revision.

Minor Comments:

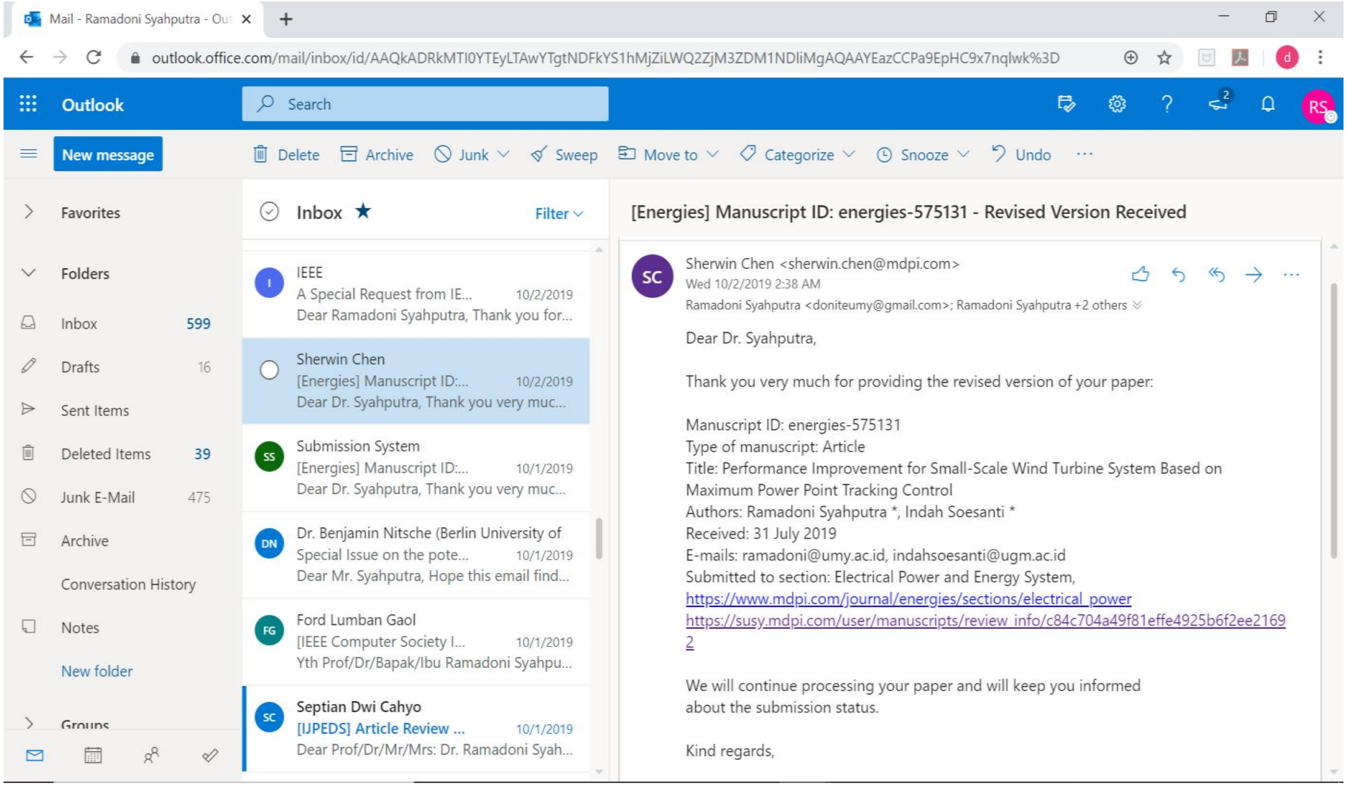
The title of x-axis in Fig. 1 should be changed to capital latter (rotor-->Rotor) It's better to enhance the quality of Figs. 7~12.

Submission Date 31 July 2019

Date of this review 30 Sep 2019 04:46:23

Response to Reviewers of Round 2 by Authors

Submitted on 2-Oct-2019



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[IJPEDS] Article Review ... 10/1/2019
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[Energies] Manuscript ID: energies-575131 - Revised Version Received

Sherwin Chen <sherwin.chen@mdpi.com>
Wed 10/2/2019 2:38 AM
Ramadoni Syahputra <doniteumy@gmail.com>; Ramadoni Syahputra +2 others

Dear Dr. Syahputra,

Thank you very much for providing the revised version of your paper:

Manuscript ID: energies-575131
Type of manuscript: Article
Title: Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors: Ramadoni Syahputra *, Indah Soesanti *
Received: 31 July 2019
E-mails: ramadoni@umy.ac.id, indahsoesanti@ugm.ac.id
Submitted to section: Electrical Power and Energy System,
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We will continue processing your paper and will keep you informed about the submission status.

Kind regards,

Manuscript Details

Manuscript ID : energies-575131
Type of manuscript : Article
Title : Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors : Ramadoni Syahputra *, Indah Soesanti

Abstract: This paper proposes a strategy for performance improvement of small-scale wind turbine systems using maximum power point tracking control (MPPT). In this study, wind turbine systems which use permanent magnet synchronous generators and converter devices are modeled in Simulink-Matlab software. In order to increase the power generated, MPPT is used based on the extended Perturb and Observe (PO) method. This algorithm has the ability to improve the speed of the turbine without oscillation. To analyze the ability of the PO-based MPPT in maximizing output power, performance examination of wind turbine systems in Simulink-Matlab software were conducted. The study is carried out with a 3000W wind turbine device serving various electrical loads of 50Ω, 100Ω, 200Ω, and 300Ω, and each Ohm varies with a wind speed of 4, 5, 6.5, 7, 8.5, 9, and 10m/s. The overall turbine system performance found that the maximum increase in system output power occurs when it is loaded with 200Ω with a wind speed of 6.5m/s. During this combination of 200Ω and 6.5m/s, there are high increments of output power at 135.62%, caused by the installation of MPPT controllers, with an average output power increase of 50.77%. The results of this study proved that PO-based MPPT has successfully improved the performance of wind turbine systems.

Response to Reviewer 2 Comments (Round 2)

Yogyakarta, Indonesia, October 2, 2019

Dear Reviewers,

The authors would like to thank the reviewers for the careful reading of the paper and the constructive comments. In light of the reviewers' observations, we have introduced some modifications to improve our paper in this round of revisions.

All changes in the body of the paper have been highlighted on yellow color.

Best regards,
Dr. Ramadoni Syahputra et al.

Response to Reviewer 2 Comments (Round 2)

Comments and Suggestions for Authors:

Point 1: "Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control"

Authors did a good job in the revising the paper, therefore I recommend the manuscript for publication after minor revision.

Response 1 from Authors:

Dear reviewer, we want to thank you for taking your time to review our paper as well as for given us useful comments for improving its quality for a possible reconsideration in "Energies".

Thank you very much for the valuable comments.

We express our gratitude for our manuscript recommendations for publication in "Energies" after minor revisions. This statement is very happy for us. We pray that reviewers will always be healthy and prosperous in their careers.

Point 2: **The title of x-axis in Fig. 1 should be changed to capital latter (rotor-->Rotor) It's better to enhance the quality of Figs. 7~12.**

Response 2 from Authors:

Thank you for the valuable comments.

We have revised the Figure 1. The word "rotor" has been changed to "Rotor", as shown in Figure 1 below.

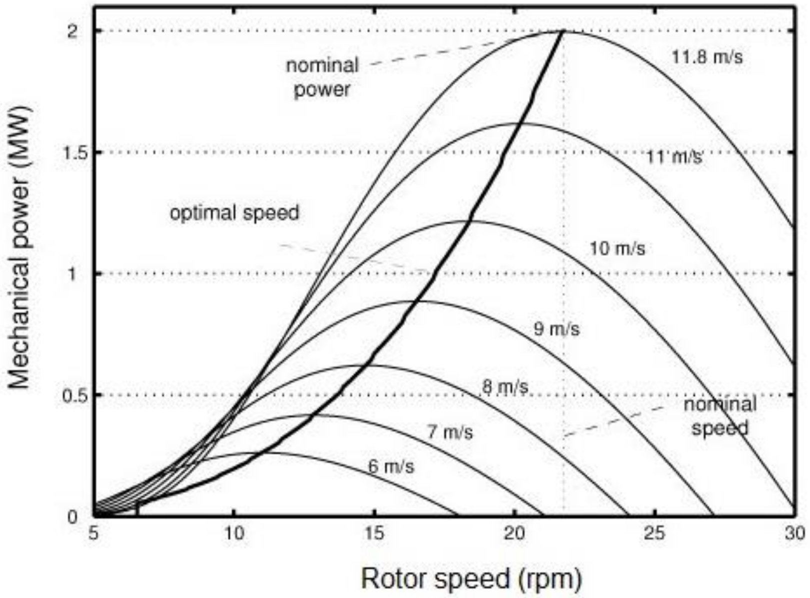

Figure 1. Wind turbine characteristics with pitch angle of 0°

We have also improved the quality of Figs. 7~12, as shown below.

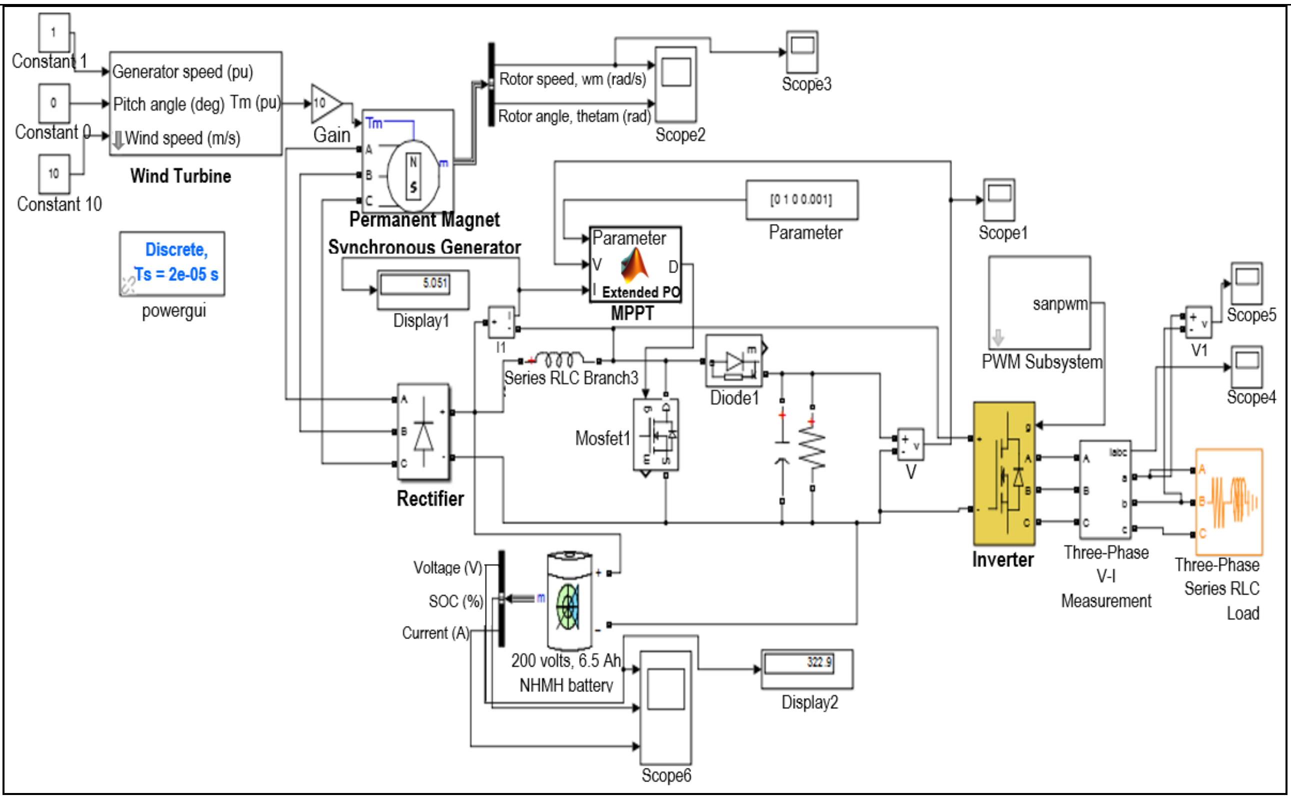

Figure 7. Wind turbine circuit diagram system with MPPT in the Simulink-Matlab software

