The research on improving the utilization of renewable energy in wind power generators using thin-film solar cells

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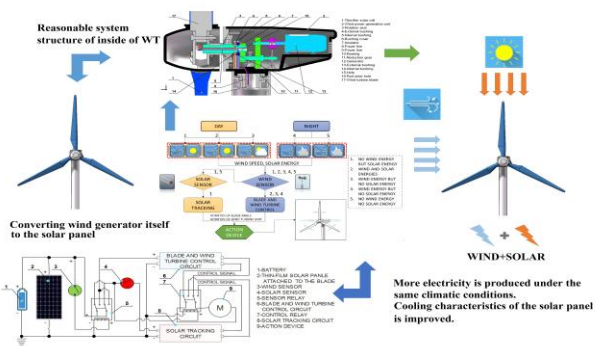
HIGHLIGHTS

- The method of attaching Thin-film solar cells to the surface of the wind generator blade can spare the installation area of the solar cell.
- Wind generator blade can play not only the role of a blade but also the role of solar cells.
- The structural design of wind generators for obtaining electricity from rotating thin-film solar cells has proposed.
- The proposed control system can produce electricity stably by using wind and solar energy more reasonably while being sensitive to climate change.

GRAPHICAL ABSTRACT



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ABSTRACT

The current research proposes the idea to increase the utilization rate of renewable energy of the wind power generation system by using thin-film solar cells to reduce the dependence on climate in the wind power generation system. The thin-film solar cell is attached to the surface of a wind generator blade by using a reasonable method, and the wind generator blade can operate not only as the blade itself but also as a thin-film solar cell. Also, the main body of the wind generator (WG) constructed and designed to obtain the energy generated by the thin-film type solar cell attached to the rotating wind generator (WG) blade. This paper proposed the drive scheme and control structure for increasing power generation to the maximum by utilizing renewable energy depending on climate change in the wind generation system with solar cells. The proposed idea, the corresponding system structure, and the drive scheme and control structure according to climate change shows that it can simultaneously generate electrical power using wind and solar energy in one device. And it shows that output characteristics of the thin-film solar cell by satisfying the cooling condition can improve. Also, to establish the reliability and accuracy of numerical solutions, the obtained results are compared with the corresponding numerical and experimental data.

1. Introduction

All renewable energy sources on earth, including solar energy and wind power, are precious resources that nature gives us. The world needs more and more to provide power by utilizing renewable energy with the development of science and technology. Several renewable technologies are presently available (a photovoltaic panel or thermal solar, biomass, geothermal, waves, hydropower, and wind). However, among all those technologies and photovoltaic panels and wind generators (WG) are the most profitable ones, from the economic point of view [1]. Solar and wind energies are the most important renewable energy, and their utilization does not affect the environment, so people are more and more interested in these two energies. The execution of solar and wind energy systems is firmly reliant on climatic conditions in the area. The power generated by a photovoltaic panel system is exceptionally subject to climate conditions [2]. For instance, amid cloudy periods and in the evening, a photovoltaic panel system cannot produce any power. In terms of solar cells, it is necessary to produce electricity by maximizing the efficiency of solar cells while the sun is shining. The solution to this problem is to ensure the cooling conditions to lower the temperature of the solar cell by solar heat, and the solar tracking system must reasonably use

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so that the solar cell can always receive more solar radiation energy. From these demands, studies to improve the output characteristics of solar cells have intensified around the world. The current output characteristics of solar cells are closely related to the temperature of solar cells [3]. Generally, in the solar cell installed and operated on the surface of the ground. The power generation efficiency decreased as the temperature of the solar cell increases due to the sunlight during its operation. In literature [4-11], studies have conducted to improve the electrical efficiency of solar cells by improving the cooling characteristics of solar cells. In literature [4], the aluminum plate was installed on the back of the solar cell to improve the cooling characteristics of the solar cell, and the superiority of the solar cell cooling system proved through the experimental verification. The significance of this research was to prevent the decrease of electricity production efficiency due to the increase of the temperature of the solar cell when the solar cell receives the sunlight vertically, and to make the solar cell work at the normal working temperature to produce more power. However, more and more research on just solar cell cooling technology, which costs less and is more advanced than the cooling system described in the literature, is attracting more and more attention. From this, the literature [5] described the research of improving the cooling condition of solar cells using an integrated system combining solar cells and wind generator systems. The wind designed to pass through the rear part of the solar cell to the wind generator so that the heat generated by the solar cell cooled to increase the performance of the solar cell. In this study, the researchers focused primarily on improving the cooling conditions of solar cells. In literature [6], the cooling conditions improved by using air and water with low operating costs as a cooling agent to cool the temperature of the solar cell. Water and air flowed through the thermal device attached to the back of the solar cell lowered the temperature of the solar cell to maintain the electrical efficiency of the solar cell introduced. The literature also shows that the proposed system improves the cooling characteristics of solar cells through experimental studies. The difference from the research described in the previous literature is that both water and air used as coolants. In literature [7], a hot water heating system was installed on the rear surface of the solar cell to improve the cooling conditions of the solar cell and to ensure the required temperature in the room by heating the hot water with the heat conducted from the solar cell. Recently, Yanping Du et al. [8] investigated using Nano coated heat pipe to remove the excess heat from the photovoltaic panels and to attain even temperatures distribution. Yongtai et al. [9] produced a photo thermal conversion model of photovoltaic panel/temperature solar water heater to optimize the photovoltaic panel coverage. Also, in literature [10], a study was performed to install Nano fluid flowing plates on top and bottom of solar cells to filter sunlight and to remove heat generated by solar cells. Through the research, a research result introduced that the proposed system could improve the performance characteristics of solar cells more than other ways. In Literature [11-12], the influences of control variables on the thermal and electrical performance of solar cells comprehensively described. Besides, researches to improve the performance of solar cells by optimizing each control variable described. Next, to improve the efficiency characteristics of solar cells, it is crucial to use a solar automatic tracking system so that solar cells receive more solar energy. For the extraction of maximum energy from the sun, the plane of the solar cell should always be normal to the incident radiation [13]. Literature [14-17] introduced a very single and stable solar tracker. The plane of the solar cell controlled so that it is always perpendicular to the incident radiation by sun trackers that automatically track the position of the sun. In the literature [18-19], research on the development of an automatic solar tracking system operated as a standalone real-time system conducted. If such a solar automatic tracking system used, the output of the solar cell can improve because the solar cell is always operated perpendicular to the sun. This paper presents all the stages of development of a solar tracker for a photovoltaic panel. In the literature [20], a standalone system that can accurately track the sun for a long time described. The stand-alone system, which consists of a two-axis solar tracking system with a small concentration device module, has proved to be much more efficient than the previous solar tracking system. As described in the literature, there are numerous researches to improve the performance characteristics of solar cells. Through literature researches, improvement of the performance characteristics of solar cells considers being the most significant problem to improve the cooling characteristics of solar cells under the condition of the automatic solar tracking system. Besides, while saving the raw materials and materials as much as possible, a right cooling system is installed to improve the efficiency of solar cells is becoming an important research direction. Research in the literature [21] has progressed to improve static and dynamic displacement characteristics of wind generator blades, which suggested in large wind generator design systems. Wind generator systems are occurred vibrations due to various external conditions during operation. This negatively influences the standard operation of wind generators, and the problem of eliminating the vibration of wind generator blades has raised as an essential problem. In the literature [21], a new method proposed to improve the vibration characteristics of wind generator blades and the results of verifying the merits of this method described through experimental and numerical studies. Also, research conducted to improve static and dynamic displacement characteristics of wind generator blades, which currently proposed in large wind generator design systems. In the literature [22], the performance characteristics of wind power generators used in Northern Africa countries where sandstorms occur have dealt with. In the literature, sandstorms in many of these countries damage the surface of wind generator blades used in these regions, which increase the aerodynamic resistance of wind generator blades and consequently lower the power production capacity of wind generators described. The signification of this research is to improve the performance of wind generators under various adverse conditions, not favorable environmental conditions by using CFD numerical simulation program. The literature [23] described a study that modified the profile of wind generator blades based on wind conditions. Through aerodynamic simulation of the modified wind generator blades, it introduced that the wind flow characteristics of the modified wind generator blades are improved and have superior characteristics to the original wind generator blades. In the literature [24], a model for predicting the pressure and momentum of the vertical axial wind generator presented. The proposed model makes it possible to predict the power output of wind generators by estimating various state amounts, such as momentum applied to wind generators. In the literature [25], the relationship between the wind generators' four coefficients effects on electric power production investigated through the study of the SCADA data, and the relationship between the wind speed and the electrical output of the wind generators also researched. A novel hybrid solar system consisting of photovoltaic panels, Fresnel lens, and thermoelectric generator was proposed and constructed [26]. Like this, many kinds of research have conducted to increase power production by effectively using solar energy and wind energy as the world's richest sources of renewable energy. However, these energies are highly dependent on climatic conditions, making them unable to produce power safely when operated as standalone systems. Nowadays, Researches are progressing on the integrating system of renewable energy that combines with wind energy and sunlight in the world to solve problems like this [27-28]. As for numerous renewable energy specialists, half and half electric system that consolidates wind and sunlight based (photovoltaic) innovations offer a few points of interest over the single system [27-28]. As shown in the paper [27-28], you can get a persistent and reliable power supply by utilizing both in a framework that intended to supplement each other. The establishment of this system is more highly entangled and costly than single wind or solar equipment. However, they are the best in giving consistent, reliable power [27-28]. In the literature [29], a new type of wind-solar hybrid system proposed, and the power performance of this system studied in comparison with conventional wind generators. The power output of both systems was measured and simulated by TRNSYS software. However, this method requires the installation of a large number of tubes for lowering the heated temperature and leads to the high cost of metal in manufacturing. Therefore, it is necessary to improve the output of the system by ensuring the operating temperature of the solar cell while reducing the cost in the operation of the wind-solar energy mixing system. According to the literature, China's new WG capacity is 31 GW, equivalent to the power generation of 10,000 large WG, and at least one WGs installed in an hour. The solar cells installed in China have a surface area equal to 10,000 football fields, and at least one solar cell with a surface area equivalent to one football field is added in an hour every year. Like this, WGs and solar cells, as part of renewable energy sources, occupy ever-larger land with the increase of their production and demand for electricity, which causes hard problems in the countries with limited land. To increase power production by using solar energy to the maximum through research on prior work of literature is to maximize solar light energy received by a solar cell using a solar tracking system. At the same time, improving the cooling conditions to lower the temperature of solar cells is becoming an essential research direction. Besides, to increase power production by using wind energy to the maximum, a wind generator that must safely operate under various adverse environmental conditions designed, and finding multiple methodologies for improving the performance of the wind generator system is the central research direction. Next, we can see that research conduct to improve the stability of power generation by integrating these two systems from the characteristics of renewable energies, which are highly dependent on climatic conditions. They focused on the components of the hybrid system of the wind energy system and the solar cell system. But they did not focus on the conversion of the wind energy system itself into a solar cell system, including the subsequent development of the surface of the WG. No research conducted to produce electricity more safely while minimizing dependence on climatic conditions and the installation area, which are the most significant problems to be solved in the field of renewable energy applications. Besides, the research has not widely conducted to improve the output of the system by ensuring the working temperature of the solar cell while reducing the cost as much as possible in operating the wind-solar energy hybrid system. Therefore, this paper focuses on the wind-solar energy hybrid system and discusses the ways to improve the output of energy generation in one WG system, which does not require the install area of solar cells and does not depend on climate conditions. Unlike the generation of electricity through fossil fuels, which allows steady production, the electricity-production which relies on wind and solar energy still has some problems as it is profoundly affected by such conditions as the climate and the installed area. For example, the generation amount of WG heavily depends on the intensity of the wind, and WG cannot produce electricity at all when the wind amount is small or empty even if it is efficient enough [30]. Besides, the solar cell cannot produce electricity when solar radiation does not exist on a cloudy day. Thus it is necessary to normalize the operation of renewable energy utilization systems under the condition of decreasing the dependence on climate conditions and minimizing its installation area.

