International Journal of Engineering Research
Sirte University
Faculty of Engineering

IJER@su.edu.ly Special Issue, Oct. 2022

Improvements of Wind Turbine Power Efficiency by Using Four-Ports Machine Structure and Phased Rotating Plates

Eljaroshi Diryak[1], Ali Algaddafi[2] and M. Abougharsa[3]*

[1,2]Electrical and Electronics Department, University of Sirte- Libya,
[3]Civil Department, University of Sirte- Libya
Corresponding author: Email: Emd202@su.edu.ly

Abstract
Wind power or wind energy is a process to generate electricity from wind speed. However, there is a large amount of money that has been invested in wind energy, which makes wind power in the innovation of the current decade. But wind energy is still required further improvement. In this paper, a new design is proposed to improve a horizontal wind turbine-type performance by using Four-Ports Wind Turbine (FPWT). The FPWT consists of two subsystems in one frame. Subsystem-1, is consisting of Permanent Magnet Machines (PMM) with two rotors i.e., inner and outer rotors and one stator. The inner rotor is a wound rotor that is connected electrically to the rotor of the other machine and mechanically to the right-side plates through a gearbox. The outer rotor is composed of surface-mounted magnets and connected to the lift side plates, that it is rotated due to electromagnetic induction with a relative of the inner rotor rotation. Subsystem -2 is an induction machine where its rotor is connected electrically to the inner rotor of subsystem-1. Power conversion such as inverter is used to control the frequency of the output voltage and current to be suitable for use with 50 or 60 Hz. Finite Element Modelling (FEM) has been carried out to simulate the innovation system. The simulation shows the generation voltage of the subsystem-1 reaches suitable and expect voltage level when the wind is facing the front plates which i.e., voltage produced in the stator windings 370 volts, while the voltage produced in the inner rotor windings is about 450 volts. The inner rotor windings are connected to a rotor of subsystem-2, then the produced voltage in its stator windings is about 1000 volts that depending on the wind speed and gearbox ratio and control mechanism.

Keywords: *FPHWT, Double rotor machine, FEM, Modelling.*

1. Introduction

There is now general acceptance that the burning of fossil fuels is having a significant influence on the global climate. Therefore, using renewable energy such as wind energy is the alternative to save our earth. Wind power provides a reliable and more consistent power source. Wind energy or wind power or windmill is defined as the process to generate electricity using the wind or air-flows naturally. The wind turbine has used the wind to generate mechanical energy which is then converted into electrical energy. The wind turbine based on this principle consists of a rotor (blades) and then wind energy is converted into mechanical energy such as a rotation shaft which is connected through a drive train (Gearbox, generator and yaw drive or yaw angle) and finally is rotating the generator to produce electricity. After the description of the importance of wind power along with its structure, it would be useful to review the previous work related to wind energy production, as follows:

1.1 Review of Related Research

The improvement of wind power technology has been going on since the tenth century. The first record of the use of the windmill is seen in the tenth century in Persia. Inhabitants who lived in Eastern Persia, which bordered on Afghanistan today, utilized the windmill, which has a vertical-axis and drag type of windmill as illustrated in Figure (1) [1].

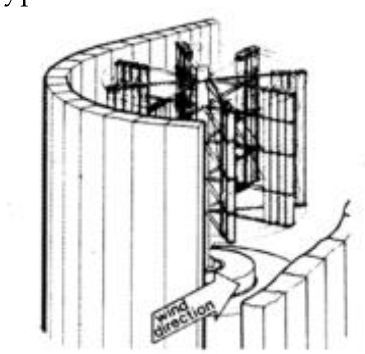

Figure 1: Early Persian windmill [1]

The transition from windmills applied to convert the wind energy into mechanical power to wind turbines which have been applied to produce electrical energy, took place in the last 19th century. The development of the aero plane in the first decades of the 19th century make it happen in intensive analysis and design studies of the rotor that could be applied to the wind turbine [2].

Developments in many areas of technology related to wind turbines have helped to accelerate its improvements. These improvements have contributed to the new generation of wind turbines include material science, computer science, aerodynamics, analytical methods and testing and power electronics [1].