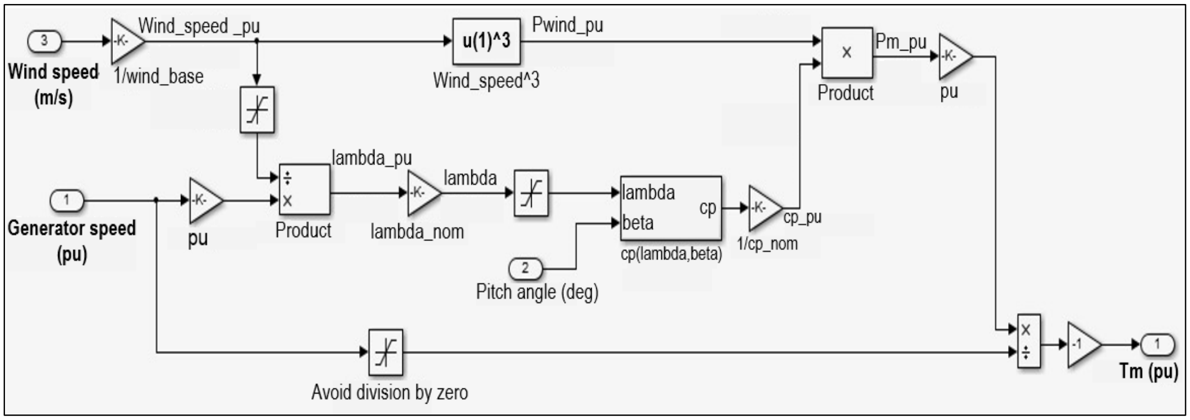

Figure 8. Wind turbine model in Simulink-Matlab software

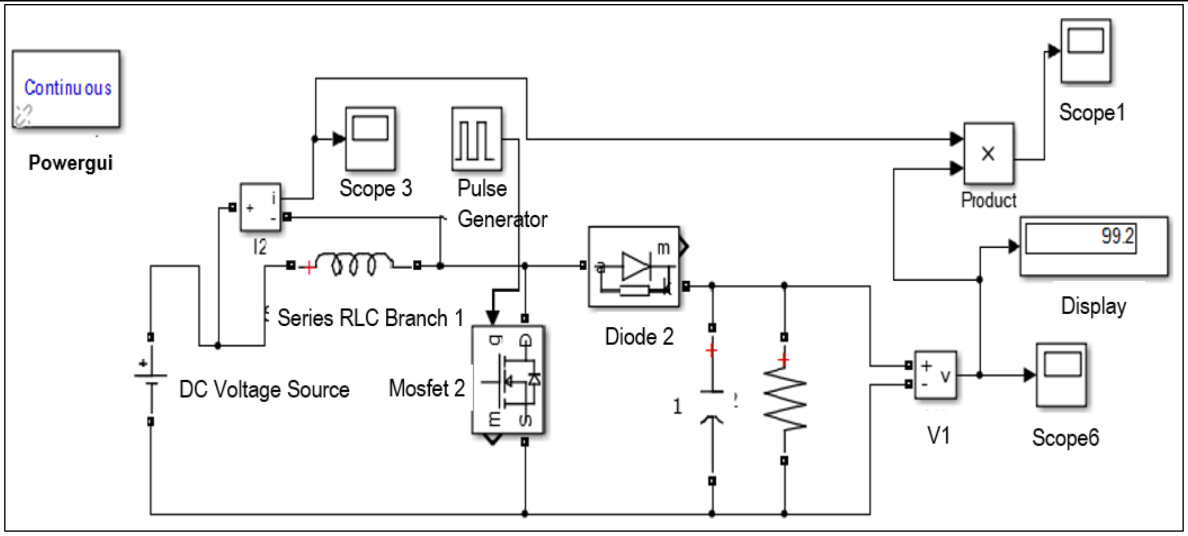

Figure 9. Boost converter model in Simulink-Matlab software

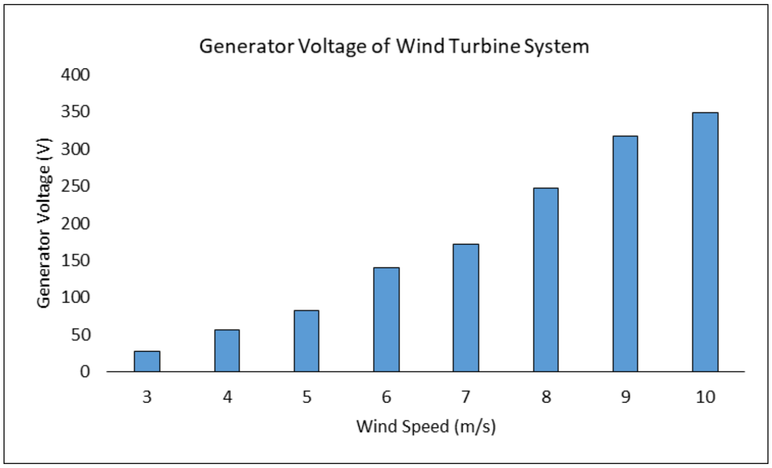

Figure 10. Generator voltage of wind turbine system

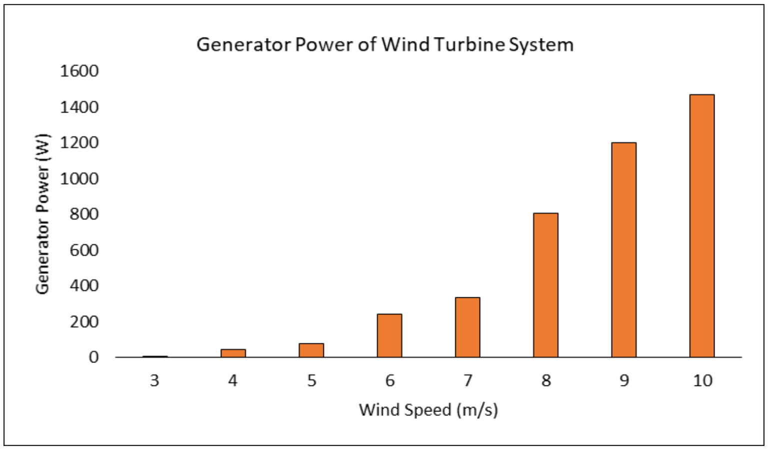

Figure 11. Generator output power of wind turbine system

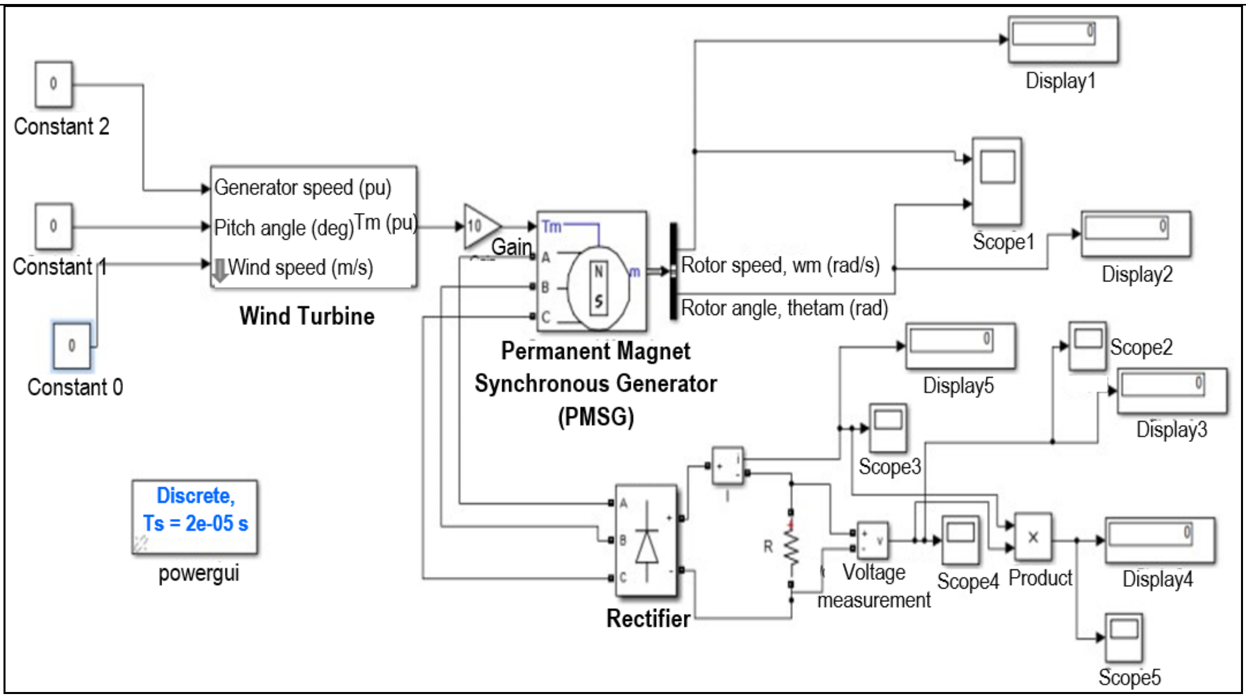

Figure 12. Wind turbine system without MPPT in Simulink-Matlab software

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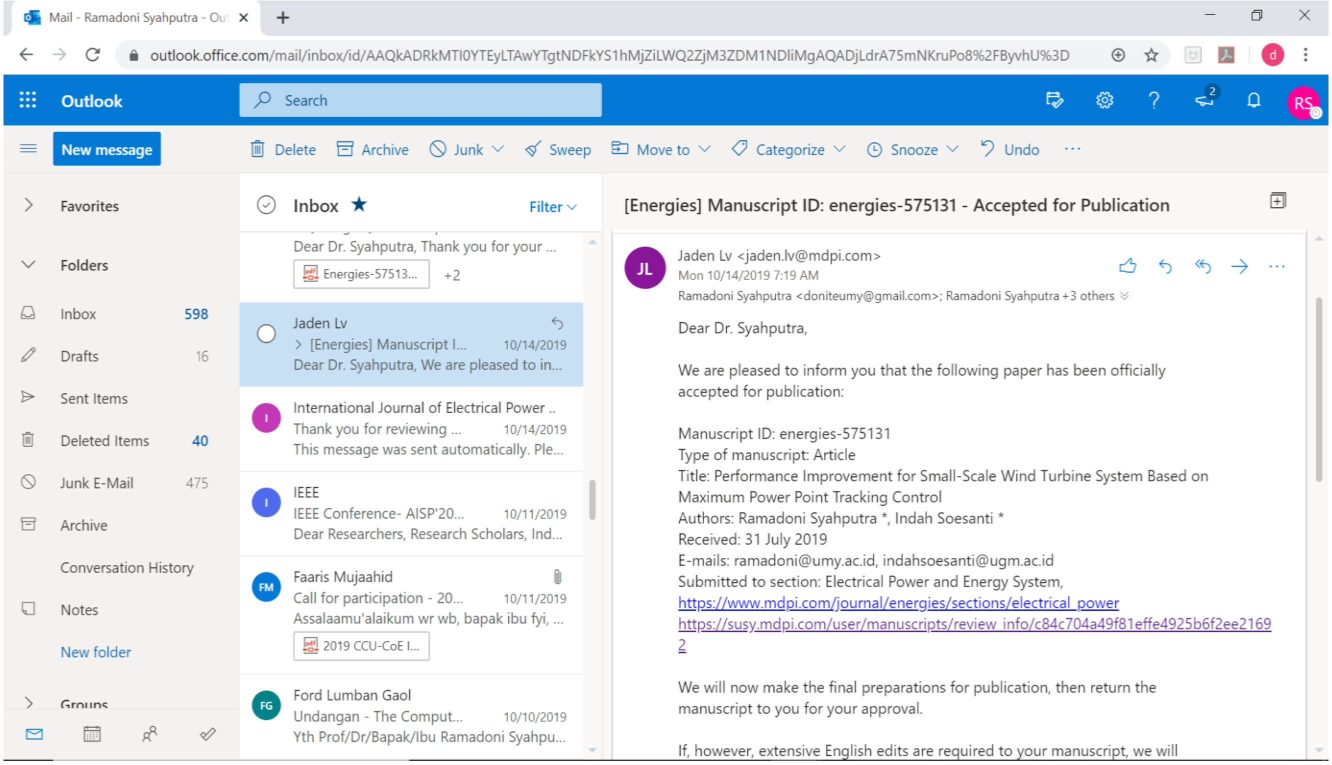

[Energies] Manuscript ID: energies-575131 - Accepted for Publication

Jaden Lv <jaden.lv@mdpi.com>
Mon 10/14/2019 7:19 AM
Ramadoni Syahputra <doniteumy@gmail.com>; Ramadoni Syahputra +3 others

Dear Dr. Syahputra,

We are pleased to inform you that the following paper has been officially accepted for publication:

Manuscript ID: energies-575131
Type of manuscript: Article
Title: Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control
Authors: Ramadoni Syahputra *, Indah Soesanti *
Received: 31 July 2019
E-mails: ramadoni@umy.ac.id, indahsoesanti@ugm.ac.id
Submitted to section: Electrical Power and Energy System,
https://www.mdpi.com/journal/energies/sections/electrical_power
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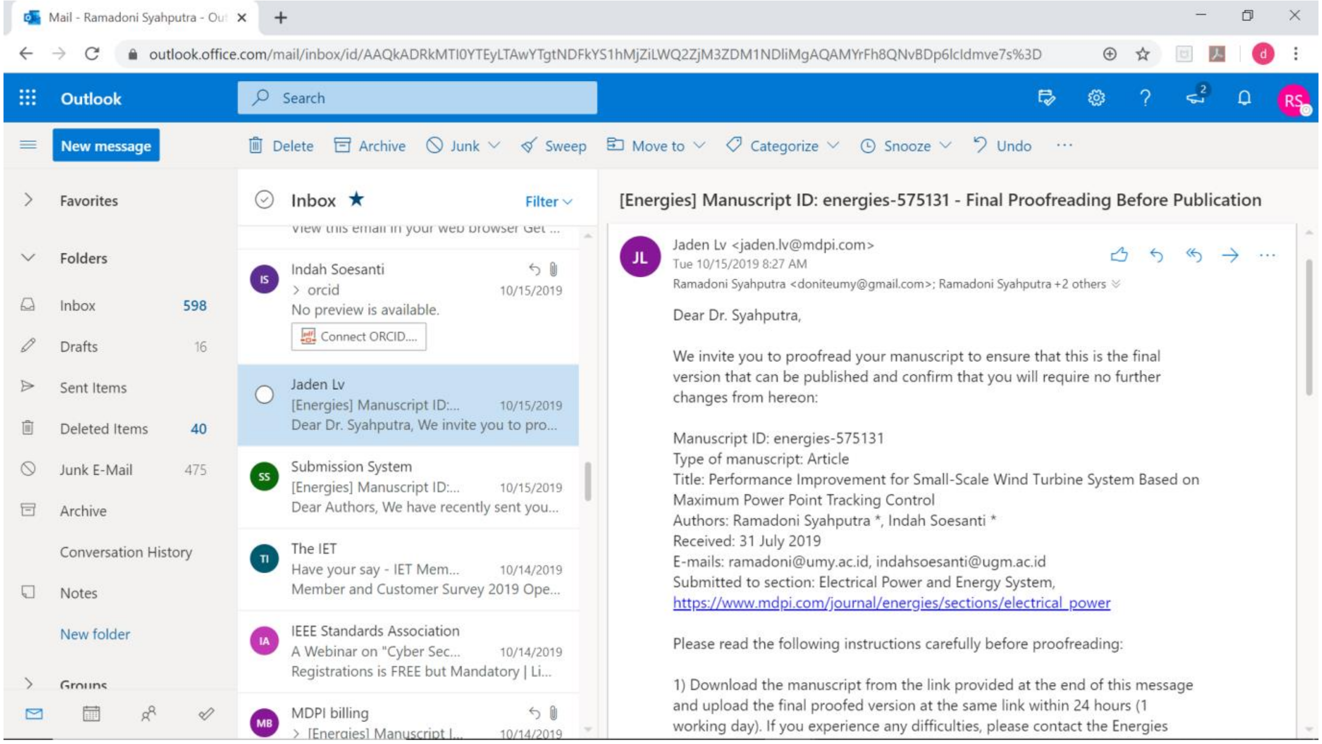
We will now make the final preparations for publication, then return the manuscript to you for your approval.

If, however, extensive English edits are required to your manuscript, we will

15-Oct-2019; Notifikasi dari Editor: **Final Proofreading Before Publication**



[Energies] Manuscript ID: energies-575131 - Final Proofreading Before Publication

Jaden Lv <jaden.lv@mdpi.com>
Tue 10/15/2019 8:27 AM
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Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control

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Abstract: This paper proposes a strategy for performance improvement of small-scale wind turbine systems using maximum power point tracking control (MPPT). In this study, wind-~~–~~turbine systems which use permanent magnet synchronous generators and converter devices are modeled in Simulink-Matlab software. In order to increase the power generated, MPPT is used based on the extended ~~P~~perturb and ~~O~~observe (PO) method. This algorithm has the ability to improve the speed of the turbine without oscillation. To analyze the ability of the PO-based MPPT in maximizing output power, performance examination of wind turbine systems in Simulink-Matlab software ~~were~~ was conducted. The study is carried out with a 3000 W wind turbine device serving various electrical loads of 50 Ω, 100 Ω, 200 Ω, and 300 