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Research Article

Optimization of a Management Algorithm for an Innovative System of Automatic Switching between Two Photovoltaic and Wind Turbine Modes for an Ecological Production of Green Energy

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Abstract. Today, renewable energy and energy efficiency are key to limiting global warming and preventing the dangerous effects of climate change. The biggest problem with conventional solar and wind turbine systems is the intermittency of electrical power generation. Even if these two energy sources can be complementary, the space occupied by these hybrid systems remains very important. This work proposes an improved management algorithm for a patented transformable photovoltaic-wind system, which mainly uses two flexible photovoltaic panels which are automatically deformed by an electromechanical system from the planar shape to the semi-cylindrical shape of the Savonius wind turbine blades. When weather conditions change, this system switches to eco-friendly photovoltaic (PV) or wind turbine (WT) mode, allowing a good total power generation from two solar power sources or wind turbine power. The contribution brought for this work relates to the realization and the improvement of the management algorithm to determine a better change to the mode PV or the mode WT. The operation test was simulated in 8760 hours for the year 2021. This developed algorithm allows several theoretical calculations of the power produced from solar radiation and wind speed data, thereafter the algorithm compare and determines the overall power and selects the optimal PV or WT mode. In this study, the overall power generated by the invented system produces more electricity per hour, the power Pt increases by 75.55% compared to the power Pwt, and also the power Pt increases by 68.15% compared to Pvp power.

Keywords: PV mode, WT mode, Savonius, patented system, management algorithm, autonomous system.

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1. Introduction

The use of non-renewable energies has very heavy environmental impacts and increases rise the fossil fuels cost. The dependence on fossil fuels causes environmental degradation and dangerous effects of climate change, despite the progress and development of several clean energy systems (Sharif *et al.*, 2021). An energy transition is a necessity to be able to control greenhouse gas emissions, so it ensures greater energy independence and energy demand. Wind and solar sources are characterized by their intermittency causing incompatibility between production and consumption (Liu *et al.*, 2020), (Jithendranath *et al.,* 2021) but they are at the top of the presently developed renewable energy sources (Söder *et al.*, 2020). These resources are considered an excellent alternative to producing energy in a sustainable way (Jelti *et al.*, 2021), also they are the most energies studied by researchers in renewable energy (Lahlou *et al.,* 2021a).

Many studies in the literature have researched wind and solar resources and complementarities, among these searches we can find the improvement of wind-solar combinations at finer scales to mitigate renewable energy variability in China (Liu *et al.,* 2020). The implications of intermittency constraints for wind and solar energy in the Chinese electricity sector (Zhou *et al.*, 2018). The impact of wind-solar complementarities on the need for energy storage, and demonstrate the benefits that renewable energy brings to the grid (Solomon *et al.,* 2016). The impact of complementarity of small-scale hybrid energy systems on power supply reliability, modeling neural networks based on hybrid resources and parameters (Jurasz *et al.,* 2018). The optimization of grid-connected PV-wind hybrid system considering reliability, cost, and environmental aspects, the study of the network's ability to sell or buy energy from the hybrid system (Barakat *et al.*, 2020). The assessment of solar and wind synergies in West African countries' energy and climate policies shows a pronounced focus on decarbonizing power supply through renewable electricity generation (Sterl *et al.*, 2018).

The hybrid system consisting of wind and solar renewable energy sources is more beneficial than a system that only depends on one source of energy. In addition, the power supply from a hybrid system is more stable and reliable. In addition, optimization of the hybrid renewable energy system is crucial for researchers to maximize the energy output from the system with the lowest cost and highest reliability (Sohail *et al.,* 2022).

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The objective of this work about improving the management algorithm of the patented system, which combines two renewable energy technologies in one device. It can partially solve the problem of intermittency energy and optimizes the space occupied. Therefore, the management algorithm is developed in the "Stateflow/Simulink" application, which has made it possible to get the best PV mode, or WT mode in state transition diagrams after checking several theoretical calculations of the power produced from the solar and wind sources over time for one year. So, it allows us to find the total power, and select the optimal PV or WT mode. All the operations of the system are automatic and reduce the profitable surface compared to conventional hybrid systems.