In Fig. 2, various concepts for horizontal axis wind turbines [2-6]. Enfield-Andreau type of Horizontal Axis Wind Turbine (HAWT) is a distinctive concept by driving the generator pneumatically instead of the traditional mechanical techniques as shown in Figure (2a). Figure (2b) shows the other concept which is the multiple rotors in the same plane on a single tower which has been designed as a new method of achieving high power levels with rotors of intermediate size to gain or capture more wind energy from wind speed. Another unconventional innovative wind turbine concept is a wind turbine composed of counter-rotating blades, in other words, multiple rotors on the same axis as illustrated in Figure (2c) [6,7]. This system differs from the multiple rotors on the same plane as mentioned in previous studies. In that multiple rotors on the same plane increase, net swept area while counter-rotating blades on the same axis do share the net swept area [6].

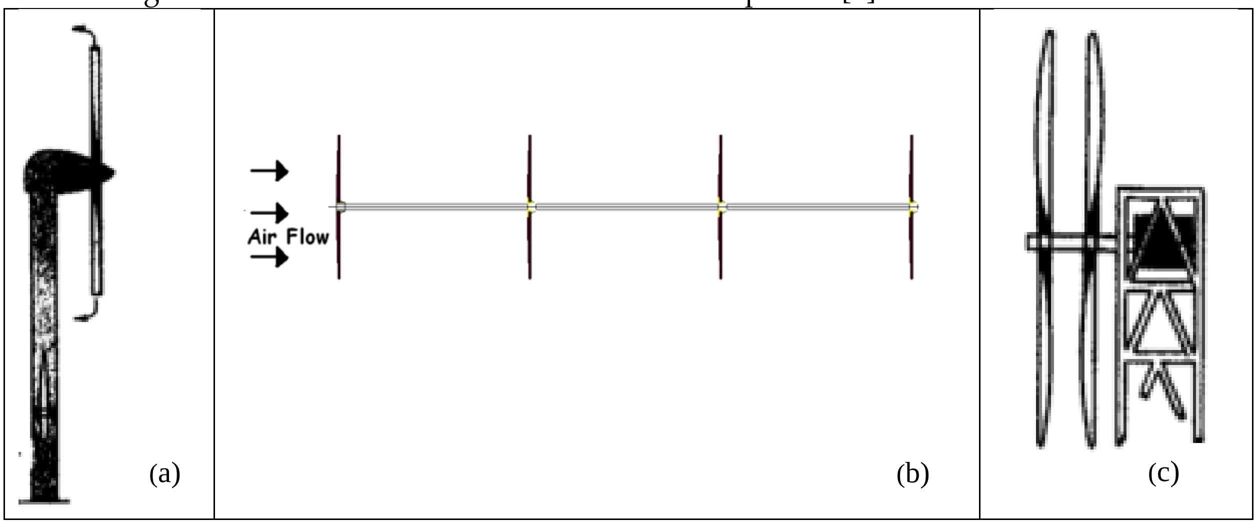

Figure 2: The previous technology as (a) The Enfield-Andreau type of Horizontal Axis Wind Turbine (HAWT), (b) the multiple rotors in the same plane on a single tower and (c) wind turbine composed of counter-rotating blades.

Figure (3) shows various wind turbine techniques which have been developed and different wind generators which have been built. Improvement of wind turbine performance using a novel tip plate structure has been studied and applied [8].

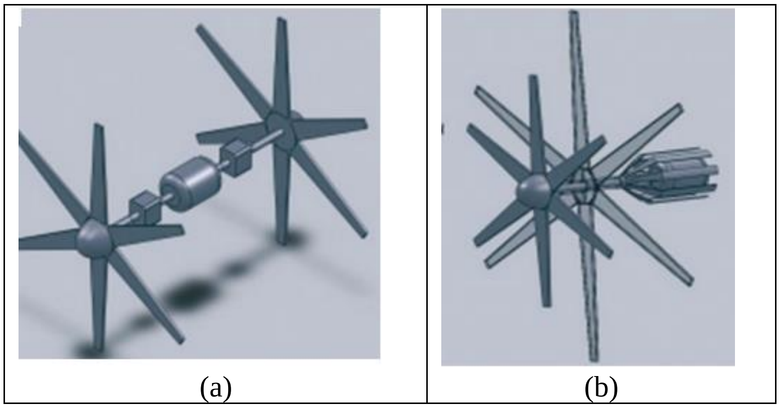

Figure 3: The relative position of two rotors in wind turbines: (a) both the rotors situated on both sides of the generator and (b) rotors situated axially one behind the other [6].