Ω, and each ~~Ohm~~ ohm varies with a wind speed of 4, 5, 6.5, 7, 8.5, 9, and 10 m/s. The overall turbine system performance found that the maximum increase in system output power occurs when it is loaded with 200 Ω with a wind speed of 6.5 m/s. During this combination of 200 Ω and 6.5 m/s, there are high increments of output power at 135.62%~~,~~ caused by the installation of MPPT controllers, with an average output power increase of 50.77%. The results of this study proved that PO-based MPPT has successfully improved the performance of wind-~~-~~turbine systems.

Keywords: Small-scale wind turbine system; MPPT; Extended perturb and observe method; Renewable energy

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1. Introduction

Due to energy issues related to potential, inventory, technology, and environmental impacts, the necessity for renewable energy has become increasingly urgent. This fact is attributed to the easy availability of fossil energy and its proven negative impact on the environment [1]. People are realizing the importance of renewable energy as a source of electricity to power our world. Indonesia, as a tropical country, has also paid serious attention to renewable energy [2], with the government creating a goal of deriving 23% of national electricity from renewable energy sources by 2025. This contribution will be increased to 31% by 2050.

Recently, the Indonesian government has encouraged the development of wind power technology in an effort to reduce carbon emissions. A wind turbine in Indonesia has become increasingly popular owing to the fact that the location has ~~the~~ wind potential. ~~The w~~Wind is one of the most readily available renewable energy sources in Indonesia, most prevalently on the southern coast of Java and Sumatra Island, and the eastern islands. Based on data from the National Energy Blueprint, Ministry of Energy and Mineral Resources of the Republic of Indonesia, the potential of

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wind energy is 9.29 GW, but the utilization is still around 0.5 GW, 5.38% of the existing potential [3, 4].

Wind generates electrical energy through ~~the~~ turbines, which are characterized by ~~the~~ various types according to shapes and shafts. The wind turbine is connected with a generator that converts kinetic into electricity. Generators commonly used in conjunction with low- to medium-~~–~~scale wind turbines are called ~~P~~permanent ~~M~~magnet ~~S~~synchronous ~~G~~generators (PMSG) [5, 6]. The output of power generated by a PMSG varies depending on wind speed [7]. In order to maximize the output power of the generator, the ~~M~~maximum ~~P~~power ~~P~~point ~~T~~tracking (MPPT) controller is used to stabilize the maximum power [8, 9].