2. Review of literature

2.1 Photovoltaic solar energy

Photovoltaic Photovoltaic solar energy is the transformation of sunlight into electricity in semiconductor materials. These photosensitive materials have the property of releasing their electrons under the influence of external energy. This is the photovoltaic effect (Zdanowicz *et al.,* 2022; Zeng *et al.,* 2022). A photovoltaic solar generator is composed of photovoltaic modules; they are composed of photovoltaic cells connected between them. The performance of a photovoltaic installation depends on the orientation of the solar panels and the areas of sunshine("Impact of Solar Gain on Energy Consumption and Thermal Comfort," n.d.; Magadley *et al.,* 2021).

Photovoltaic solar is an energy source, it has specific advantages, such as its operation generates no pollution and no greenhouse gas emissions, and it is made from silicon, which is its raw material widely available (Lo Piano and Mayumi, 2017). Photovoltaic technology has made enormous progress in recent years, it was necessary to find an alternative to the traditional photovoltaic module to be able to consume solar energy in all circumstances. The technological limitations of traditional solar cells will give rise to solar energy conversion systems that are flexible in form factor. The kind of solar panels is thin and flexible, capable of flexing 30 degrees for the majority of models (Sunpower, n.d.) and up to 248 degrees (Renogy, n.d.) for a specific model. This flexible solar panel weighs only 1/10 of the equivalent traditional model. Flexible solar panels can have different yields and power generation capabilities depending on several parameters. This type of flexible panel cools easily compared to a rigid panel and also produces electricity even when the weather is cloudy. It can be installed on curved surfaces and is also suitable for several new projects and applications (Kim *et al.,* 2021).

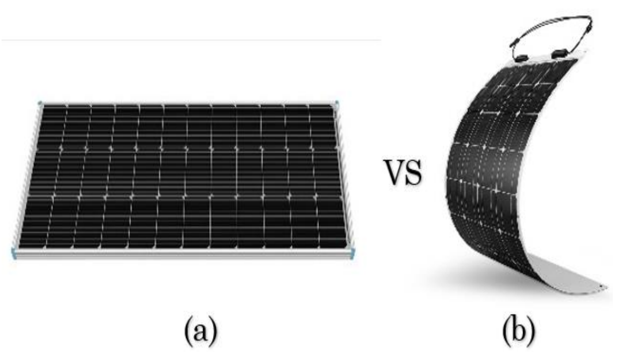

Fig. 1 Comparison "Renogy" (a) Rigid and (b) Flexible Solar PV Panel ("RNG-100DB-H," n.d.) and ("RNG-100D-SS G3 Datasheet.pdf," n.d.)

Table 1
Electrical data of "Renogy" flexible and rigid photovoltaic Monocrystalline solar panel

Electrical data	Flexible	Rigid
Maximum Power at STC	100 W	100 W
Optimum Operating Voltage (Vmp)	18.9 V	20.4 V
Optimum Operating Current (Imp)	5.29 A	4.91 A
Open Circuit Voltage (Voc)	22.5 V	24.3 V
Short Circuit Current (Isc)	5.75 A	5.21 A
Cell Efficiency	21 %	17.8 %

Source: ("RNG-100DB-H,"n.d.) and ("RNG-100D-SS G3 Datasheet.pdf," n.d.)

2.2 Solar cell efficiency

Photovoltaic efficiency is the most commonly used parameter to compare the performance of one solar cell to another. The photovoltaic efficiency (η) is defined as the ratio between the generated power (P_g) by the solar cell and received power by the sun (See equations 1 – 3 below).

$$\eta = \quad P_g \, / \, P_r \tag{1}$$

Knowing that the received power is given by equation (2):

$$P_r = R_s \, . \, A_s \tag{2}$$

So, the generated power is given by equation (3):

$$P_g = \eta \, . \, R_s \, . \, A_s \tag{3}$$

Where (R_s) is the Solar radiation, and the (A_s) is the area of solar panel.
The photovoltaic efficiency (η) depends on the intensity of incident sunlight and the temperature of the solar cell.