Therefore, this paper proposes the following methods.

First, this paper proposes the new method for converting WG itself to solar cell without solar cell installation area by installing TFSC on the parts which can use solar energy such as blade in the WG. Second, based on the theoretical calculation of the wind turbine blade, predict values the amount of power that can obtain by using solar cells in the wind turbine has proposed. Also, simulation method to select the part where the thin-film solar cells can be attached to the blade by using the application program ANSYS has proposed. Thirdly, this paper proposes the reasonable system structure of inner WG for producing solar cell electricity obtained on the surface of the rotating blade when the WG converted to solar cells. Forth, this paper proposes the drive scheme and control system of the wind generation system with solar cells for increasing power generation to the maximum by utilizing renewable energy depending on climate change. Fifth, the validity of the proposed scientific and technological content is confirmed through experimental calculations.

2. METHEODOLOGY

2.1. THE METHODOLOGY OF IMPROVING UTILIZATION OF RENEWABLE ENERGY IN WIND GENERATORS USING TFSC

The wind power generator mainly divided into two types with the Horizontal Axis Wind Turbine, Lift Type Vertical Axis Wind Turbine.

It can see that the vertical axis wind turbine's blades rotate around the tower vertically placed on the ground so that it cannot receive constant solar from structural features and work characteristics, and it is difficult to automatically solar tracking. However, as shown in the Fig.1, the horizontal axis wind turbine can be adjusted with the wind angle and the blade position depending on the wind strength and wind direction.

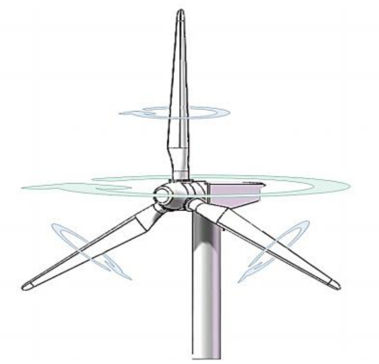


Fig.1. Control characteristics of horizontal axis turbine

As can see in the picture, if a thin-film solar cell is attached to the horizontal axis wind turbine, it can receive sunlight by using a solar tracking system even when the wind velocity is lower than the working speed of wind generator. From this consideration, it can see that it is reasonable to combine the solar cell with a horizontal axis wind turbine.

As shown in Fig.2, the number of TFSC is selected corresponding to the effective adhesion area of the WG blade, and it is attached to the curve part of the blade by using adhesive to utilize two renewable energy at equipment under the enhancing heat exchange of TFSC. In this case, the adhesive intensity must ensure because the WG blades rotate.

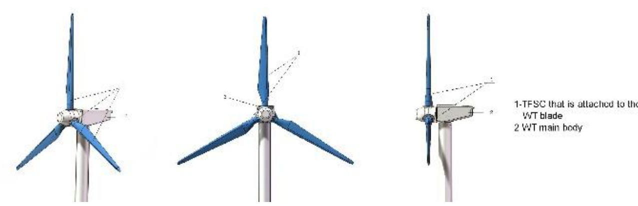


Fig.2. Methodology of improving utilization of renewable energy in wind power generators using TFSC

2.2. THEORETICAL CONSIDERATION

2.2.1. Calculation of the amount of extra electric power when TFSC is attached to the area of the WG blade.

First, it is important to pre-calculate how much more electric power can produce when the WG converted to a solar cell. The calculation formula of the WG output is as follows [31].

$$P = \rho C_p A_r \vartheta^3 = \rho 4a(1-a)^2 A_r \vartheta^3 \qquad (1)$$

Where ϑ is the wind speed, A_r is the rotor area, ρ is the air density, C_p is Function of the axial induction factor. a, and its maximum value of 59.3%, obtained for $a = 1/3$, was first derived by Betz in 1919 (known as Betz's limit) [31]. Area of the blade to ensure the output of the wind power generator:

Induced into

$$A_r = P / \left[4\rho a (1-a)^2 \vartheta^3 \right] \qquad (2)$$

Based on this equation, the area of a 10 kW WG blade calculated first. The area calculated at a rating speed of 6.5 m / s at which the WG can operate [31].

$$A_r = \frac{P}{\left[4\rho a(1-a)^2 \vartheta^3\right]} = \frac{10000}{\left[4\times 1.29\times 0.33\times(1-0.33)^2\times 6.5^3\right]} = 47.63 \qquad (3)$$

Table1. Blade area according to the output

$P(kW)$	$A_r\,(m^2)$	$r(m)$	$P(kW)$	$A_r\,(m^2)$	$r(m)$
10.00	47.63	3.89	60.00	285.82	9.54
20.00	95.27	5.51	70.00	333.46	10.30
30.00	142.91	6.74	80.00	381.09	11.00
40.00	190.55	7.79	90.00	428.73	11.70
50.00	238.19	8.71	100.00	476.37	12.30

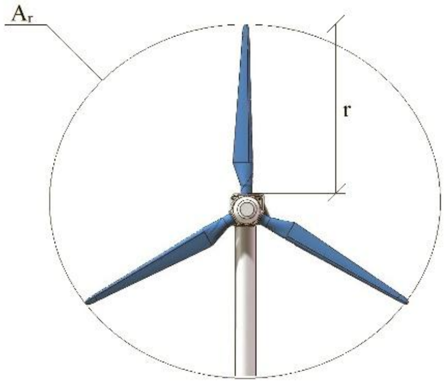


Fig.3. Relation of A_r and r

Where r-radius of blade （length of one blade） $r = \sqrt{A_r / \pi}$

2.2.2. The calculation of extra power which can produce when the solar cells are attached to the blades of the WG.

Table2. Technical Characteristics of 68W Thin-Film Flexible Solar cell

Technical Characteristics	Symbol	Unit	Value
Maximum Power	P_{max}	(W)	68.00
Voltage at Pmax	V_{mp}	(V)	16.50
Current at Pmax	I_{mp}	(A)	4.10
Short-circuit Current	I_{sc}	(A)	5.10
Open-circuit Voltage	V_{oc}	(V)	23.10
Length	a	m	2.84
Width	b	m	0.39
Area	A	m^2	1.12
Power density unit area	ρ_{p-A}	W/m^2	60.58
Weight	W	Kg	3.90
Power density unit weight	ρ_{p-w}	W/Kg	17.44
Cell Area (356×239)	A_{cell}	m^2	0.94
Available Area (336×239)	A_{AA}	m^2	0.88
Available Area Efficiency	η_{AAE}	%	7.70
Module Efficiency	η_{modul}	%	6.10

-Number of TFSCs that can be attached to the WG blade

Also, the number of TFSCs attached to the blade is related to the length of the blade. The number of TFSCs that can be attached to the blade, and the theoretical extra power output from the wind generator is as the following Table3.