~~The m~~Methods for MPPT that are commonly used~~,~~ ~~including~~ include gradient approximation, artificial neural network method, fuzzy logic, particle swarm optimization, ant colony optimization, and the p~~P~~erturb and ~~O~~observe (PO) methods [10 - 14]. In the study of [15], stand-alone wind turbines and MPPT using the gradient approximation method is carried out. ~~It~~ This works by measuring the voltage and current, then changing the duty cycle in the direct current (DC~~-~~)-DC converter to obtain the maximum power. The alternating current (AC) output voltage used single phase full bridge inverter. Simulation results show that the maximum power ratio without MPPT is 79.41%, while with it, the maximum power is 94.51%. The results of this study indicate that wind turbines have a higher average power when using MPPT.

Furthermore, research [16] shows that MPPT technology is used to regulate the output voltage of the generator through a DC-~~–~~DC c~~C~~onverter circuit, where the switching technique uses ~~P~~pulse ~~W~~width ~~M~~modulation (PWM) by adjusting the duty cycle. The change of the duty cycle value depends on the wind speed. Therefore, a f~~F~~uzzy ~~L~~logic ~~C~~controller (FLC) algorithm is used to set the cost as well as accelerate the PWM control-~~–~~switching response. The results showed that with FLC-based MPPT technology, the efficiency of power output is increased from 45.5% to 87%.

The objective of this study is to improve the performance of generators in wind-~~–~~power plants so that the power generated is always maximum. The technique used is the control strategy using the ~~Maximum Power Point Tracking (~~MPPT~~)~~ controller. In this MPPT, a control method is applied, namely the extended ~~Perturb and Observe (~~PO~~)~~ method. The ~~Perturb and Observe (~~PO~~)~~ ~~ ~~-based MPPT algorithm has been widely used in searching for maximum power values [17] due to its simplicity. Furthermore, the use of the PO does not require wind speed information and turbine parameters, and it is faster and more efficient in searching the maximum point of power. However, it has the disadvantage of producing oscillations under steady-state conditions due to constant duty cycle changes. Therefore, modifications were made in the study, combining the PO and predictive method. Both methods work alternately according to current and voltage conditions on the input side of the converter. Predictive methods are used to determine the magnitude of step changes in the PO algorithm, the larger the voltage, the larger the step size used, and vice versa. The combination of the PO and predictive method applied to the MPPT technique for optimizing the generator output power of wind power systems is the novelty of this research. The technique used in the MPPT is the extended PO algorithm. The algorithm contains the foundations of standard PO, with changes to the step size value of each iteration according to the response of the system based on the predefined C constant. The modification of the method ~~is resulting~~ results in faster convergence of the computation.

2. Small-Scale Wind-~~–~~Turbine System

The Indonesian government has encouraged the development of wind-~~–~~power technology in an effort to reduce carbon emissions. The wind turbine in Indonesia has become increasingly popular owing to the fact that the location has ~~the~~ wind potential. Indonesia is located in a tropical climate area, with moderate wind potential at speeds ranging from 3 m/s to 15 m/s [18]. Wind-~~–~~turbine systems are commonly used for smaller scales [19]. The turbine works to convert the kinetic energy in the wind to mechanical energy via rotation by generating a torque. The magnitude of the kinetic energy depends on air density and wind speed [7]. Equation (1) expresses the electric power of the wind-~~–~~turbine system as follows:

$$P = 0.5\ C_p\ \rho\ A\ v^3 \tag{1}$$

As can be seen in E~~e~~quation (1), the coefficient of C_p generates a fraction of the kinetic energy converted into mechanical energy caused by the wind turbine. Some factors contribute to determining the wind-~~–~~turbine power, such as the ratio of tip speed λ. This wind speed ratio depends on the angle of the pitch blade for the turbine controlled by the pitch. The speed ratio can be defined as a correlation between the linear speed of the turbine blade and the wind velocity, which can be expressed by the following E~~e~~quation (2)~~.~~:

$$\lambda = r\ \omega / v \tag{2}$$

Substituting equation (2) in (1), the electric power that a wind turbine system is as follows,

$$P = 0.5\ C_p\ \lambda\ \rho\ A\ (r/\lambda)^3(\omega)^3 \tag{3}$$

Further torque can be calculated using the following ~~e~~Equation (4)~~.~~:

$$P = 0.5\ C_p\ \rho\ A\ (v/\lambda) \tag{4}$$

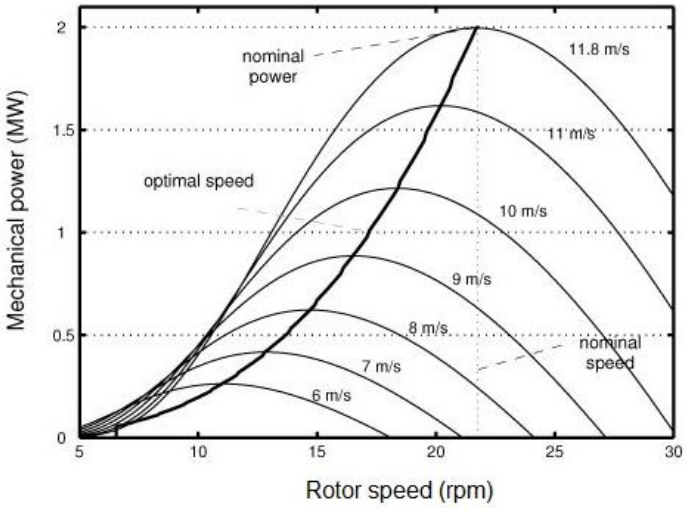

Figure 1. Wind turbine characteristics with pitch angle of 0°.

Based on (4), it can be concluded that the value of the ratio of speed at which the coefficient of power reaches a maximum is possible. Wind turbines can generate maximum electrical energy by optimizing the tip speed ratio λ, achieved by adjusting the pace of the blade according to the wind speed. Figure 1 shows the power generated at different winds with a pitch angle of 0^0, indicating divergent speeds leading to a difference in output power. The mechanical power is dependent on the rotation speed, as shown by the winds ranging from 4 m/s to 10 m/s. Based on this example, the nominal wind speed that produces nominal mechanical power (1 p.u. = 3 MW) is 9 m/s. A complete list of quantity symbols is presented in Table A1 in the Appendix.

3. Maximum Power Point Tracking Control (MPPT) Control Using Extended Perturb and Observe (PO) Algorithm

3.1. MPPT Control for Small-Scale Wind-Turbine System

Figure 2 shows the typical diagram of a wind turbine system, composed of a turbine and PMSG generator that both serve to convert wind into mechanical energy, a generator-side converter that rectifies the 3 phase ~~ac~~ AC electrical voltage into ~~dc~~DC, and a boost converter. There is also an MPPT

Controller which maximizes the output power, and a grid-side converter that turns dc electrical voltage into ac [20]. Furthermore, the output from the inverter can be integrated into the grid of the distribution system.

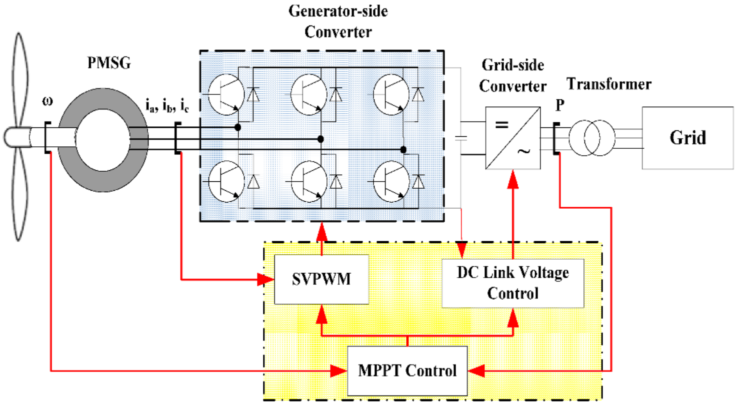

Figure 2. Typical diagram of wind ~~-~~turbine system.

A wind turbine is a piece of equipment for converting wind energy into mechanical energy. As expressed in E~~e~~quation (4) that the power produced by the wind turbine (P) is the result of a process of half the mass density of the air type (ρ) with the area of cross-sectional coverage (A) and the power of the wind velocity (v^3). Wind energy drives the turbine rotor connected to the generator to create electrical energy. The maximum output power of the wind turbine is limited to the power coefficient (C_p), a function of tip speed ratio λ, rated from 25% to 45%. Based on the experimental results, this value will not exceed 59.3%. A generator is a tool to convert mechanical energy into electricity, changing the torque (T) and rotational speed of the rotor (ω) it receives from the blade into voltage (V) and current (I) values. The output of this generator is 3-phase AC voltage.

The ~~Permanent Magnet Synchronous Generator (~~PMSG~~)~~ does not require an excitation system because its source is provided by a permanent magnet on the rotor [7], therefore eliminating the need for voltage control, simplifying the overall system. A PMSG is usually ~~used~~ employed to generate electrical energy in wind turbines with low to medium power capacity. It is suitable for small scale power generators, hence useful in the Indonesian region where wind speeds are not too high. The advantage of using a PMSG is ~~the~~ its low cost, durability, simplicity, and more straightforward clutch grid, however, a significant disadvantage is its need for smaller power factor and efficiency compensators [21].

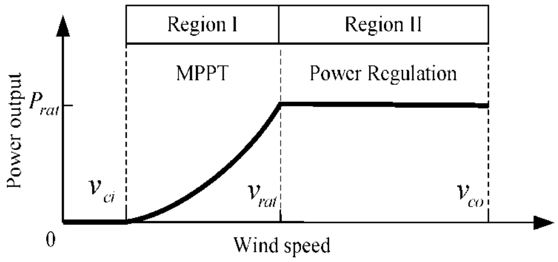

Figure 3. Ideal power curve in wind turbines with varying wind speeds.

The wind ~~-~~energy system extracts ~~the~~ wind energy and converts it to electrical energy. The output power of the wind energy system varies depending on the wind speed [22,23]. When wind speed is below the expected value, an MPPT is required to produce maximum power. The generator load is adjusted when the turbine ratings are smaller than the wind speeds. Figure 3 shows the ideal power curve in turbines with varying wind speeds. Region I illustrates areas where MPPT maximizes turbine power, while Region II portrays its regulation.

MPPT is the method of tracking the maximum power value of a power-~~-~~plant system [24,25], in order to produce higher levels of efficiency. The working principle is to increase and decrease the voltage by adjusting the duty cycle on the power side converter. However, with MPPT, the maximum power output from the generator can be optimized. The methods used in MPPT vary according to the algorithm used; this study used an extended PO.