On the other hand, the double rotor for the mini wind turbine has been investigated experimentally in both the rotors situated on both sides of the generator, and the rotors situated axially one behind the other [4]. The two rotors of wind turbine with counter-rotation also have been studied in [5,9,10 and 11]. However, all these publications are considered the auxiliary rotor of the double rotor wind turbine that is rotating freely, which may not have the wind speed enough to drive its plates.

In this paper, the auxiliary rotor is rotated according to the main rotor rotation. This can be approached by using electromagnetic induction between both rotors. The proposed system of the double wind turbine can be shown in Figure (4).

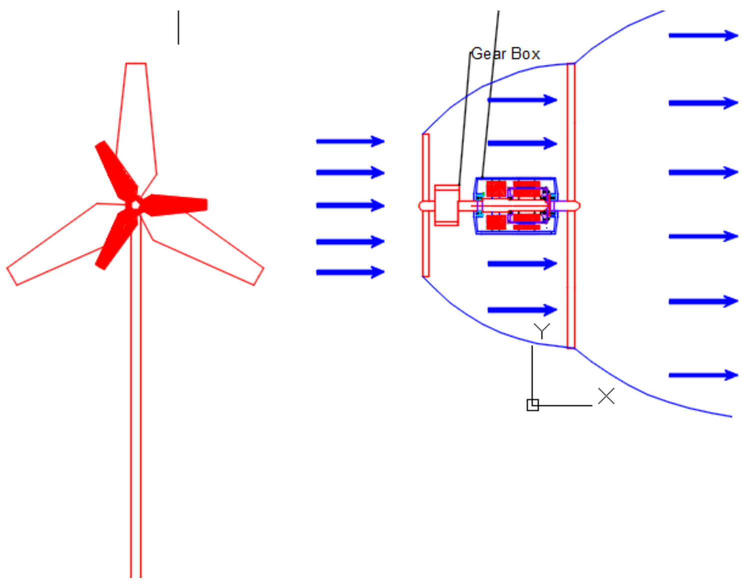

Figure 4: The proposed technique for wind power improvement

2. Four Port Horizontal Wind Turbine Description

Four Port Horizontal Wind Turbine (FPWT) that is shown in Figure (5), is proposed in wind power system application to improve the functionality of the wind turbine's production. An FPWT works as an element of a wind power system, as shown in Figure (5), where the main wind turbine converts wind energy into electrical and mechanical energies, and the auxiliary wind turbine renovates the remaining wind with helping the induction rotation into another electrical energy. For an FPWT, both subsystems are equipped with poly-phase AC windings. The stator, the inner and outer rotors of subsystem-1 have the same number of poles P. On the other hand, subsystem-2 has only one stator and one rotor. An FPWT system can deliver power to the national grid through the stator of both subsystems. The difference between the inner and outer rotor speed depends on the wind speed. Both generators are operated at synchronous speed because the outer rotor has a Permanent Magnet Machine (PMM) on both sides. The stator of subsystem-2 may obtain a different frequency of the inner rotor of subsystem-1. Therefore, the AC/DC or DC/AC either converter/inverter or rectifier processes are needed to deliver appropriate power to the network.