2.3 Temperature Effect

The variation in operating temperature of photovoltaic panels influences the performance of photovoltaic energy production ("Temperature effect," 2022). The temperature has a considerable influence on the behavior of the cell and its efficiency. This influence is mainly reflected in a decrease in the voltage generated and a very slight increase in current). Figure 2 shows the increase of temperature influences on the open circuit voltage, for a simulated standard photovoltaic solar module, which decreases linearly.

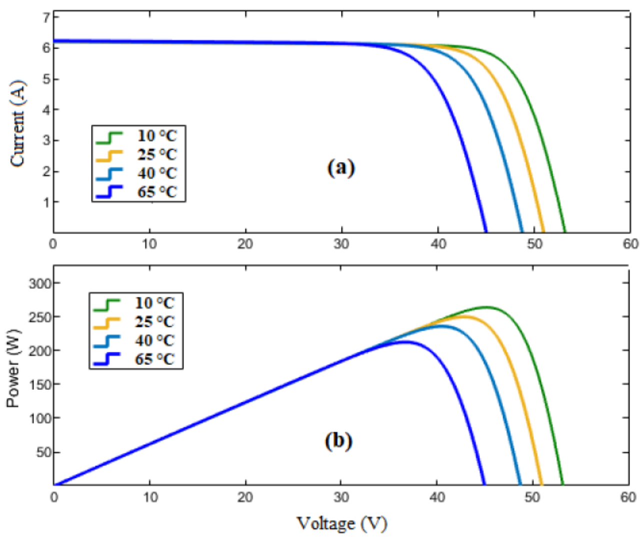

Fig. 2 The (a) I(V) and (b) P(V) characteristics at different ambient temperatures

Cell temperature varies not only due to changes in ambient temperature, but also due to insolation on the cells, only a small fraction of the insolation striking a module is converted into electricity and carried away, and most of the incident energy is absorbed and converted into heat.

Manufacturers often provide an indicator called NOCT (nominal operating cell temperature) to account for changes in cell performance with temperature. The NOCT is the temperature of the cells of a module when the ambient temperature is 20°C, the solar irradiation is 0.8 kW/m² and the wind speed is 1 m/s (STC) ("specifications of solar photovoltaic panels," 2022). The optimal value of NOCT for a photovoltaic panel is considered to be in the range of 40–45°C, to have less power lost during photovoltaic panel heating ("Sohani and Sayyaadi, 2020; Sun *et al.*, 2020). In general, to calculate the cell temperature at ambient conditions, we can use the equation (4):

$$T_{cell} = T_{amb} + \left(\frac{NOCT - 20}{0,8}\right) S \quad (4)$$

In our study case, the maximum photovoltaic power should drop by approximately 0.42%/°C, as depicted in Table 2.

The consideration of the temperature effect, is requisite for the calculation of cell temperature Tcell, by using equation (4) to get the mathematical model in block form Simulink. Figure 3 shows the mathematical model in blocks of cell temperature Tcell calculated from the real solar radiation data and the ambient temperature Ta, according to the normal operating cell temperature (NOCT) of the 100 W flexible solar panel from the thermal characteristics in Table 2, at standard test condition when the ambient temperature is 20°C, the solar irradiation is 800 W/m² and the wind speed is 1 m/s ("Analysis of specifications of solar photovoltaic panels," 2022).

Table 2
Thermal characteristics of 'Renogy' 100W flexible and rigid photovoltaic solar panel

Thermal characteristics	Flexible	Rigid
Operating module temperature	-40°C to +85°C	
Nominal Operating Cell Temperature (NOCT)	45±2°C	47±2°C
Temperature Coefficient of Pmax	-0.42%/°C	-0.37%/°C
Temperature Coefficient of Voc	-0.31%/°C	-0.28%/°C
Temperature Coefficient of Isc	0.05%/°C	0.05%/°C

Source: ("RNG-100DB-H,"n.d.) and ("RNG-100D-SS G3 Datasheet.pdf," n.d.)