3.2. Extended Perturb and Observe Algorithm

The PO algorithm can be used to determine the ~~optimum~~ optimal point of a system [17]. In this study, the ~~optimum~~ optimal point is the maximum power value that a PMSG generator can achieve in a wind turbine system. The maximum power value is obtained by adjusting the dc voltage on the generator side converter, which in turn changes the output power. To monitor and manage these changes, a certain step-size (ΔD) and time need to be specified: that is the output power generated compared to previous electrical power, so that the power changes (ΔP) and the next variable ΔD can be determined. If the generated power increases, then the variable ΔD will be fixed, if it decreases, then the ΔD will change. The working principle of this extended PO algorithm can be seen in the flow chart in Figure 4 and Figure 5, with several parameters in the initial value to calculate the change of step size value in each iteration done. Furthermore, it is necessary to identify the limit of the duty cycle in running this algorithm to maintain the ability of the buck converter. Figure 4 shows the standard PO method, while Figure 5 shows the extended PO method used in this study.

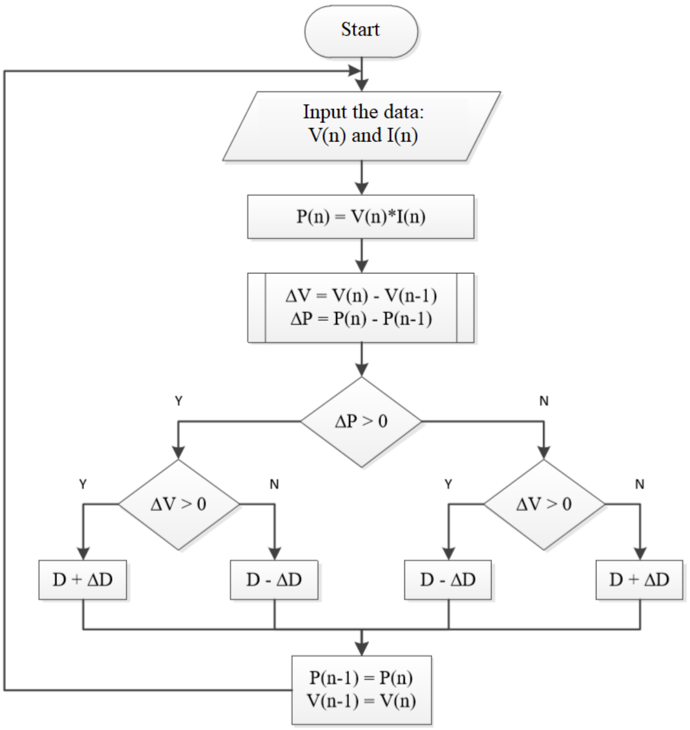

Figure 4. Flow chart of the standard perturb and observe (PO) algorithm.

Based on the analysis and literature study, the standard version of the PO algorithm (Figure 4) has disadvantages, including the time taken to reach a relatively slow convergence and high oscillation in maximum power search. However, this weakness can be overcome by changing the value of ΔD used to find the maximum point value of power generated, where the quantity of ΔD

will be multiplied by a constant value of 0–1. When the system has reached the maximum power point then *ΔD* automatically decrease. The working principle of the extended PO algorithm can be seen in Figure 5.

The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of *ΔD*, resulting in faster convergence of the computation.

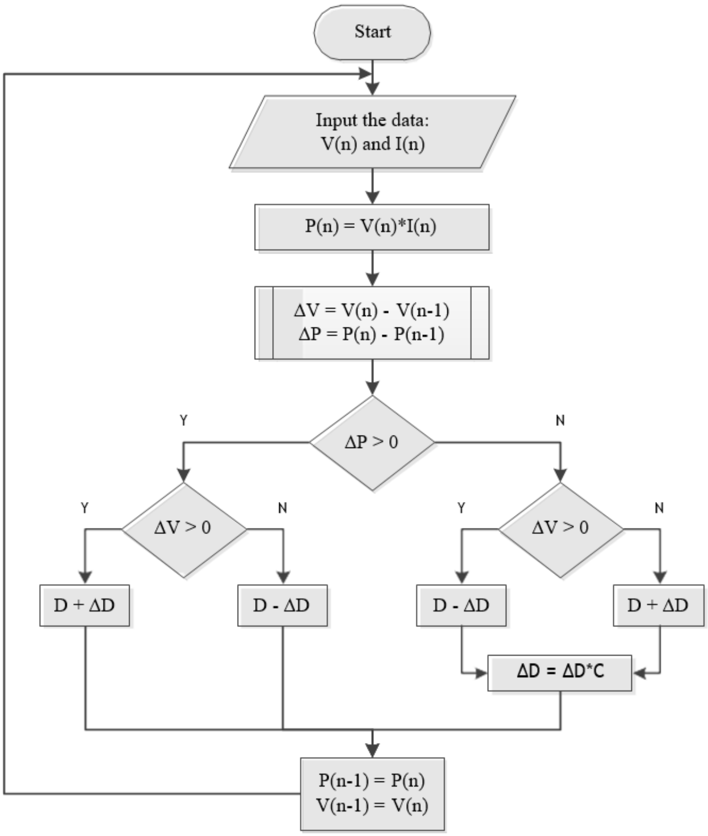

Figure 5. Flow chart of the extended perturb and observe algorithm.

This extended PO algorithm contains the foundations of the original, with changes to the value of the step size of each iteration according to the response of the system based on the predefined *C* constant. The duty cycle value limit is also specified in order to keep the system working in accordance with the capabilities of the buck converter. Time delay running the program in a one-time iteration is to respond due to changes in the given duty cycle.

4. Results and Discussion

4.1. Model of Wind–Turbine System

This study analyzes the wind–turbine system modelled by the Simulink-Matlab software. The system comprises a wind turbine, PMSG, a rectifier, MPPT, and an inverter. The turbine converts wind into mechanical energy, the PMSG transforms the mechanical energy into electricity, and the rectifier ensures that the ~~ac~~ AC electrical voltage is transformed into ~~dc~~ DC electrical current. Furthermore, the MPPT maximizes the output power of the wind turbine system, and the inverter converts the ~~dc~~ DC into ~~ac~~ AC voltage. The block diagram of the wind turbine system with MPPT and circuit diagram are shown in Figure 6 and Figure 7.

Table 1. Parameters of wind turbine in this study.

Parameters	Quantities and Units
Nominal mechanical output power	3000 W
Base power of the electrical generator	3000/0.9 VA
Base wind speed	12 m/s
Maximum power at base wind speed of nominal mechanical power	0.73 p.u.
Base rotational speed of base generator speed	1.2 p.u.
Pitch angle beta to display wind turbine power characteristics	0

The parameters used in this study are shown in Table 1, where the mechanical output of power is 3000 W. It has a base electrical generator power of 1,111.11 VA and a base wind speed of 12 m/s. The maximum power at base wind speed is 0.73 p.u, while the base rotational speed of the generator is 1.2 p.u. The pitch angle employed is 0^0.

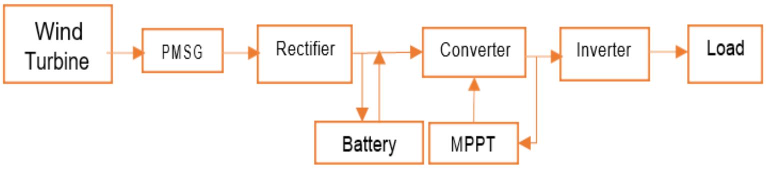

Figure 6. Block diagram of the wind turbine system with maximum power point tracking (MPPT).

Table 2. Parameters of permanent magnet synchronous generator (PMSG).

Parameters	Quantities and Units
Back EMF waveform	Sinusoidal
Rotor type	Salient pole
Mechanical input	Torque (Tm)
Stator phase resistance	0.00867 Ω
Inductances (L_d)	0.00286 H
Inductances (L_q)	0.00344 H
Flux linkage	0.175 V.s.
Voltage constant	126.966 Ω
Torque constant	1.05 N.m.

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Wind turbine circuit diagram system with MPPT in the Simulink software, as shown in Figure 7, is an implementation of a block diagram of the wind turbine system with MPPT, as shown in Figure 6. The wind turbine model in Simulink-Matlab software is presented in Figure 8.

There are three inputs and one output of the system, as shown in Figure 8. The first input is the speed of the generator from the rotor. There is a pitch angle measured in degrees, and in this study, we use 0^0. The third input is the wind speed in m/s, adjusted for the simulated conditions, namely both are constant and changing. The output of the turbine is the mechanical torque of the rotation. The turbine is then connected to the PMSG generator.

This wind turbine system is adapted to speeds ranging from 3 to 15_m/s, with optimal occurrence between 11:00 AM to 02:00 PM. Along with this condition, the off-grid system is required to store the electrical energy produced. In this study, the generator used is a 3-phase PMSG type, as shown in Table 2. The 3-phase power voltage generated uses a rectifier to achieve a 48_V ~~dc~~ DC voltage, which can be connected to the battery, a converter, and an inverter to serve electric loads. As shown in Figures 1 and 2, the MPPT is used to optimize generator voltage through rectifiers at boost converter locations. Furthermore, rectifier parameters are used in this study, as shown in Table 3. The power used is a bridge-type, where the RC snubber circuits are connected to each switch device in parallel form.

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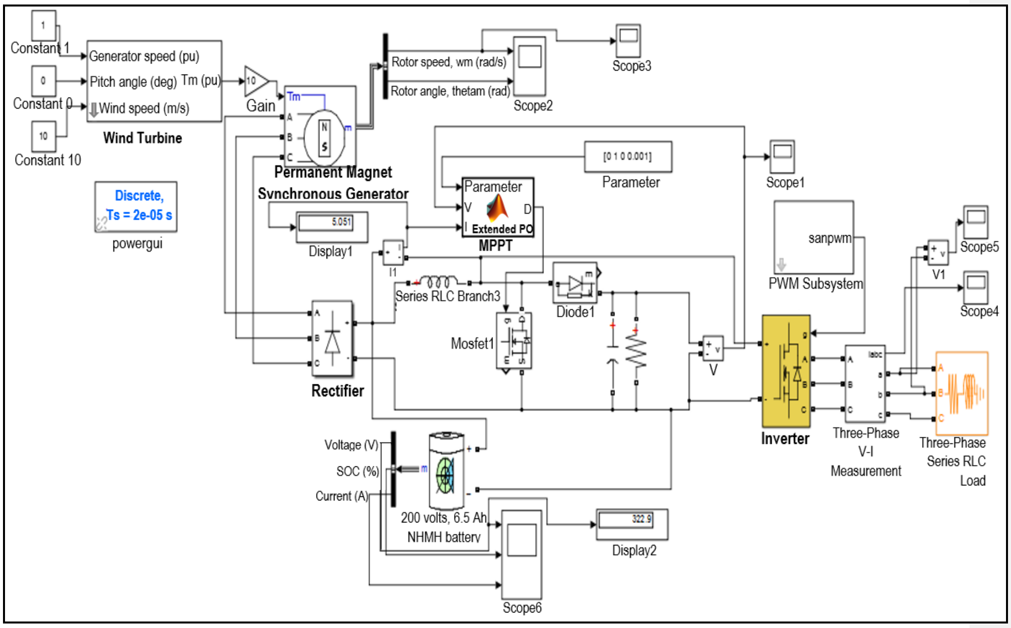

Figure 7. Wind turbine circuit diagram system with MPPT in the Simulink-Matlab software.