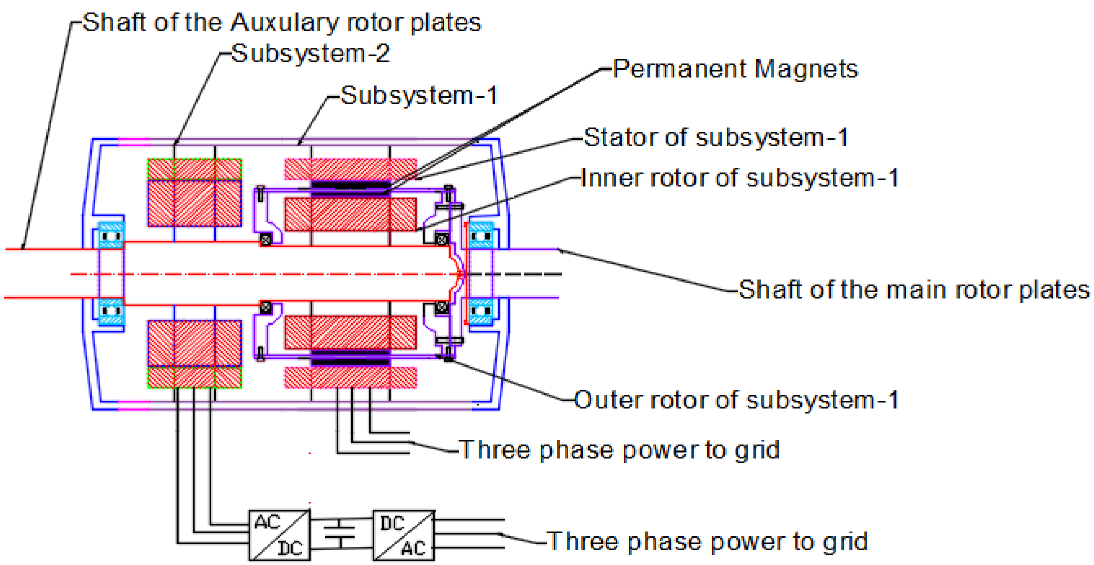

Figure 5: The Top view of the proposed FPWT

2.1 Geometric Dimension and Parameters Design of FPWT Study

The Finite Element (FM) package has been used for Modelling and analyzing the proposed system. The structure of subsystem-1 including its stator, inner rotor and outer rotor is shown in Figure (6a), and the structural geometry of subsystem-2 including its stator and rotor is shown in Figure(6b).

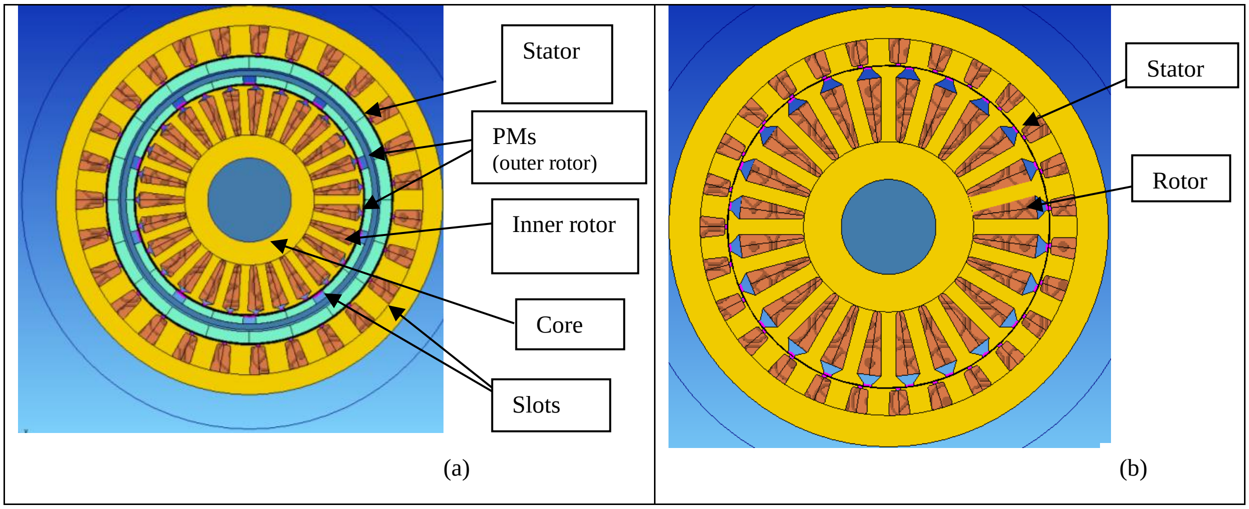

Figure 5: The FPWT system structure in FEM simulation (a) the subsystem-1 and (b) the subsystem-2.

2.1.1 Parameters and Design Model

Table (1) lists the design specification of the proposed FPWT subsystem-1, while the specification of subsystem-2 is listed in Table (2).

Table (1): Design specification of subsystem-1 of FPWT

No	Parts	Value
1.	The inner rotor rated speed	3000 rpm
2.	The outer rotor rated speed	1000 rpm
3.	Rated torque	20 Nm
4.	Permanent magnet material	NdFeB
5.	Coil material	Copper 5.77e7 Siemens/meter
6.	Air-gap thickness (Inner and Outer)	1 mm
7.	Magnet thickness of BLDCM	6 mm
8.	Magnet thickness of PMIM	4 mm
9.	Core material	caLocal 400

Design of the subsystem-2 of the proposed FPWT machine is presented in Table (2). It can be classified as a Variable Frequency Rotary Transformer (VFRT) machine. It is composed of primary and secondary windings. In both windings, the number of turns is 50. However, their coils' number is different, i.e. for the primary side, there are eight coils and for the secondary side, there are nine coils per phase.