Table3. Theoretical extra power output from the wind generator

Power of wind generator $P\ (kW)$	Radius of blade $r = \sqrt{A_r / \pi}$	Number of TFSCs $n = r / a$	Power of TFSCs $P_{TFSC} = B \cdot n$
10.00	3.89	1.37	0.28
20.00	5.51	1.94	0.40
30.00	6.74	2.37	0.48
40.00	7.79	2.74	0.56
50.00	8.71	3.07	0.63
60.00	9.54	3.36	0.68
70.00	10.30	3.63	0.74
80.00	11.00	3.87	0.79
90.00	11.70	4.12	0.84
100.00	12.30	4.33	0.88

Where P is Output of wind generator, r is the radius of blade（length of one blade）, $n = r / a$ is the number of TFSCs that can be attached to the WG blade and B=3 is the Number of wind generator blades.

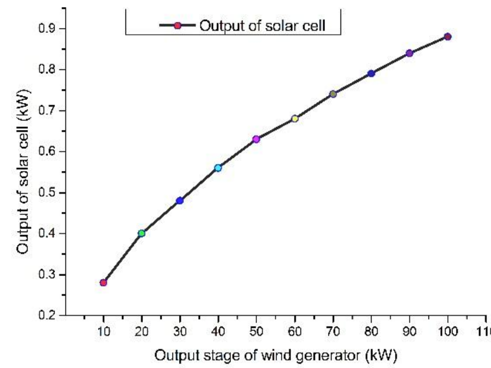


Fig.4. Theoretical amount of extra electricity that can produce after installing solar cells in a WG

As shown in Fig.4 and Table 3, a theoretical solution proves that extra electricity can produced in renewable energy equipment. Also, a large area of solar cell installation area can spare when using the new method for converting WG itself to solar cells without the solar cell installation area.

2.3. SIMULATION CALCULATION

2.3.1. A Study on the Characteristics of the Shape Change Simulation of Wind generator blade Using Application program ANSYS

-The solar cells placed on the blades have to face several issues:

• Aerodynamics: It is safe to operate without attaching solar cells to the severe part of blade change.

It is necessary to consider the change in the shape of the wind generator blade under the working conditions to solve this problem.

• Structural issues: Rotating blades face high bending, centrifugal, and twisting stresses, which are unsteady.

The solar cells fixed on the blade will face the same stresses as well.

The use of TFSC requires perfect attaching to the blade so that it should not affect the aerodynamics of the wind generator. Every blade has its Natural Frequency, and vibrations occur by various external conditions in the working processes. This vibration phenomenon, which is in the working process of wind generator blades, causes the shape of the blade to change. At this time, if the solar cell is attached to this part, the solar cell can be destroyed.

To solve this problem, the working of the wind generator needs to stop and solar cells removed, or replaced, which takes a lot of time labor and money. Therefore, the rational attachment position of the TFSC must be determined.

It is better not to attach TFSCs to the areas where the blade shape change is big to improve the stability of the apparatus. From this demand, the shape change characteristic of wind generator blades according to the Natural Frequency of the object considered by using the application program ANSYS.

- Modal analysis

The modal analysis used to determine the vibration characteristics of the structure — natural frequency and mode. It is not only the foundation of all dynamic analysis but also the starting point of other further dynamic analysis.

Of course, we can proceed with modeling in ANSYS. However, since the model must create by entering the digits of each point, modeling is time-consuming and relatively complex. Therefore, the geometric model created using the application program Solid works.

Application program Solid works can not only create the model to be simulated most accurately but also is compatible with other application programs.

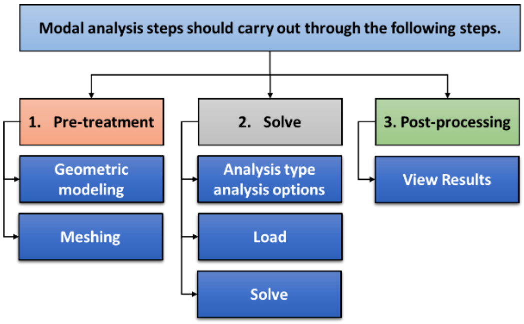


Fig.5. Modal analysis steps

Application program when memorizing a model created in Solid works, the extension is stored as a x_t (Para solid) file. The file types that can be loaded by the ANSYS application program are as follows. Through UG, you can import ANSYS in multiple file formats, such as prt, model, iges, x_t, etc. When importing models in different formats, the repair work in the ANSYS system may not be the same. You cannot say that the format must be good. So try more different interfaces, but IGES usually has more problems and is not recommended.

When importing complex models, it is more difficult to import all the entities at once, and it is also very difficult to mesh. Therefore, it is recommended to import after splitting. If it is difficult to import the entities, you can consider importing the surface model first, and then find a way in ANSYS Spawn. But there are problems with it,

For entities imported several times, if you want to perform Boolean operations in ANSYS, you will often encounter problems. It is not as easy as in the CAD system. Therefore, how to split the model and import, the guide surface or the conductor, this needs to be weighed.

In short, when complex models are imported into ANSYS, more time is spent on pre-processing, and the model may need to be repaired and rebuilt. However, if make more complex models, pre-processing capabilities will definitely be greatly improved. It is not very good to pour UG directly. But after importing, remember to save the disk, this will speed up the speed. In addition, after importing, use/facet, normal to display the face and body normally. When make complex models, usually use SolidWorks to do it and then import it into ANSYS in para and sat format. There is no problem with data loss. We can load the model file you remembered using ANSYS 'Import function.

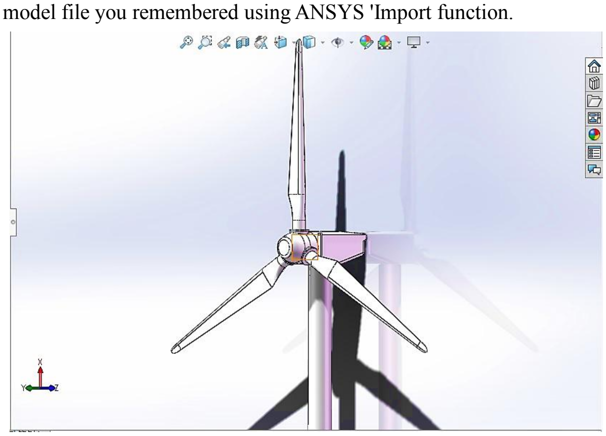


Fig.6. Model created using the application program Solid works

Meshing

Main Menu > Preprocessor > Meshing > Mesh Tool

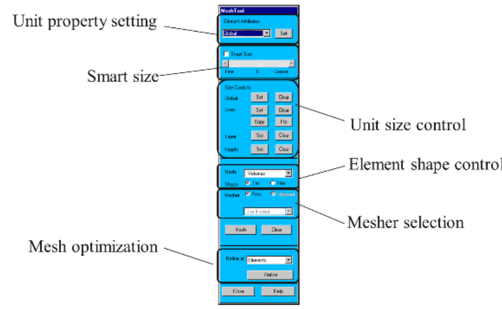


Fig.7. Mesh Tool

Unit property setting

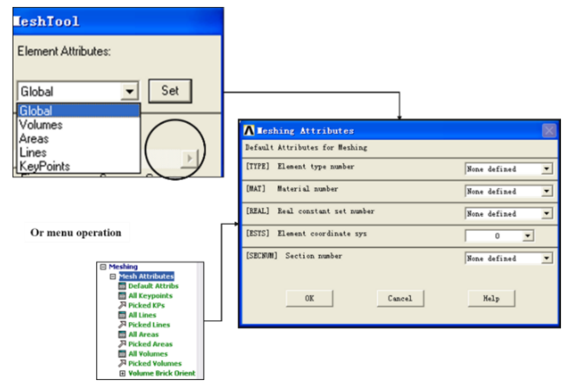


Fig.8. Unit property setting

In the process of creating a finite element model, there are generally three methods for setting element properties: Set the current default unit attributes, namely MAT, TYPE, and REAL of "global" before splitting the network. Then the corresponding region of the regular model is divided into systems, and all the networks completed in sequence. Before dividing the system, assign the unit attributes to the corresponding parts of the regular model in advance, and then deal the network together. After splitting the network, modify the unit attributes. If no element properties are set, ANSYS automatically assigns all elements. Default values: MAT = 1, TYPE = 1, and REAL = 1

Size control

Default unit size

When you first enter ANSYS for free and mapped meshing, the program automatically sets the default element size. The default unit size based on the following quantities: The minimum number of cells and the maximum number of cells in the smallest undivided grid line.