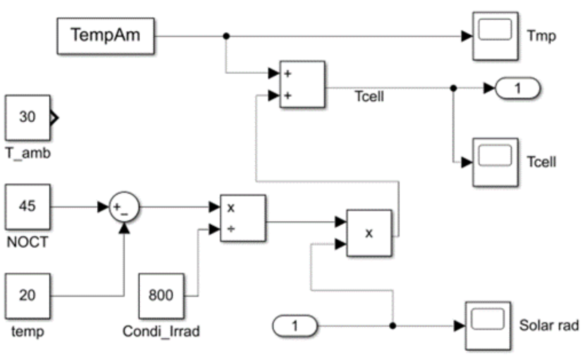

Fig. 3 Mathematical model in blocks form to calculate the cell temperature

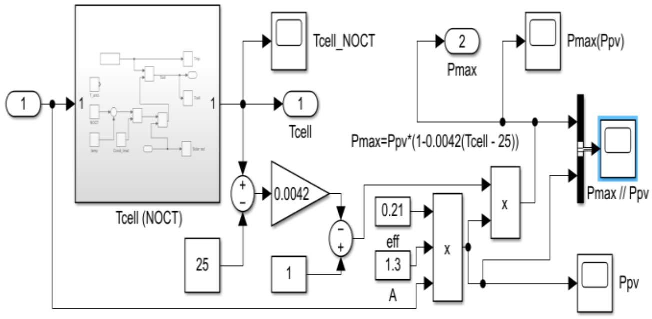

Fig. 4 Mathematical model to calculate the Ppvmax and Ppv

In this calculation method, we used the electrical characteristics shown in Table 1 of two flexible monocrystalline solar panels of 100w power and 21% efficiency ("RNG-100DB-H_spec.pdf," n.d.),

According to Table 2, at standard temperature, as the VOC voltage decreases by 0.31%/°C, the new VOCmax with temperature effect is given in equation 5

$$V_{OCmax} = V_{OC}[1 - 0.0031(Tcell - 25)] \quad (5)$$

To calculate the maximum PV power with temperature effect, (show equation 6)

$$P_{pvmax} = p_{pv}[1 - 0.0042(Tcell - 25)] \quad (6)$$

Cell temperature varies not only due to ambient temperature changes but also due to insolation on the PV cells. The mathematical blocks forms are realized in Figure 4, also, the calculation of the maximum photovoltaic power generation P_{pvmax} with temperature effect according to the Tcell and Ppv in equations (3) and (5).

2.4 Savonius wind turbine

Wind energy is one of the most promising renewable energy resources for power generation. Today, many countries in the world depend on this source to produce a part of their energy needs. The wind turbines convert the wind's kinetic energy into electrical energy. The vertical axis wind turbines (VAWT) have a rotational axis of the turbine perpendicular to the ground. They are primarily used in small wind projects and residential applications. Vertical axis turbines are powered by the wind coming from all directions (360 degrees), which is an advantage on a site where the wind direction is highly variable; also, they are classified as operating in very low wind speed, low vibration, and low noise.

The aerodynamic efficiency of the turbine is defined by the power coefficient (Cp), which is the ratio of the power of the wind turbine and the power of the wind speed given in equations 7 - 9 (Mrigua *et al.*, 2020), (Zemamou *et al.*, 2020).

$$C_P = \frac{P_{turbine}}{P_{wind}} \quad (7)$$

Knowing that (P_{wind}) is the wind speed power is provided by the equation (8):

$$P_{wind} = \frac{1}{2}\rho A_S \vartheta^3 \quad (8)$$

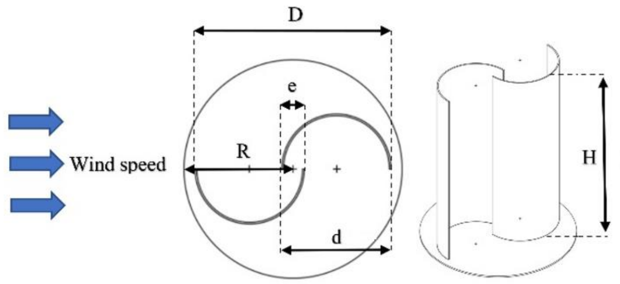

Fig. 5 Schematic representations of a Savonius vertical wind turbine

Table 3
Electrical data of wind generator (Scheaua, 2021) and (Lee *et al.*, 2018)

Specifications	Data
Rated wattage	600 W
Operating Voltage	12 V / 24V
turbine swept area	1 m^2
Start wind speed	2 m/s
Safe wind speed	45 m/s
Power coefficient	0.3

Where, (ρ) is the air density, (A_s) is the swept area, and (ϑ^3) is the cubic wind speed.