Table (2): Design and specification of subsystem-2 of FPWT

No	Parts	Value
1.	The rotor rated speed	3000
2.	Coil material	Copper 5.77e7 Siemens/meter
3.	Air-gap thickness	0.5 mm
4.	Core material	Losil 400

Table (3) lists the system parameters that are used in the simulation model in this paper, where the acquired results are presented in the next sections.

Table (3): The system parameters

No.	Parameters	Value
1	Rated wind speed (m/s)	8
2	Maximum wind speed (m/s)	12
3	Minimum wind speed (m/s)	1
4	Rotor diameter (m)	5.5/11
5	Number of rotor plates (-)	3/3
6	Generator type	Synchronous/ Induction
7	Excitation	PMs
8	Number of poles (p)	10
9	Maximum voltage (V) from the stator of subsystem-1	400
10	Frequency of induced voltage of subsystem-1 (Hz)	83
11	No. of slots for stator and inner rotor of subsystem-1	27
12	Maximum voltage (V) from the stator of subsystem-2	1000
13	Frequency of induced voltage of subsystem-2 (Hz)	166.6
14	No. of slots for stator and inner rotor of subsystem-2	27/24
15`	Output voltage (V)	380 AC

3. Results and Discussion

The terminal voltage in the stator winding and in the inner rotor windings of subsystem-1 are shown in Figure (7). The FEM simulation is carried out at the speed of the inner rotor and outer rotor 3000 rpm and 1000 rpm respectively. Due to the inner rotor windings being connected electrically with the rotor of the subsystem-2 rotor windings, the voltage in the subsystem-2 stator terminals is produced as demonstrated in Figure (8).

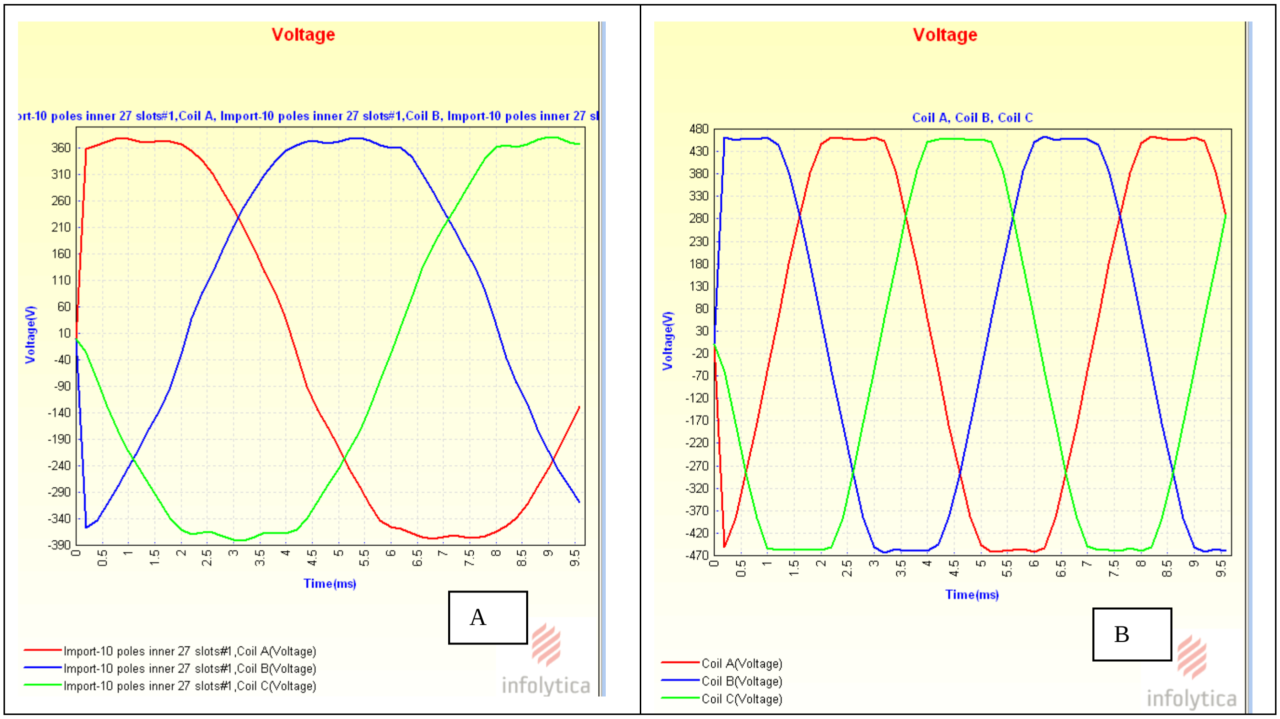

Figure (7): The voltage produced in windings of, A: The stator windings of subsystem-1 and B: The inner rotor windings of subsystem-1.