Maximum span angle of each unit

Element minimum and maximum side length

The control of the default cell size can be changed:

Main Menu: Preprocessor> Meshing> Size Cntrls> Manual Size> Global> Other

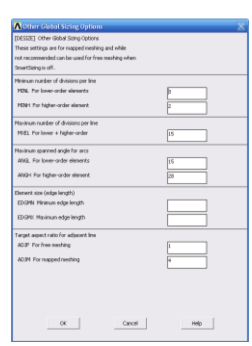


Fig.9. Size control

In many cases, the resulting cell size or smart size makes the resulting mesh unsuitable.

In these cases, more processing must do when meshing. More control can do by specifying the unit size described below.

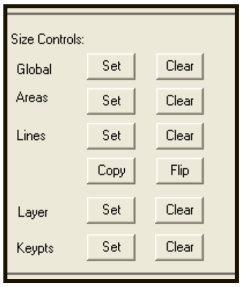


Fig.10. MESHTOOL dialog

When performing free mesh division, it recommended using Smart size to control the size of the mesh. When performing automatic meshing, smart meshing provides a reliable choice for the mesher to create reasonable cell shapes. Turning on the smart grid does not affect the division of the mapping grid. The mapping grid still uses the default size.

Main Menu > Preprocessor > Meshing > Mesh Tool

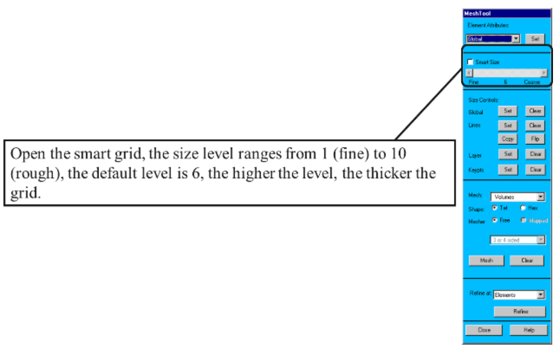


Fig.11. Mesh control

Main Menu > Preprocessor > Meshing > Size Cntrls > SmartSize > Basic

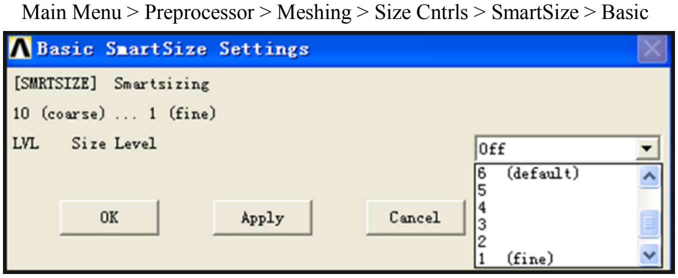
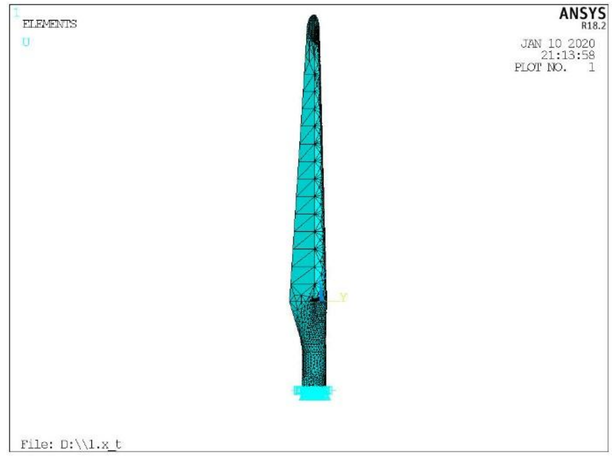


Fig.12. Smart size mesh control

The mesh of the wind turbine blades created through the above steps is as follows.



a)

b)

Fig.13. Mesh Model of Wind generator blade for Analysis

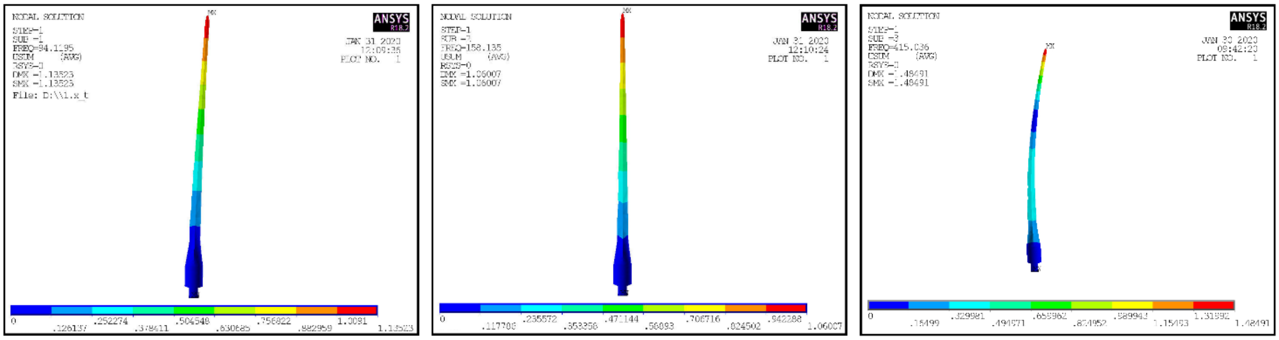
Simulation results for the shape change of the blade are as follows.

S O L U T I O N   O P T I O N S

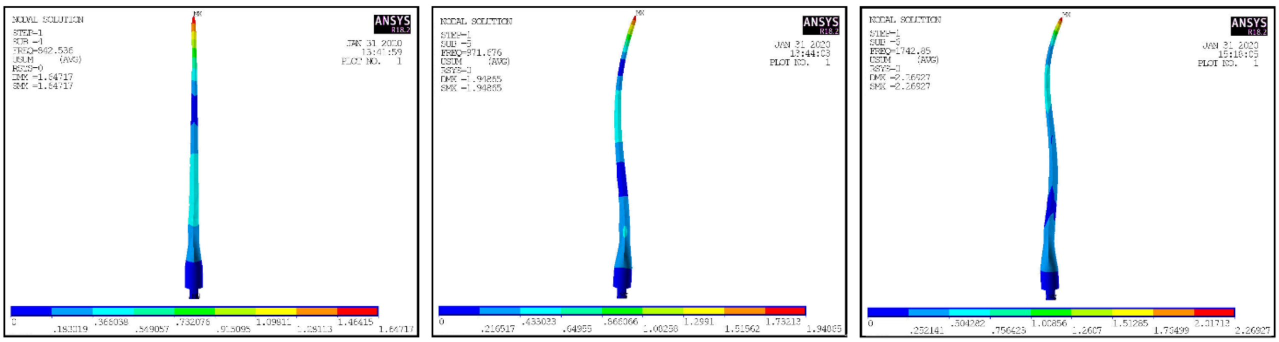
PROBLEM DIMENSIONALITY. 3-D
DEGREES OF FREEDOM. . . . . UX UY UZ
ANALYSIS TYPE . . . . MODAL
EXTRACTION METHOD . . . . BLOCK LANCZOS
EQUATION SOLVER OPTION. . . . . SPARSE
NUMBER OF MODES TO EXTRACT. . . .20
MODAL EXTRACTION RANGE. . . . . . . .0.0000 TO 20000.
GLOBALLY ASSEMBLED MATRIX . . . . SYMMETRIC
NUMBER OF MODES TO EXPAND 20
ELEMENT RESULTS CALCULATION . . . OFF