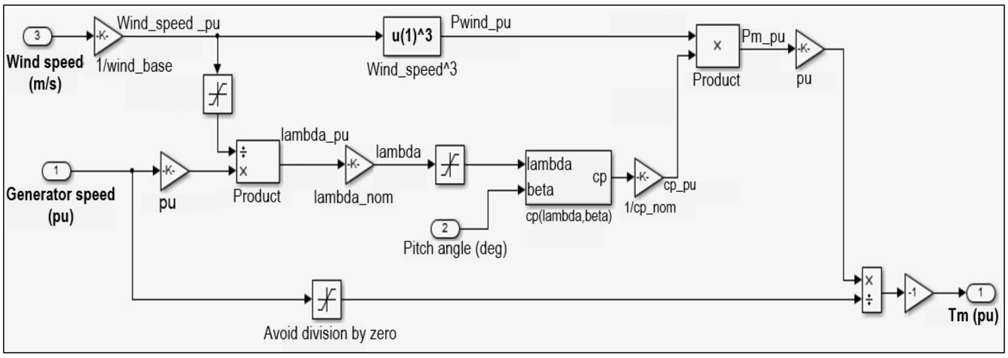

Figure 8. Wind turbine model in Simulink-Matlab software.

Figure 9 shows the model of the boost converter circuit in Simulink-Matlab. The parameters in the boost converter are shown in Table 4. In order to determine the boost converter circuit, an input voltage (V_{in}) of 100 V, is used to test the system, as shown in Figure 10. Results obtained prove that the model is able to produce the required voltage. Table 4 shows battery parameters, while the inverter, which is a bridge of selected power electronic devices consisting of RC snubber circuits connected in parallel with each switch device is shown in Table 5.

Table 3. Parameters of rectifier.

Parameters	Quantities and Units
Number of bridge arms	3
Snubber resistance (R_s)	100 Ω
Snubber capacitance (C_s)	0.1 µF
Power electronic device	diodes
Forward voltage (V_f)	0.8 V

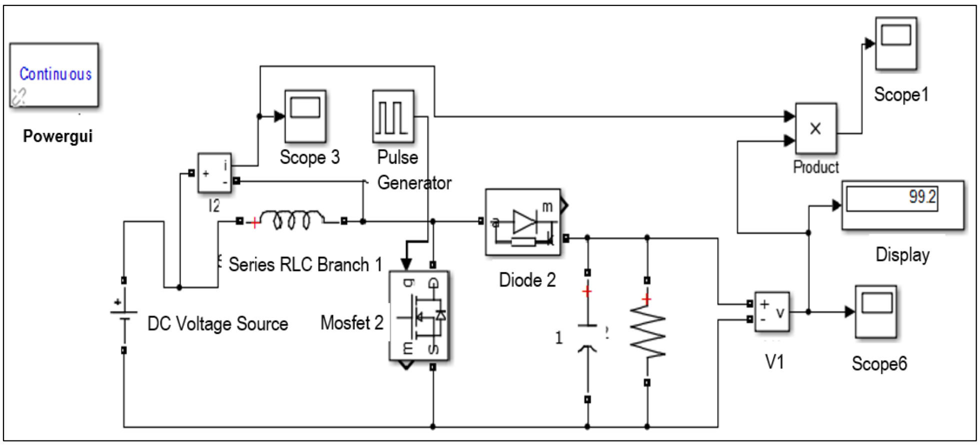

Figure 9. Boost converter model in Simulink-Matlab software.

Table 4. Parameters of battery.

Parameters	Quantities and Units
Nominal voltage	300 V
Rated capacity	6.5 Ah
Initial state of charge	60%
Maximum capacity	7 Ah
Fully charged voltage	353.39 V
Nominal discharge current	1.3 A
Internal resistance	0.4615 Ω
Capacity at nominal voltage	6.25 Ah
Exponential zone	325.42V, 1.3 Ah

Table 5. Parameters of inverter.

Parameters	Quantities and Units
Snubber resistance	100k Ω
Snubber capacitance	Infinite
Power electronic device	Mosfet, diodes
Internal resistance	0.001 Ω

4.2. Evaluation of Perturb and Observe Algorithm

In the PO algorithm, the quantity of input is voltage, and the output is the current of PMSG generator. These voltages and currents are further utilized in order to obtain ~~a more~~ an ~~optimum~~ optimal output, as shown in Figure 7. The following stages are involved in the ~~Perturb and Observe~~ PO algorithm process.

1) Initial voltage measurement is determined to study the exact value of the current PMSG generator output voltage.
2) The p~~P~~ower PMSG generator is measured to determine its current value.
3) The power difference is calculated to actuate the difference between the present and the previously measured power.
4) The voltage and power are compared to figure out the process involved in the changes. From this comparison, the generator voltage will be larger or smaller, depending on the generator power and measured voltage differences.
5) If the above stages turn out to be successful, step 1 is repeated.

Table 6. Results of the PO algorithm validity test.

Number of Experiments	Wind Speed (m/s)	Turbine Rotation (rpm)	Load Resistance (Ω)	Output Power (W)
1	10	508.06	200	2032
2	10	508.06	200	2032
3	10	508.06	200	2032
4	10	508.06	200	2032
5	10	508.06	200	2032
6	10	508.06	200	2032
Mean	10	508.06	200	2032
Standard deviation	0	0	0	0

After the PO algorithm is ~~made~~ applied to ~~on~~ the wind ~~–~~turbine system, its validity and sensitivity are evaluated. In this study, the algorithm is valid if the standard value of deviation is less than 1% in 6 experiments. This fact is also similar to its sensitivity, which is also conducted by changing the wind speed.

A validity test is carried out to examine the results using the PO algorithm, and by conducting repetitive experiments for fixed parameters with a particular input, followed by an observation of mean and standard deviation from the experimental data. In this test, a winding rate of 10 m/s is used as an input with fixed turbine ~~-~~system parameters. The results of the algorithm validity test are shown in Table 6.

Table 7. Results of the PO algorithm sensitivity test.

Wind speed (m/s)	**Generator Voltage (V)**	**Output Power (W)**
3	27.92	8.22
4	57.07	43.89
5	82.21	78.02
6	140.03	242.13
7	171.41	334.23
8	247.24	809.31
9	316.90	1201.18
10	348.62	1472.34

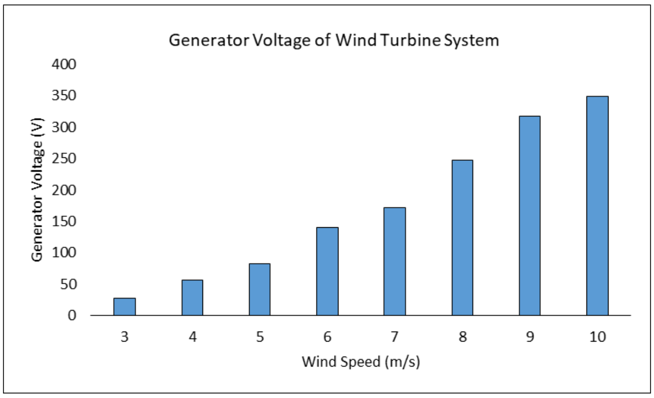

Figure 10. Generator voltage of wind--turbine system.

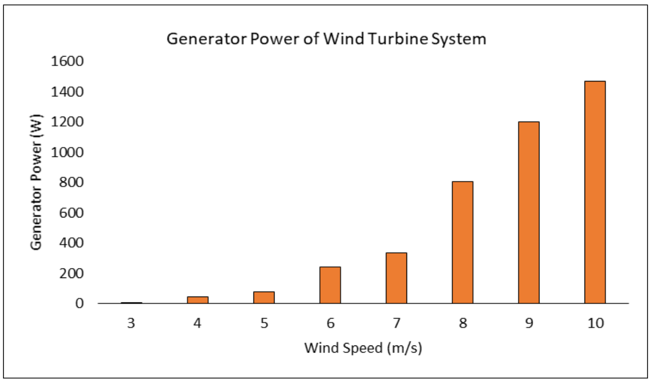

Figure 11. Generator output power of wind--turbine system.

The test resulted to a standard deviation value of 0, which means that the optimization procedure produced the same value in each experiment; hence, the output power of the wind-turbine system can be categorized as valid.

In order to determine the effect of the changes associated with the parameter values, a sensitivity analysis of the PO algorithm is tested by varying the value of the wind speed between 3 to

10 m/s with a fixed power generator value of 3000 W. In this experiment, 100 Ω resistance was used, and results obtained are shown in Table 7 and Figure 10. From the experimental results, it can be seen that the higher the wind speeds the more significant the voltage and power of the generator. This fact is because the rotor speed increases with a rise in wind speed, which also affects the power generated. The results of experiments in Table 7 and Figure 11 also prove that same.

4.3. Performance Test of Wind–Turbine System

In this section, a test is conducted on the wind turbine systems in order to improve the performance. Figure 12 and Figure 13 are used to test the Simulink Matlab performance with the installation of MPPT controllers. Test results of the system performance with and without the MPPT controller are shown in Table 8.

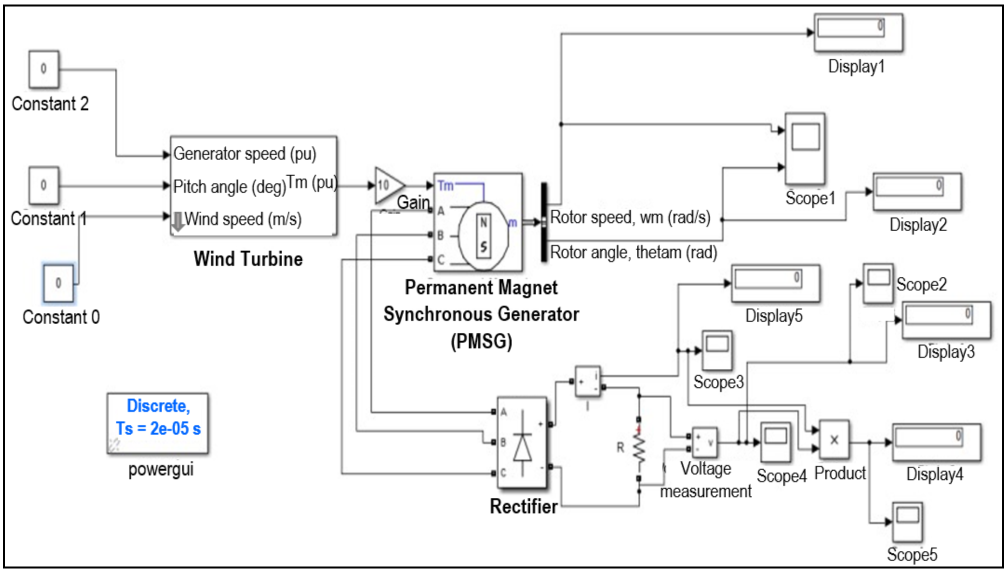

Figure 12. Wind–turbine system without MPPT in Simulink-Matlab software

Table 8 shows the results of the wind turbine system performance test from simulations in Figure 12 and Figure 13. The performance test is carried out with a 3000 W wind turbine with electrical loads of 50 Ω, 100 Ω, 200 Ω, and 300 Ω, respectively in order to assess the performance of the turbine while serving the increased load with and without the MPPT controller.