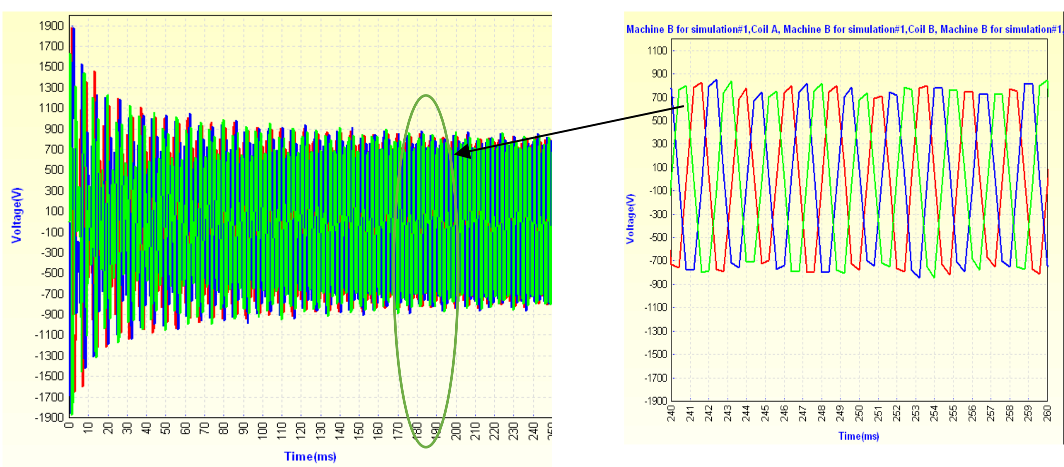

Figure (8): The voltage produced in windings of the stator windings of subsystem-2.

3.1 Calculation of wind turbine efficiency

The efficiency of the conventional wind turbines can be verified with its power coefficient (cp), which can be computed with the following equation [8]:

$$\mathbf{C_p} = \mathbf{P_{rotor}}/\mathbf{P_{wind}} = \mathbf{T.\omega/0.5\,.\,\rho.A.v^3} \qquad (1)$$

Where, the C_p is the power coefficient, P_{rotor} is the mechanical power generated by the rotor, P_{wind} is the power generated by the wind, T is the torque on the rotor, ω is the rotor's angular velocity, ϱ is the density of the air, A is the swept area, v is the freestream velocity. The swept area for dual rotor wind turbines may alter depending on the second turbine's position and kind of its driven. its value can be $A_1 = \pi \cdot r^2$ and $A_2 = 2 \cdot \pi \cdot r^2$ (r is the swept area's radius). Also, the mechanical power generated by the rotor will be more than the single rotor. These factores will give more output power than the single wind turbines. Therefore, the proposed double wind turbines have more efficient system [8].

$$\boldsymbol{\lambda} = \mathbf{\omega.R_B}/\mathbf{v} \qquad (2)$$

The second parameter which is important for wind power energy is the tip speed ratio which illustrates the relation between the wind turbine's angular speed and the wind speed, and it can be calculated by previous equation (2)[8], where λ is the tip speed ratio, ω is the angular velocity, R_B is the blade's radius and v is the freestream velocity. This parameter may improved due to two rotors have been installed.

Conclusion

Finite element Modelling (FEM) is a frequently used method for modelling and analysis of electrical machines. As a numerical analysis method, FEM allows for including any practical material. A 2D model of the Four-Port Horizontal Wind Turbine (FPWT) subsystem-1 is given, solved, some simulation result is given, these results give an effective way to design and calculate the proposed system performance. This work is the necessary preparation for designing high reliability and high security of FPWT system. Althogh, this proposal system may increase the cost of the whole system, the improvement of the production power is considered much more advantageous. This is because two generators in this system related to each other.

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