And also, ($P_{turbine}$) the wind turbine power is provided by the equation (9).

$$P_{turbine} = C_p P_{wind} \quad (9)$$

The geometric parameters of the turbine in Figure 5 such as the diameter (D), the rotor blade radius (R), the overlap (e), and the height (H) have an important role to decide the performance of the wind turbine rotor.

The considered vertical axis wind turbine for this work has about 600 W wind generator and gearbox with several specifications as seen in Table 3. The simulation of the mathematical models is made in Simulink as shown in Figure 6, The calculation of the wind energy production Pwt is done by this block model in Figure 6, from the input data of the wind speed and other parameters given in Table 3.

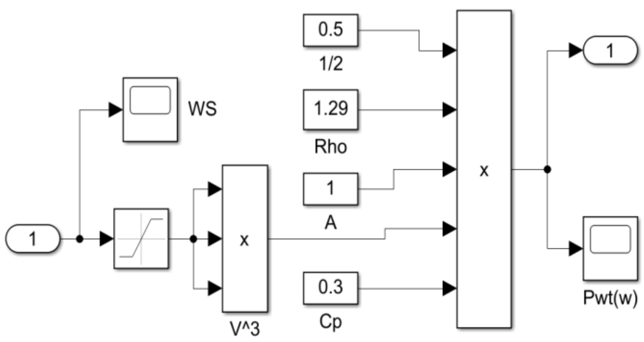

Fig. 6 Mathematical block model wind turbine power generation

3. The compact system developed

3.1 Description of the operating principle

The traditional photovoltaic and wind systems require a large installation area and do not generate continuous electric power, due to intermittency (Jithendranath *et al.*, 2021; Liu *et al.*, 2020; Sovacool, 2009; Zhou *et al.*, 2018). In this study, the patented system (Lahlou *et al.*, 2021) combines solar and wind power into a compact self-transforming device that can produce clean electricity and request just a small area of installation. The algorithm used an improving operating method. Figure 7 shows the general principle. The patented system (Lahlou *et al.*, 2021) allows an ecological production of green energy over time, according to the input parameters of the solar radiation, ambient temperature, and wind speed, so after the power calculation of Ppv and Pwt, the algorithm selects automatically to transform in photovoltaic (PV) mode or wind turbine (WT) mode. The system uses a mechanism responsible for bending the PV modules, controlled by the embedded electronic and artificial intelligence.

3.2 Description of the invented compact system

The invention of Lahlou *et al.*, (2021b) represents a compact system (two in one) for the power generation from PV and WT modes. This device is mainly based on two flexible solar crystalline modules which automatically switch from a PV mode (Figure 8a), where the modules adopt a planar shape, into Savonius wind turbine mode (Figure 8b), with semi-cylindrical concave and convex modules, and vice versa.

The bending mechanism ensures the transformation procedure to the flat format of the flexible modules. The system has also a seasonal solar tracking system used just for the PV mode, to ensure different inclined positions, as shown in Figure 8a. The flexible modules are symmetrical and well attached, which allows vertical rotation of these semi-cylindrical shaped modules by wind speed effect. The invented device is based on a vertical mast, which supports the flexible PV modules in inflected format, this system attaches to the ground with the necessary foundations, which ensures its stability while rotating modules, then the electrical generator produce electrical energy, as shown in Figure 8b.

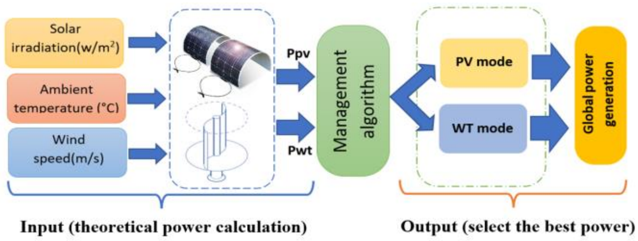

Fig. 7 Schema of operating principle in two modes.