As seen in Table 8, the greater the electrical load served, the higher the output power of the PMSG generator from the wind turbine. The most considerable output power is obtained when the system serves the highest electrical load of 300 Ω. Furthermore, the electrical load, and wind speed variation, on the prevailing wind conditions in Indonesia (i.e., 4, 5, 6.5, 7, 8.5, 9, and 10 m/s), is examined. Overall, the MPPT controller is able to increase the wind turbine system's power output significantly. The average power increase after installing the MPPT controller using the PO algorithm is 50.77%. The results are presented in graphical form to clearly analyze the effect of the MPPT controller on various wind speed variations, as shown in Figures 14, 15, 16, and 17.

Table 8. Results of performance test of wind–turbine system.

Load resistance (Ω)	Wind speed (m/s)	Performance test variables of wind turbine system						
		Without MPPT			With MPPT			Power increasing (%)
		Output voltage	Electric Current	Output power	Output voltage	Electric Current	Output power	

		(V)	(A)	(W)	(V)	(A)	(W)	
50	4	33.76	0.67	22.62	33.83	0.69	23.34	3.20
	5	54.09	1.08	58.42	60.05	1.15	69.06	18.21
	6.5	71.51	1.43	102.26	73.21	1.53	112.01	9.54
	7	83.03	1.66	137.83	85.92	1.81	155.52	12.83
	8.5	124.24	2.42	300.66	130.54	2.77	361.60	20.27
	9	140.41	2.81	394.55	147.52	3.14	463.21	17.40
	10	174.35	3.49	608.48	183.81	3.95	726.05	19.32
100	4	62.63	0.62	38.83	66.24	0.75	49.68	27.94
	5	95.09	1.09	103.65	119.12	1.12	133.41	28.72
	6.5	137.64	1.38	189.94	149.02	1.81	269.73	42.00
	7	160.12	1.62	259.39	171.41	2.05	351.39	35.47
	8.5	238.23	2.35	559.84	265.5	3.62	961.11	71.68
	9	269.32	2.69	724.47	296.04	4.07	1204.88	66.31
	10	335.09	3.35	1122.55	348.61	4.45	1551.31	38.20
200	4	116.51	0.58	67.58	134.81	1.14	153.68	127.42
	5	189.89	0.89	169.00	215.66	1.65	355.84	110.55
	6.5	240.64	1.23	295.99	280.08	2.49	697.40	135.62
	7	299.11	1.49	445.67	315.31	2.65	835.57	87.48
	8.5	376.07	1.88	707.01	431.62	2.92	1260.33	78.26
	9	438.01	2.51	1099.41	485.41	3.26	1582.44	43.94
	10	547.11	2.73	1493.61	586.44	3.53	2070.13	38.60
300	4	166.03	0.55	91.32	184.25	1.03	189.78	107.82
	5	234.09	0.89	208.34	256.05	1.35	345.67	65.92
	6.5	354.81	1.18	418.68	360.26	1.93	695.30	66.07
	7	426.22	1.44	613.76	412.06	2.07	852.96	38.97
	8.5	574.05	1.93	1107.92	589.92	2.48	1463.00	32.05
	9	483.15	2.18	1053.27	658.09	2.69	1770.26	68.07
	10	902.72	3.04	2734.67	817.71	3.72	2999.88	9.63
Average of power increasing (%)								50.77

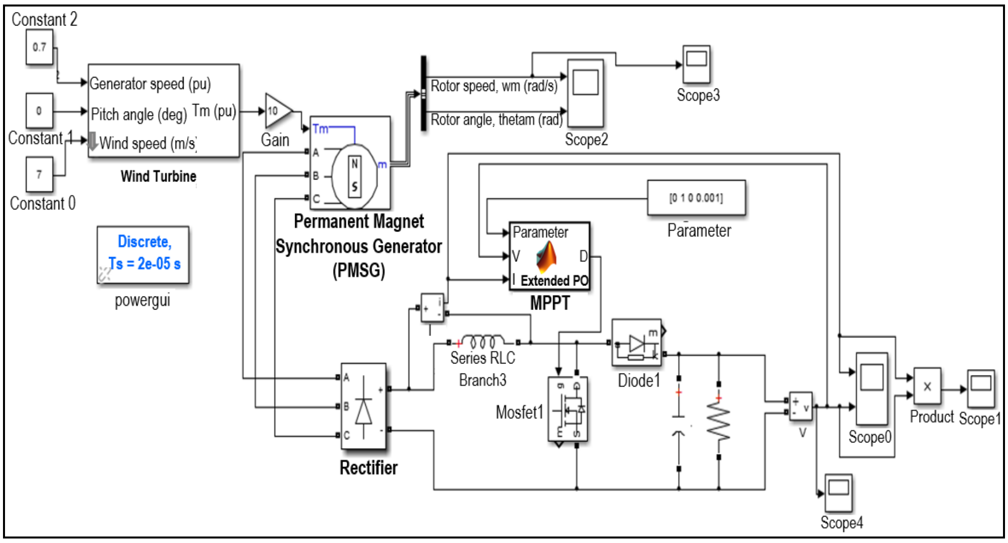

Figure 13. Wind-turbine system with MPPT in Simulink-Matlab software.

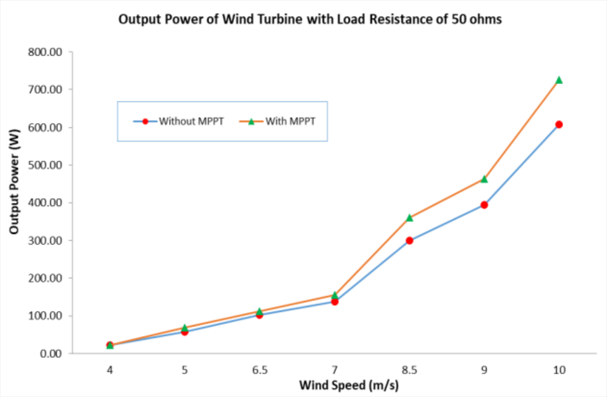

Figure 14. Output power of wind-turbine system with load resistance of 50 Ω.

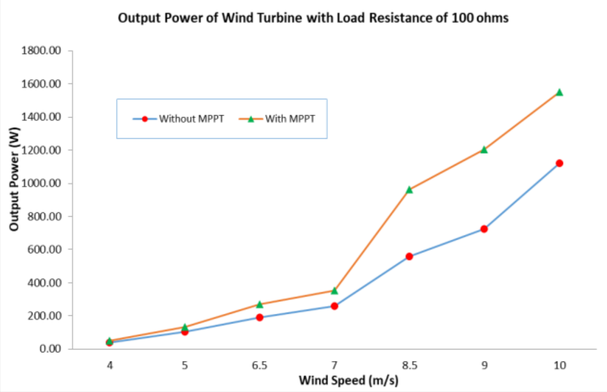

Figure 15. Output power of wind--turbine system with load resistance of 100 Ω.

Figure 14 shows the output power of the wind-turbine system with a load resistance of 50 Ω. At wind speeds of 4m/s, the turbine system without MPPT produces 33.76 V, and at an electrical current of 0.67 A, and the output power of the turbine is 22.62 W. The application of an MPPT controller on the PMSG generator side converter generated both voltage and current of 33.83 V and 0.69 A, respectively, resulting in output power of 23.34 W. In this case, the system output power is increased by 3.20% before implementing the MPPT controller. Furthermore, the system performance test with wind speeds of 5, 6.5, 7, 8.5, 9, and 10 m/s, respectively, were examined. Based on the graph in Figure 14, it can be concluded that the higher the wind speed that hits the turbine, the greater the voltage, current, and output power with the best output recorded at 10 m/s. The condition without MPPT produced a voltage of 174.35 V with a load current of 3.49 A, thereby, generating power of 608.48 W.

Furthermore, with the application of the MPPT controller, there is an increase in voltage, load current, and system output power of 183.81 V, 3.95 A, and 726.05 W, respectively. When compared to the condition before the application, an increase in system output power by 19.32% is displayed. Based on the graph in Figure 14, the best performance of the MPPT controller in increasing the output power occurs precisely at wind speeds of 8.5 m/s, where the percentage increase in output power is 20.27%. Overall, it can be seen that the MPPT controller using the PO algorithm has successfully improved the performance of wind turbine systems.

The output power of the wind turbine system with a load resistance of 100 Ω is shown in Figure 15. At a wind speed of 4 m/s, and without MPPT, the system produces a voltage of 62.63 V and an electric current of 0.62 A to serve the load resistance of 100 Ω, with an output turbine power of 38.83 W. Furthermore, the application of the MPPT controller on the PMSG generator side converter, as well as the voltage and current generated was 66.24 V and 0.75 A, respectively, resulting in output power of 49.68 W. This result means that the system output power is increased by 27.94% compared to when the MPPT controller ~~wasn't~~ was not implemented. Furthermore, the system performance test with a wind speed of 5, 6.5, 7, 8.5, 9, and 10 m/s, was examined. Based on the graph in Figure 15, it can be seen that the higher the wind speed, the greater the voltage, current, and output power of the system. The results show that the best output is produced with a wind speed of 10 m/s. Without applying the MPPT, the voltage produced was 335.09 V with a load current of 3.35 A, and power of 1,122.55 W.

Furthermore, with the application of the MPPT, there is an increase in voltage, load current, and system output power of 348.61 V, 4.45 A, and 1,151.3 W, respectively. When compared to the condition before the application of the MPPT, an increase in system output power by 38.20% is noticed. Based on the graph in Figure 15, it can also be seen that the best performance of the MPPT controller in increasing the output power of the system occurs precisely at the of 8.5 m/s wind speed, where the percentage increase in output power is 71.68%. Overall, it can be seen that the MPPT controller using the extended PO algorithm has successfully improved the performance of wind-turbine systems.