L O A D   S T E P   O P T I O N S

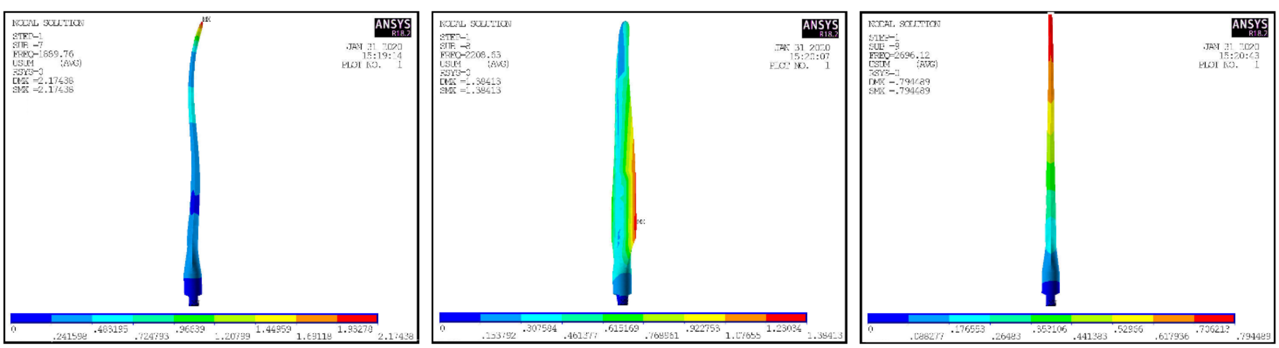
LOAD STEP NUMBER. 1
THERMAL STRAINS INCLUDED IN THE LOAD VECTOR. YES
PRINT OUTPUT CONTROLS . . . . NO PRINTOUT
DATABASE OUTPUT CONTROLS . . . . ALL DATA WRITTEN



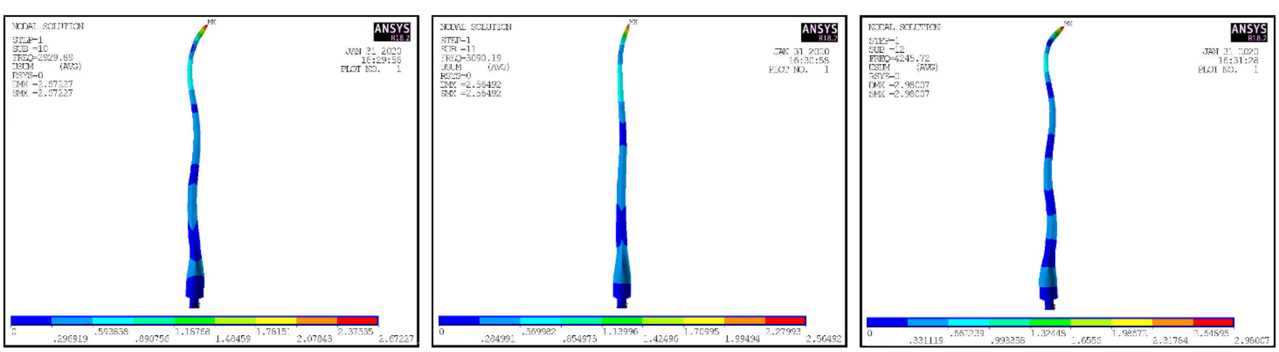
1-3 OF MODES TO EXTRACT



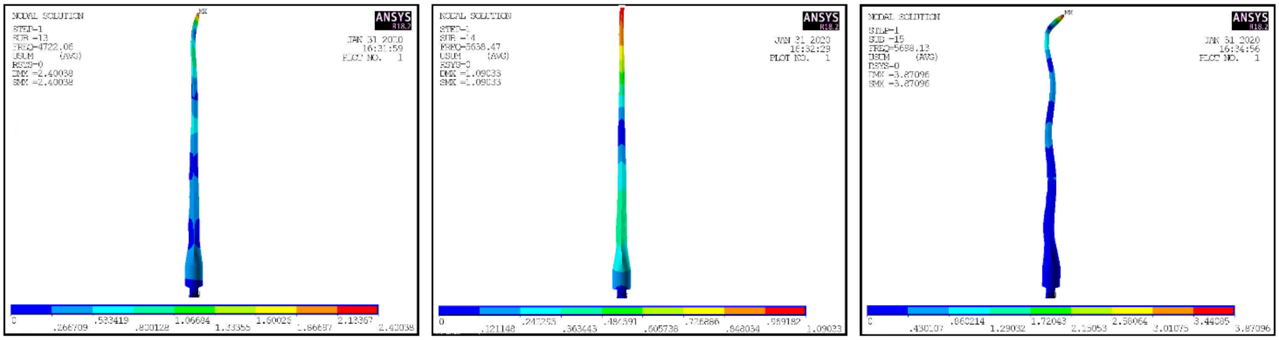
4-6　OF MODES TO EXTRA



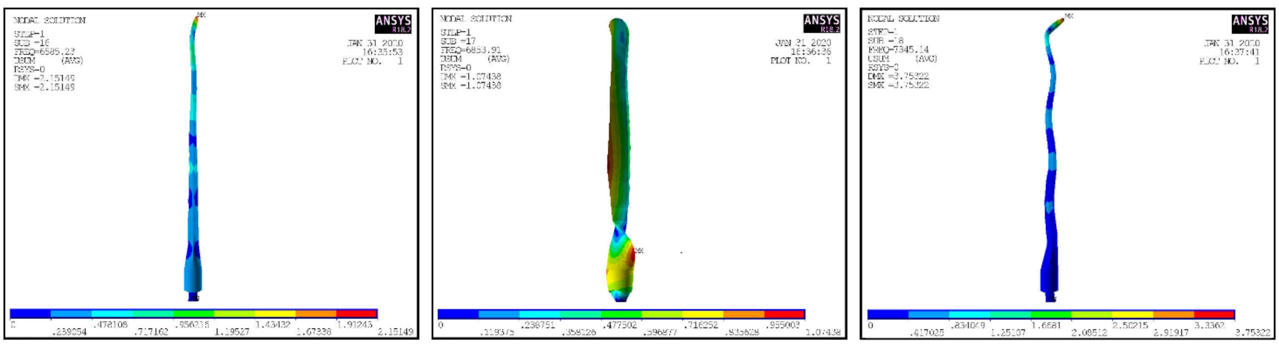
7-9 OF MODES TO EXTRACT



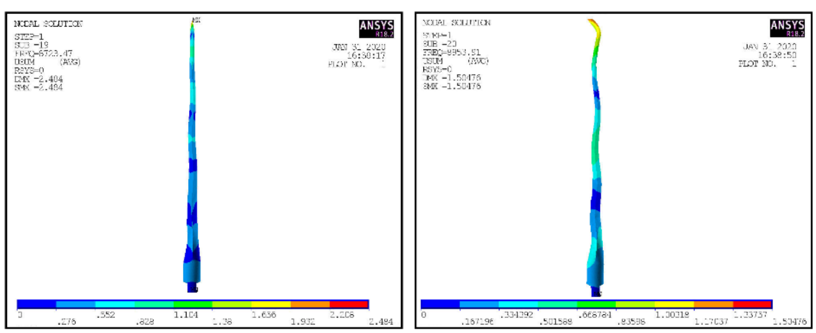
10-12 OF MODES TO EXTRACT



13-15 OF MODES TO EXTRACT



16-18 OF MODES TO EXTRACT



19-20 OF MODES TO EXTRACT

Fig.14. Simulation results for the shape change of the blade according to the Natural Frequency characteristics

Table4. Index of data sets on results file

STEP	TIME/FREQ	DMX	SUBSTEP	TIME/FREQ	DMX
1	94.12	1.14	11	3090.20	2.56
2	158.13	1.06	12	4245.70	2.98
3	415.04	1.48	13	4722.10	2.40
4	842.54	1.65	14	5638.50	1.09
5	971.68	1.95	15	5698.10	3.87
6	1742.80	2.26	16	6585.20	2.15
7	1889.80	2.17	17	6853.90	1.07
8	2208.60	1.38	18	7345.10	3.75
9	2696.10	0.79	19	8723.50	2.48
10	2929.90	2.67	20	8953.90	1.50

Where, DMX-Displacement Max

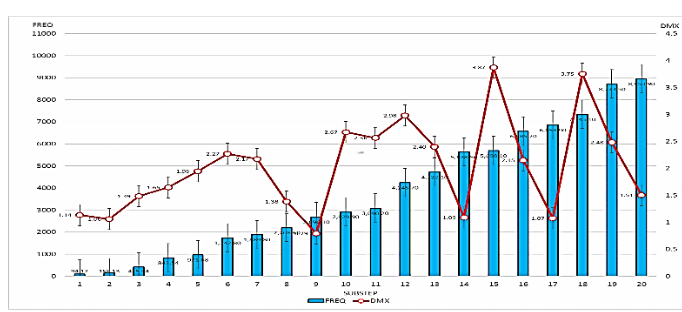
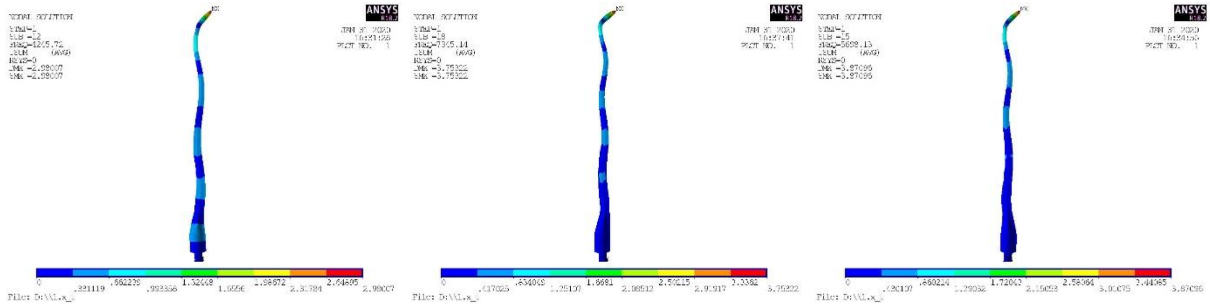


Fig.15. Displacement Characteristic Graph According to Natural Frequency in the blade

As seen in the graph of Fig.16, the highest values of the blade displacement are 2.98, 3.75, and 3.87. At this time, the frequency and displacement of the blades are as follows.