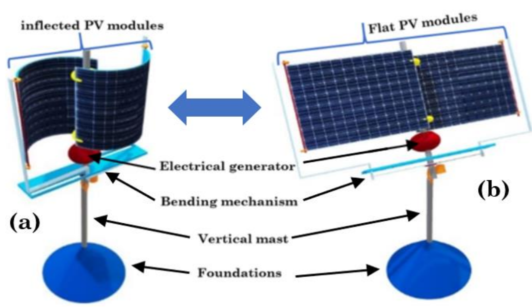

Fig. 8 Presentation of the invented system in (a) WT mode and in (b) PV mode

3.3 Benefits compared to conventional systems

In urban areas there is a lack of exploitation of renewable energies despite their availability, which is mainly due to insufficient installation space, cannot support conventional systems, and also providing energy needs. In addition, the electrical production of traditional systems is intermittent and depends on favorable conditions and their availability. On another side, the investment required is still significant for the majority of consumers (Liu *et al*., 2022).

The patented system by Lahlou *et al*., (2021) can keep a high efficiency while dynamic operating because the cleaning and cooling of its flexible modules happen naturally. The investment cost of this system is competitive because the majority of pieces of equipment are shared between PV – WT modes. Therefore, this invented system can improve electrical production with the contribution of the improved algorithm, and also reduce the space occupied compared to existing systems.

3.4 Management of the developed algorithm

The objective of this study is to develop an algorithm that depends on the variation of the input signals of solar radiation and wind speed that provide the behavior of the system (see Figure 9). The invented system adopts the configuration wind turbine mode or PV mode, which ensures the maximum generation of electricity according to the algorithm in Figure 10. This algorithm defines the correct operation of the system according to the experimental input data of solar radiation, ambient temperature, and wind speed. The algorithm calculates and compares the theoretical power of photovoltaic and wind turbine sparely. Therefore, to select finally the PV or WT mode for the operation of the invented device, if the start threshold is not checked, the system remains in intermediate mode (Abdelghani *et al*., 2021). Finally, the total power is generated from PV and WT modes, with an accumulation of both modes' states.

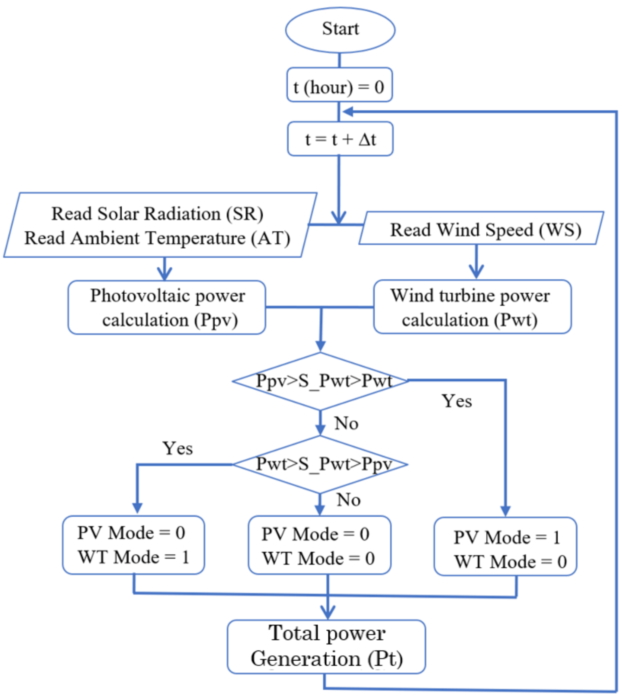

Fig. 9 Algorithm for different operating modes for the invented system

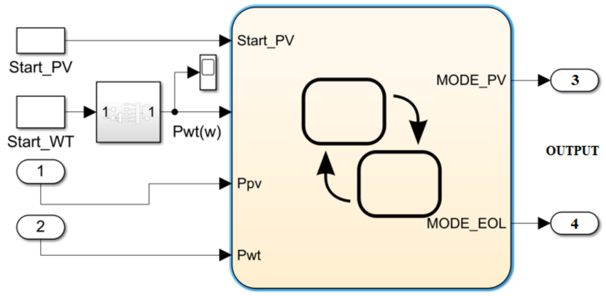

Fig. 10 Presentation of the algorithm equivalent realized in Stateflow/Simulink

The simulation results of the proposed management algorithm are developed and modeled under MATLAB/Simulink with the "Stateflow" application, which allows switching between PV or WT mode when the values of the conditions are verified (See Figure 11).