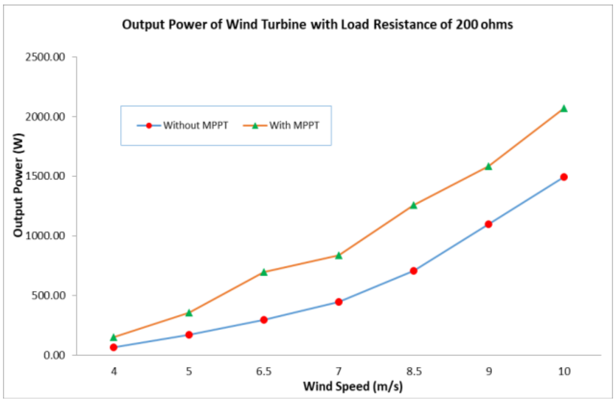

Figure 16. Output power of wind turbine system with load resistance of 200Ω.

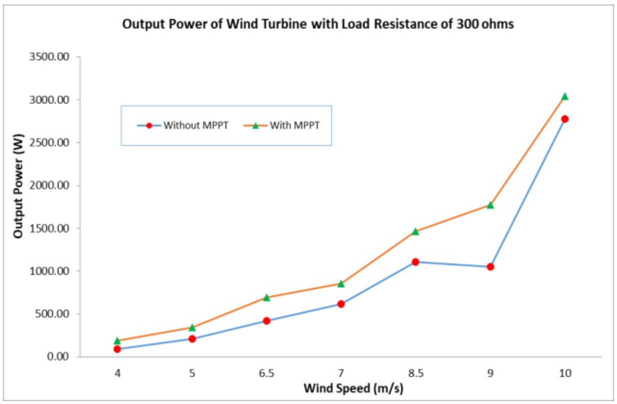

Figure 17. Output power of wind~~-~~-turbine system with load resistance of 300 Ω.

Figure 16 shows the output power of the turbine system with a load resistance of 200 Ω. At a wind speed of 4 m/s, and without implementing the MPPT, it produces a voltage of 116.51 V and electric current of 0.58 A to serve the load resistance of 200 Ω with an output power of 67.58 W. Along with the application of the MPPT controller on the PMSG generator, both voltage and current of 134.81 V and 1.14 A were generated, which resulted in output power of 153.68 W. Furthermore, the system performance test with wind speeds of 5, 6.5, 7, 8.5, 9, and 10 m/s, respectively, was examined. Based on the graph in Figure 16, it can be seen that the higher the wind speed, the greater the voltage, current, and output power of the wind turbine system. The results show that at a wind speed of 10 m/s, the system produces the optimal output.

Similarly, without implementing the MPPT, 547.11 V with a load current of 2.73 A were produced, which generated a total power of 1493.61 W. However, with the application of the MPPT controller, an increase in voltage, load current, and system output power of 586.44 V, 3.53 A, and 2070.13 W, respectively, was recorded. When compared to the condition before the application of the MPPT, the system output power is increased by 38.60%. Based on the graph in Figure 16, it can also be seen that the best performance of the MPPT controller in increasing the output power of the system occurs precisely when the wind speed is 6.5 m/s, with an output percentage power output of 135.62%. Overall, implementing the MPPT controller using the extended PO algorithm has successfully enhanced the performance of wind turbine systems.

The output power of the wind turbine system with a load resistance of 300 Ω is shown in Figure 17. At wind speeds of 4m /s, the system without MPPT produces a voltage of 166.03 V and electric current of 0.55 A which is used to serve the load resistance of 300 Ω with an overall output power of 91.32 W. The application of the MPPT controller on the PMSG generator produced a voltage and current of 184.25 V and 1.03 A, respectively, with an overall power output of 189.78 W. In this case, the system output power increased by 107.82% compared to when the MPPT controller ~~wasn't~~ was not implemented. Furthermore, the system performance test with wind speeds of 5, 6.5, 7, 8.5, 9, and 10m/s, respectively, was examined.

Based on the graph in Figure 17, the higher the wind speed, the greater the voltage, current, and output power of the wind turbine system. The results show that the system produces an outstanding wind speed of 10 m/s. Without the implementation of the MPPT, the generated voltage is 902.72 V with a load current of 3.04 A, thus creating a power of 2,734.67 W. Furthermore, with the application of the MPPT controller, there is an increase in voltage, load current, and system output power of 817.71 V, 3.72 A, and 2,999.88 W, respectively. When compared to the initial condition, an increase in system output power by 9.63% can be detected. Based on the graph in Figure 17, the best performance of the MPPT controller in increasing the output power of the system occurs when the wind speed is 4 m/s, with a percentage increase in output power of 107.82%.

Based on the results of the overall wind-turbine system performance test, the most significant increase in system output power occurs when the system is loaded with 200 Ω, with a wind speed of 6.5 m/s. In this condition, there has been a high increase of output power by 135.62%, caused by the installation of the MPPT controller in the wind-turbine system, while the average growth of output power is only 50.77%. Thus, it can be concluded that MPPT ~~uses~~ using the extended PO method in this study has been proven to be able to increase the performance of wind-turbine systems.

5. Conclusions

In this study, the research of wind-turbine system performance using an MPPT controller based on an extended PO algorithm was performed. This algorithm can calibrate without oscillation to determine the maximum power output. To analyze the performance, the Simulink-Matlab software was employed. The performance examination is carried out with a 3000 W wind-turbine system which served varying electrical loads of 50 Ω, 100 Ω, 200 Ω, and 300 Ω, respectively. In each of the variations, various wind speeds based on the prevailing wind conditions in Indonesia, i.e., 4, 5, 6.5, 7, 8.5, 9, and 10 m/s, respectively, were performed. Based on the results of the overall wind-turbine system performance examination, the most significant increase in system output power occurs when the system is loaded with 200 Ω with a wind speed of 6.5 m/s. Similarly, the installation of the MPPT controller increased the output power by 135.62%, with an average power increase of 50.77%. The benefits of developing this PO algorithm include eliminating oscillation problems which occur due to fluctuations in power when it reaches maximum value. With the modification of the algorithm, this is expected to decrease due to the change of the value of ΔD, resulting in faster convergence of the computation. The results of this study have ~~proven~~ proved that an extended PO-based MPPT~~,~~ is capable of successfully enhancing the performance of wind-turbine systems.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Abbreviations~~ Lists~~

Abbreviation	Meaning
AC	alternating current
DC	direct current
EMF	electro-motive force
FLC	fuzzy logic controller
GW	giga watts
MPPT	maximum power point tracking

PMSG	permanent magnet synchronous generator
PO	perturb and observe
PWM	pulse width modulation
RC	resistance-capacitance
A	the area of cross-sectional coverage, in m^2
C_p	the coefficient of electric power of the wind turbine system
C_s	snubber capacitance
I	electric currents, in amperes
P	the electric power of the wind turbine system, in watts
R_s	Snubber resistance
T	the torque of generator, in Nm
V	electric voltages, in volts
V_f	forward voltage, in volts
v	wind velocity, in m/s
ω	rotational speed of the rotor, in rad/s
λ	the ratio of tip speed
ρ	the mass density of the air type, in kg/m^3

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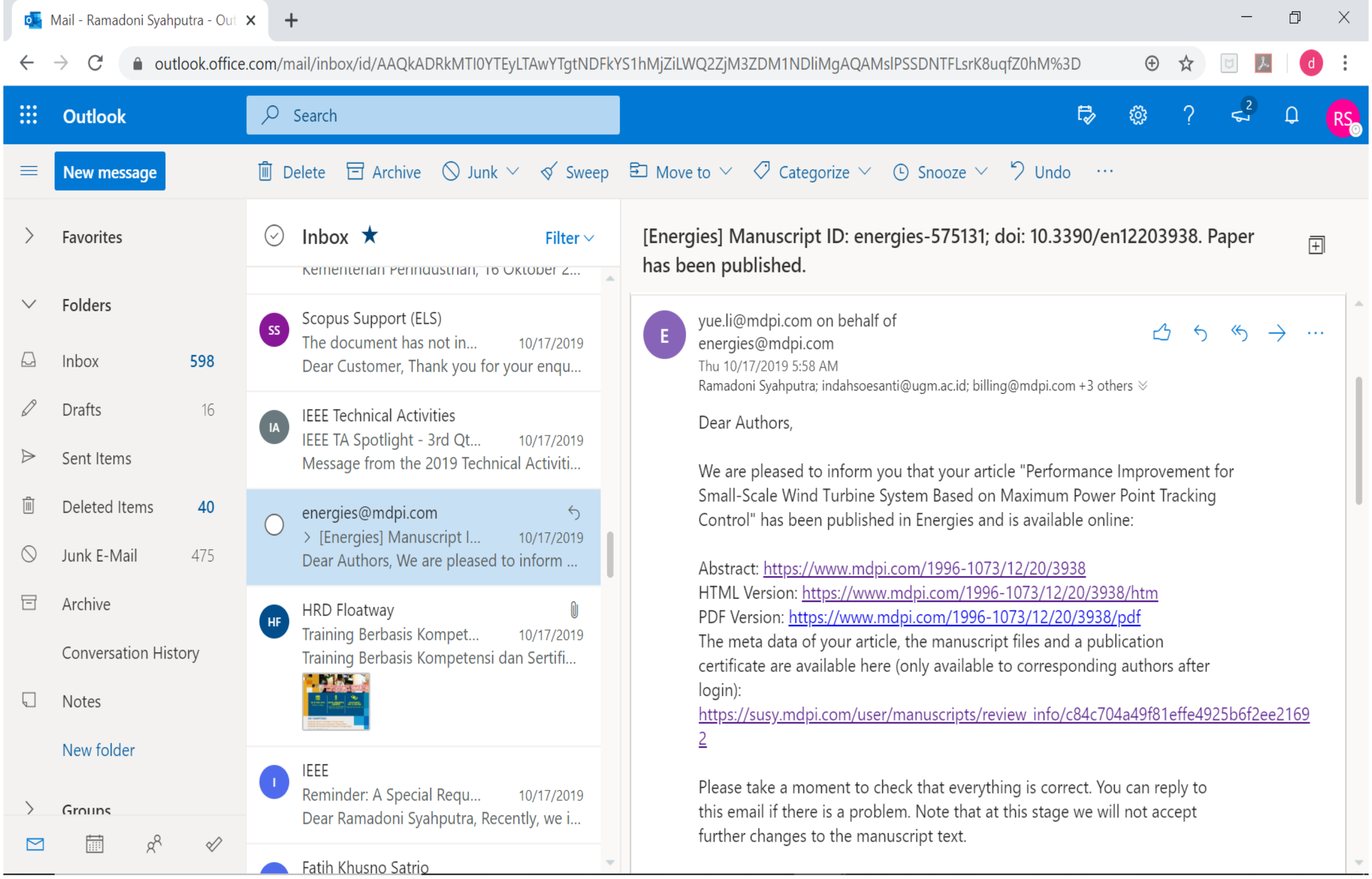

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