A) DMX=2.98, FREQ=4245.70 B) DMX=3.75, FREQ=7345.14 C) DMX=3.87, FREQ=5698.13

Fig.16. Frequency and Displacement shapes of the Blade at the Largest Displacement

3. REASONABLE SYSTEM STRUCTURE OF THE WG, THE DRIVE SCHEME AND CONTROL SYSTEM

3.1 REASONABLE SYSTEM STRUCTURE OF THE WG

The problem in operation after attaching TFSC to the blade as follows.

Electricity can be generated directly from the WG the axis, which connects with the rotating blade.

However, the electricity generated by the solar cell on the rotating blade must obtain by using a specific mechanical structure. Therefore, a reasonable system structure inside the WG is as follows

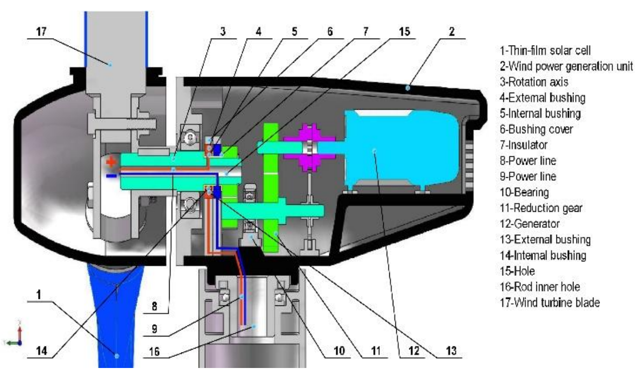


Fig.17. Reasonable system structure of inside of WG

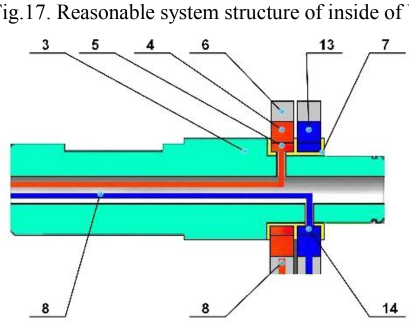


Fig.18. Hollow shaft part drawing

As shown in Fig. 17 and Fig. 18, TFSCs are attached to every blade, and the same polarities connect in parallel with each other. The power line pulls out through the groove of each blade to the front of the rotating shaft portion. It is also important to study a method for reasonably obtaining electric power generated from the TFSC under the condition of rotating TFSC. This can be achieved by changing the structure of the rotating shaft to a hollow shaft and installing two bushings on the outside of the hollow shaft. Two holes must drill in each part of the axis where the bush located to connect the bush with the power line. It is important to insulate the bush and axis and bushes themselves from each other by using the separator. In this way, DC power can be safely transmitted to the power control system through the surface contact of two bushes while the blade is rotating. In other words, extra power can be produced more safely than ever by utilizing more than two renewable energies in one equipment, and a large solar cell installation area can save.

3.2. THE DRIVE SCHEME AND CONTROL SYSTEM

It is important to increase the output to the maximum under various climatic conditions by taking control measures by changes of climate of the solar and wind energies in operating the solar-wind power system. The wind generating system is to use mainly under the condition of normal wind velocity. The solar tracking system is to use mainly under the condition of minimum wind velocity, where the blade cannot rotate.

3.2.1. THE OPERATION SCHEMATIC ACCORDING TO THE CLIMATE

- Operating schematic

Classification of climatic conditions

First, day and night

Second, under daytime conditions： (1) no wind energy but solar energy (2) wind and solar energies (3) wind energy but no solar energy

The operation, schematic according to the climate, is shown in the figure below (Fig. 19).

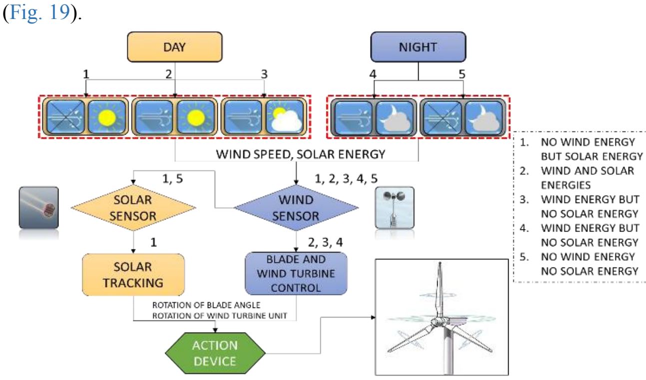


Fig.19. Operation schematic according to the climate

3.2.2. THE CONTROL SYSTEM ACCORDING TO THE CLIMATE

The control system consists of the battery, solar cell attached to the WG blade, wind sensor, solar sensor, sensor relay, and a control relay, wind blade automatic control circuit, solar tracking circuit, and action devices. The control system is as follows (Fig.20).

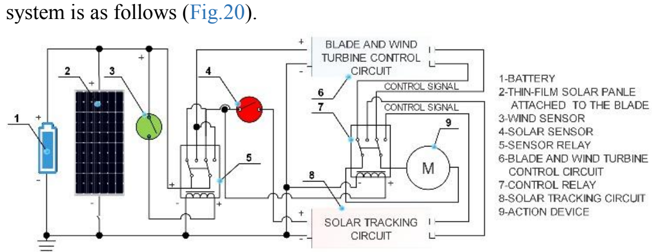


Fig.20. Control system according to the climate

All of the power of the control system is supplied by a battery connected in parallel with the solar cells attached to the blades. The operations of the wind control system and the solar tracking system of the whole control system switched by the relay. Sensor relay activates when electricity flows like the wind speed sensor is closed when the wind speed is high enough for the blade to turn. Then, power connected to the WG automatic control circuit at the contact point of the sensing relay is connected. Meanwhile, the control relay is non-operating, and the control signal from the WG automatic control circuit outlet is in a state of connection with the actuator, as shown in the control diagram. Automatic control of the blades by the wind performed with the activation of an actuator connected to the control relay when the control signal is output from the WG automatic control circuit outlet. In the case of weak or no wind, the sensing relay is on the open state because the current does not flow with the opening of the wind sensor, and the current flows into solar sensor inlet and control relay operating terminal. The solar sensor is in a state of passing current in case sunlight is existed and is in a state of cutting current in case of no sunlight. Solar tracking circuit activates when current flows through solar sensors, and the actuator activated by the control signal from the outlet of the solar tracking circuit. The actuator makes a wind-solar generation system output more electricity by changing blade angles and rotating angles of supporting rod to make solar cells attached to the blade track automatically the sunlight.

Advantages of the proposed method

WG itself converted to the solar cell by attaching the thin-film type solar cell to the blades of the wind power generator, the electric power from solar cell on the rotating blade easily obtained through optimization of structure and design of the WG, and generation system of solar and wind automatically control according to the change of climate conditions. Therefore, the utilization of renewable energy can be considerably enhanced.

4. EXPERIMENTAL MEASUREMENT

Based on the theoretical and simulation calculations, TFSCs are attached to the blades of the 10KW wind generator, and the shaft part of the wind generator recreated by a reasonable system structure of the wind power generator described in Section 2.1.2 of paper. Besides, the control system described in section 3.2 was added to the wind generator to maximize the output of the solar cell attached to the blade when no wind exists. In experimental characteristics, Wind speed and weather conditions considered as the inlet effect. As consideration factors, the output of the whole wind power generator and the surface temperature characteristics of the TFSC attached to the wind generator blade considered. Infrared cameras used to measure the surface temperature characteristics of TFSCs attached to the blades of the wind power generators. This value compared with the temperature characteristics of individually installed solar cells. The technical parameters of the wind generator used in the experiment are as follows.