3.5 Calculation of total power production:

To compare the analysis of the results obtained from this algorithm applied to the invented system, we have gathered the previous subsystems shown above in Figures 3, 4, 5, and 10, in a new subsystem in block form.

The instructions and conditions used on the previous algorithm in Figure 9, are also applied to the algorithm block equivalent in Figure 10, for example, the threshold values to start the generation of photovoltaic and wind production are well chosen after several tests. Then, we integrated this algorithm with other subsystems to get the global system in block format shown in Figure 11.

To obtain the algorithm results for the invented system, In the beginning, we used different input parameters to calculate the generated powers of photovoltaic and wind turbine by mathematical modeling method for each subsystem separately, in the next step, after analyzing and showing the added value in this study, test and compare the performance of the algorithm is done at the end.

At standard conditions, we calculated separately the generated power from photovoltaic and wind turbine in Watt, then the algorithm will compare them to choose the optimal operating mode of the invented system. Finally, the total power generated by this system will be determined. The global system works intelligently to output relevant results based on different input data of solar radiation, ambient temperature, and wind speed.

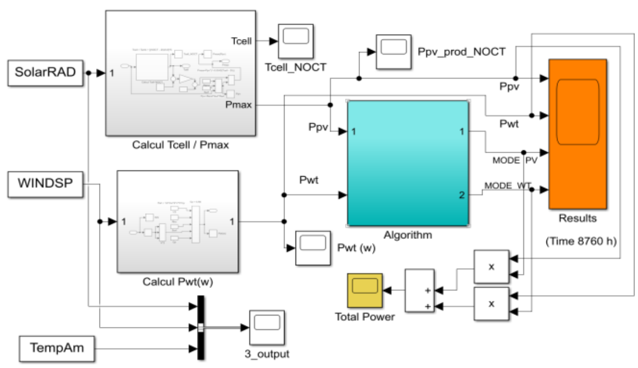

Fig. 11 Overview of the global system in the block model for the best power generation switching algorithm by calculation and analysis

4. Results and analysis

4.1 The experimental data case study

In this case study, we used climate data from the city of Basel, which is located in northwestern Switzerland, near the French and German borders, 300 meters above sea level. The climate of Basel is moderately continental, with cold winters and fairly hot summers (Epting *et al*., 2020).

A good analysis of the algorithm performance needs several real input data of solar radiation, ambient temperature, and wind speed for this study. All the input experimental parameters are got from ("Weather History Download Basel," n.d.) for each hour during the year 2021 of Basel city in Switzerland as shown in Figure 12. The climatic parameters considered for this region of Basel allow us to test the functioning of the improved algorithm in various situations. Therefore, they are more relevant compared to other regions (Ren *et al*., 2021) and (Zhang *et al*., 2022).

Figure 12a shows the evolution of real solar radiation data, which can reach 890 W/m2 during 8760 hours in one year. The presentation of the curve of several values can not better visualize the results, so this is why we considered just 48 hours as shown in Figure 13 for solar radiation. So, Figure 13 has a maximum value of approximately 820 W/m2 for real solar radiation input data, such as (Rajput and Dheer, 2021), which is interesting to get a good test of the algorithm in this scenario, this period study is considered also to present the photovoltaic power generated as shown in Figure 15.