Table5. The technical parameters of the wind power plant used in the experiment

Technical parameters	Value
Power	10kW
Blade diameter	7m
Material of the blades	Fiberglass-Reinforced Plastic
Rated speed	10m/s
Rated Power	10 kW
Max Power	15 kW
Max start torsional moment	<7.5 N/m
The output voltage	380V
Startup Wind speed	3m/s
Rated speed, rpm	200
Working wind speed	3.0-30m/s
Safe wind speed	45m/s
Generator type	3-phase AC PM
Body weight	1300kg

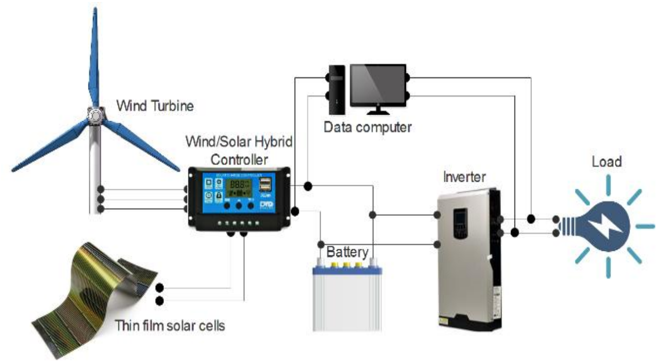


Fig.21. System Configuration for the experiment

Table6. Experimental calculation (Date: 2019-10.1~10.20 Tianjin)

Date	Weather	Max T ℃	Min T ℃	Wind speed m/s	Wind direction	P1 kW	P2 kW	P3 kW	T1 ℃	T2 ℃
1		30.00	21.00	0.30	SE	0.00	0.10	0.12	25.00	25.00
2		30.00	20.00	0.30	SW	0.00	0.20	0.24	26.00	26.00
3		31.00	15.00	1.60	SE	0.00	0.10	0.13	26.00	26.00
4		16.00	9.00	5.40	NE	0.20	0.20	0.20	15.00	10.00
5		19.00	11.00	1.00	NW	0.00	0.20	0.26	18.00	18.00
6		18.00	13.00	3.30	NW	0.12	0.12	0.12	16.00	12.00
7		23.00	11.00	3.40	SW	0.13	0.40	0.42	24.00	18.00
8		22.00	11.00	1.20	SW	0.00	0.20	0.26	23.00	23.00
9		24.00	13.00	2.00	SW	0.00	0.10	0.12	24.00	24.00
10		19.00	14.00	0.90	NW	0.00	0.00	0.00	18.00	18.00
11		19.00	15.00	3.20	SE	0.10	0.00	0.10	18.00	14.00
12		20.00	13.00	1.20	SE	0.00	0.00	0.00	19.00	19.00
13		15.00	7.00	4.00	NE	0.15	0.15	0.15	14.00	8.00
14		15.00	5.00	0.60	SE	0.00	0.22	0.26	17.00	17.00
15		17.00	8.00	0.90	NW	0.00	0.20	0.26	19.00	19.00
16		15.00	11.00	1.50	SW	0.00	0.00	0.00	14.00	14.00
17		15.00	10.00	1.40	NW	0.00	0.00	0.00	14.00	14.00
18		18.00	11.00	0.20	S	0.00	0.00	0.00	17.00	17.00
19		21.00	13.00	1.50	SE	0.00	0.10	0.14	20.00	20.00
20		22.00	9.00	0.00	S	0.00	0.11	0.13	21.00	21.00

Where, P1- The electrical power of wind power generators without solar cells attached to the wind generator blades, P2- The mixed output of the wind power generator with a solar cell attached to the wind generator blade, P3- Mixed output when the control system additionally installed under the condition that solar cell is attached to the blade of wind generator, T1- Temperature Characteristics of Individually Installed Solar Cells and T2- Temperature Characteristics of TFSC Attached to Wind generator blades.

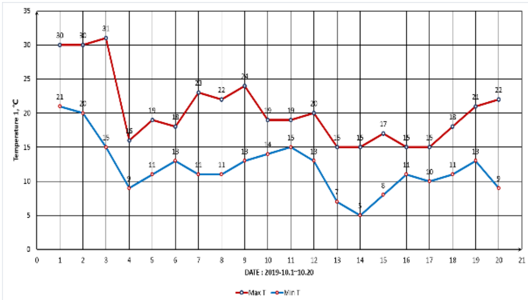


Fig.22. Temperature characteristic curve according to the weather

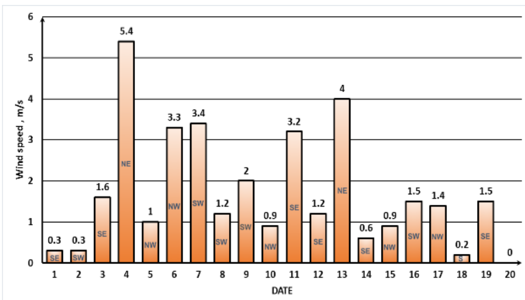


Fig.23. Wind speed and wind direction depending on the date

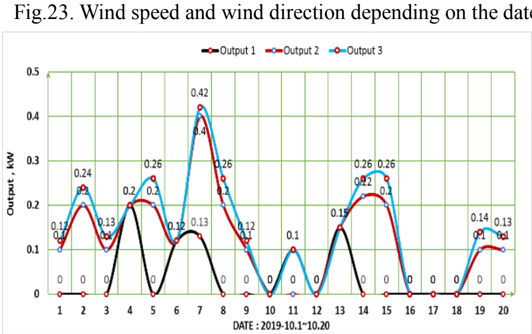


Fig.24. Output Characteristic Contrast Curve of Wind generator System According to Weather and Wind Conditions

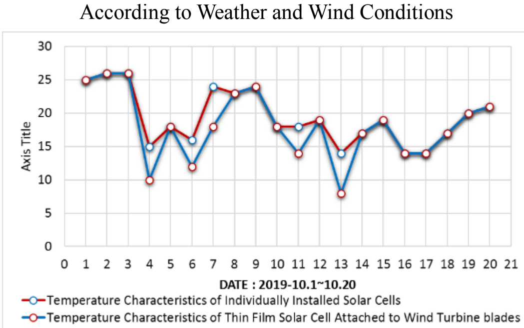


Fig.25. Temperature Characteristics Contrast Curves of Thin-film Solar Cells Attached to Wind Power Generator blades and Separately Installed Solar Cells

5. RESULTS AND DISCUSSIONS

5.1. RESULTS

The results induced from the theoretical calculation is as follows.

First, it is important to attach the TFSC with higher efficiency to the blade based on the careful consideration of economic efficiency in converting WG itself to the solar cell. Secondly, it is important to use a reasonable system structure of WG to utilize the electricity produced in the solar cell attached to the blade. Thirdly, under the condition that the sensor detects wind velocity and solar energy, it is important to give priority to wind energy generation at the initial speed of the wind, which is high enough to rotate the blade. Finally, it is important to convert the wind generation system to the solar cell generation system when the wind speed is not high enough to rotate the blade to utilize renewable energy. When the initial wind velocity is high enough to rotate the blade of WG, the solar cell generation system by solar tracking is converted automatically to the wind generation system. Like this, one equipment can produce more electricity by utilizing the two renewable energy when the solar cell is attached to the surface of the blade to convert itself to the solar cell.

Analysis of simulation and experimental results

As shown in Fig.16, it can see that the highest vibration displacement in the wind generator blade is the tip of the blade. Therefore, the TFSCs should not attached to the tip of the blade. As shown in Table 6 and Fig.22, the highest temperature is 31 ° C and the lowest is 5 ° C. Five of them were sunny days, and others were cloudy or a little rain. Also, as shown in Fig.23, the maximum wind speed is 5.4 m / s, which is slightly higher than the initial starting speed of wind generators, and the wind speed is very weak on most days. According to the weather conditions and the wind speed, the output characteristics of the wind power generation system measured in three types with P1, P2, and P3. As shown in Fig.24, more power can be produced from wind generators with solar cells compared to the power generated from independent wind generators under the same climatic conditions. Besides, when wind and solar control systems introduced, the power generation effect is more pronounced. As shown in Fig.25, when the blades of the wind generator rotate and produce power, the temperature of the TFSCs attached to the blades is lower than those of the solar cells installed and operated independently. This proves that the heat exchange conditions of the solar cells attached to the blades are improved when the wind turbine blades rotated by the wind. From the above results, the power generation system consisting of wind generators and solar cells attached to wind generator blades can use two renewable energies under the same climatic conditions, so that more power can produce than before. Also, the temperature characteristics of the solar cells attached to the wind generator blades are improved compared to the solar cells installed and operated independently, thereby improving the output characteristics of the solar cells. Besides, the installation area of the solar cell area can save, which is also economically significant in zone and country with small land areas.

Future work

In the future, we intend to conduct research projects to ensure the stability and high output of electricity production by utilizing more renewable energy from one facility that produces electricity using renewable energy as a power source.

5.2. DISCUSSIONS

The problems solved through the research are as follows:

First, this paper proposed the method of attaching TFSC to the surface of the WG blade to make the WG blade play not only the role of a blade but also the role of TFSC. It also advanced photoelectric conversion efficiency by improving the cooling characteristic of the solar cell by natural convection. The new way of converting WG itself to solar cells can save a large installation area of solar cells while producing extra electricity in one renewable equipment. Also, this paper improved the output of the TFSC by enhancing the cooling of TFSCs attached to the rotating blade while producing electric energy by using wind and solar energy at the same time in one equipment. Secondly, this paper solved the problems in improving and designing the structure of WG for obtaining electricity from the TFSC attached to the rotating blade. The design structure of the interior of the WG described above is relatively reasonable for utilizing the power of the TFSCs obtain from the surface of the rotating blades and may be introduced into WGs with different outputs. Thirdly, this paper proposed the drive scheme and control system for increasing power generation to the maximum by utilizing renewable energy depending on climate change in the wind generation system combined with solar cells. Operating methods and automatic control systems depending on climatic conditions cost less and are simple to operate, and considerably increase the utilization of renewable energy. Operating methods and automatic control systems depending on climatic conditions cost less and are easy to operate, and considerably increase the utilization of renewable energy. Finally, this paper proved that the proposed system outperformed the original wind generator system according to the climatic conditions through the analysis simulation and experimental verification. There are still some technical issues that need to be improved.

However, we hope that this paper will help scientists and engineers in the relevant field. Thank you.

NOMENCLATURE

P Output of WG, W

ρ The air density，kg/m^3

C_P Function of the axial induction factor

A_r Rotor area, m^2

ϑ Wind speed，m/s

a $a = 1/3$, was first derived by Betz in 1919 (known as Betz's limit).

r radius of blade, m

P_{max} Maximum Power, W

V_{mp} Voltage at Pmax, V

I_{mp} Current at Pmax, A

I_{sc} Short-circuit Current, A

V_{oc} Open-circuit Voltage, V

a Length of Thin-film Flexible Solar cell, m

b Width of Thin-film Flexible Solar cell, m

A Area, m^2

ρ_{p-A} Power density unit area, W/m^2

W Weight, Kg

ρ_{p-w} Power density unit weight, W/Kg

A_{cell} Cell Area, m^2

A_{AA} Available Area, m^2

η_{AAE} Available Area Efficiency, %

η_{modul} Module Efficiency, %

P Power of wind generator, kW

PTFSC Power of TFSCs, kW

n Number of TFSCs

Acknowledgments

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References

[1] Fathy A. A reliable methodology based on mine blast optimization algorithm for optimal sizing of hybrid PV-wind-FC system for remote area in Egypt [J]. Renewable Energy, 2016, 95:367-380.

[2] Lingfeng Wang, Chanan Singh, "PSO-Based Multidiscipline-ary Design of a Hybrid Power Generation System with Stat- istical Models of Wind Speed and Solar Insolation", IEEE, 0-7803-9772-X/06/2006.

[3] Du Y , Le N C H , Chen D , et al. Thermal management of solar cells using a Nano-coated heat pipe plate: An indoor experimental study[J]. International Journal of Energy Research, 2016, 41(6).

[4] Grubišić－Čabo F, Nižetić S, Marinić Kragić I, Čoko D. Further progress in the research of fin－based passive cooling technique for the free－standing silicon photovoltaic panels. [J] International Journal of Energy Research, 2019; 43:3475–3495.

[5] Al-Nimr M A , Kiwan S , Sharadga H . Simulation of a novel hybrid solar photovoltaic/wind system to maintain the cell surface temperature and to generate electricity [J]. International Journal of Energy Research, 2017.

[6] Tonui J K, Tripanagnostopoulos Y. Air-cooled PV/T solar collectors with low cost performance improvements [J]. Solar Energy, 2007, 81(4):498-511.

[7] Ahn J G, Kim J H, Kim J T. A Study on Experimental Performance of Air-Type PV/T Collector with HRV [J]. Energy Procedia, 2015, 78:3007-3012.

[8] Du Y , Le N C H , Chen D , et al. Thermal management of solar cells using a Nano-coated heat pipe plate: An indoor experimental study[J]. International Journal of Energy Research, 2016, 41(6).

[9] He Y, Xiao L, Li L. Research on the influence of PV cell to thermal characteristics of photovoltaic/thermal solar system [J]. International Journal of Energy Research, 2017.

[10] Hassani S, Taylor R A, Mekhilef S, et al. A cascade nanofluid-based PV/T system with optimized optical and thermal properties [J]. Energy, 2016, 112:963-975.

[11] Wu S Y, Zhang Q L, Xiao L, et al. A heat pipe photovoltaic/thermal (PV/T) hybrid system and its performance evaluation [J]. Energy and Buildings, 2011, 43(12):3558-3567.

[12] Moradi K, Ebadian M A, Lin C X. A review of PV/T technologies: Effects of control parameters [J]. International Journal of Heat and Mass Transfer, 2013, 64(3):483-500.

[13] Mohd Rashid M I, Fadhil B N M N, Suliana B A G, et al. Design, Development and Performance Test of Two-Axis Solar Tracker System [J]. Applied Mechanics and Materials, 2014, 704:350-354.

[14] Poulek V, Libra M. A very simple solar tracker for space and terrestrial applications [J]. Solar Energy Materials and Solar Cells, 2000, 60(2):99-103.

[15] Yazidi A , Betin F , Notton G , et al. Low cost two-axis solar tracker with high precision positioning[C]// Environment Identities and Mediterranean Area, 2006. ISEIMA '06. First international Symposium on. IEEE, 2006.

[16] Alexandru C, Irina Tatu N. Optimal design of the solar tracker used for a photovoltaic string [J]. Journal of Renewable and Sustainable Energy, 2013, 5(2):023133.

[17] Agee J T, Obok Opok A, De Lazzer M. Solar Tracker Technologies: Market Trends and Field Applications [J]. Advanced Materials Research, 2007, 18-19:339-344.

[18] Oh S J , Lee Y J , Chen K , et al. Development of an embedded solar tracker for the enhancement of solar energy utilization[J]. International Journal of Energy Research, 2012, 36(2):249-258.

[19] Beltran J A, Rubio J L S G, Garcia-Beltran C D. Design, Manufacturing and Performance Test of a Solar Tracker Made by a Embedded Control[C]// Electronics, Robotics and Automotive Mechanics Conference, 2007. CERMA 2007. IEEE Computer Society, 2007.

[20] Oh S J, Burhan M, Ng K C, et al. Development and performance analysis of a two-axis solar tracker for concentrated photovoltaics [J]. International Journal of Energy Research, 2015, 39(7):965-976.

[21] Lu H, Zeng P, Lei L. Dynamic characteristics and enhanced performance of a novel wind generator rotor analyzed via experiments and numerical simulation [J]. International Journal of Energy Research, 2016.

[22] Zidane I F, Saqr K M, Swadener G, et al. On the role of surface roughness in the aerodynamic performance and energy conversion of horizontal wind generator blades: a review [J]. International Journal of Energy Research, 2016.

[23] Krawczyk P, Beyene A, Macphee D. Fluid structure interaction of a morphed wind generator blade [J]. International Journal of Energy Research, 2013, 37(14):1784-1793.

[24] Pope K, Naterer G F. Multiple streamtube approximation of flow-induced forces on a Savonius wind generator [J]. International Journal of Energy Research, 2013, 37(9):1079-1087.

[25] Dai J , Yang X , Hu W , et al. Effect investigation of yaw on wind generator performance based on SCADA data[J]. Energy, 2018:S0360544218302871.

[26] F. J. Willars-Rodríguez, E. A. Chávez-Urbiola, Vorobiev P , et al. Investigation of solar hybrid system with concentrating Fresnel lens, photovoltaic and thermoelectric generators[J]. International Journal of Energy Research, 2017, 41(3).

[27] B.N. Prashanth, R. Pramod, G.B. Veeresh Kumar, Design and Development of Hybrid Wind and Solar Energy System for Power Generation [J]. ScienceDirect, Materials Today: Proceedings 5 (2018) 11415–11422

[28]Fathy, Ahmed. A reliable methodology based on mine blast optimization algorithm for optimal sizing of hybrid PV-wind-FC system for remote area in Egypt [J]. Renewable Energy, 2016, 95:367-380.

[29] Huang Q, Shi Y, Wang Y, et al. Multi-turbine wind-solar hybrid system [J]. Renewable Energy, 2015, 76:401-407.

[30] Baredar P, Sethi V K, Pandey M. Correlation analysis of small wind–solar–biomass hybrid energy system installed at RGTU Bhopal, MP (India)[J]. Clean Technologies & Environmental Policy, 2010, 12(3):265-271.

[31] Buonomano A, Calise F, D'Accadia M D, et al. A hybrid renewable system based on wind and solar energy coupled with an electrical storage: Dynamic simulation and economic assessment [J]. Energy, 2018.

FIGURE AND TABLE OPTIONS

Figure captions

Table captions