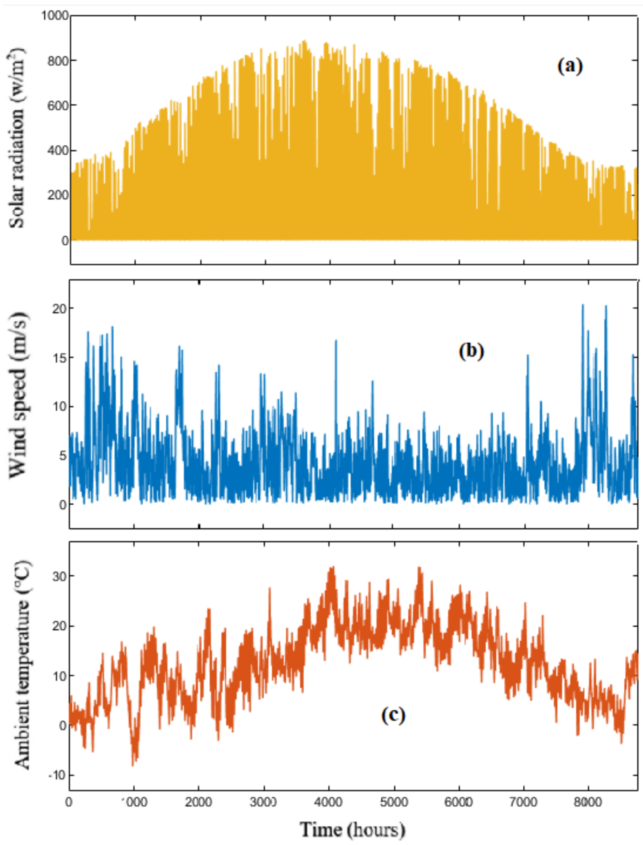

Fig. 12 The experimental data of (a) solar radiation, (b) wind speed and (c) ambient temperature for each hour during the year 2021 of Basel city in Switzerland ("Weather History Download Basel," n.d.)

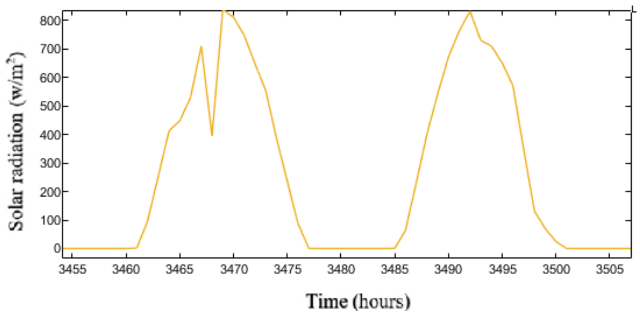

Fig. 13 Real solar radiation input data for 48h

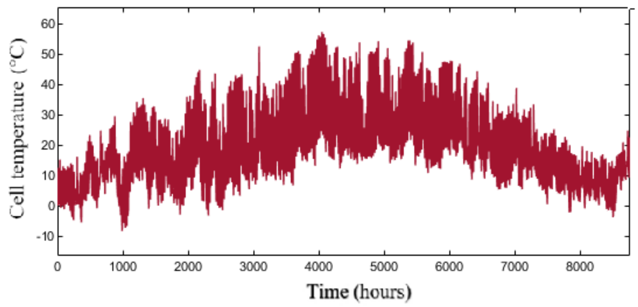

Fig. 14 Cell temperature Tcell during 2021 according to the NOCT.

4.2 Cell temperature calculation

All the ambient temperature (AT) input data are used first to calculate the cell temperature (Tcell) and then to obtain the photovoltaic power generated with and without the effect of temperature. The results of the Simulink block from (AT) data in Figure 12c allow us to get the Tcell shown in Figure 14. The cell temperature (Tcell) calculated, provides several fluctuations with a maximum increase of 57°C for the Tcell, such as (Al-Bashir *et al*., 2020) and (Rajput and Dheer, 2021), which depends proportionally on the ambient temperature (AT) input data, with a peak of 33°C, presented in Figure 12c, for the year 2021.

4.3 Photovoltaic power results with and without temperature effect

The temperature effect on the PV modules is shown after the PV power is calculated with and without the temperature effect. The corresponding Ppv and Pmax results during 48h from experimental solar radiation input data shown in Figure 13 are combined in the same Figure 15.

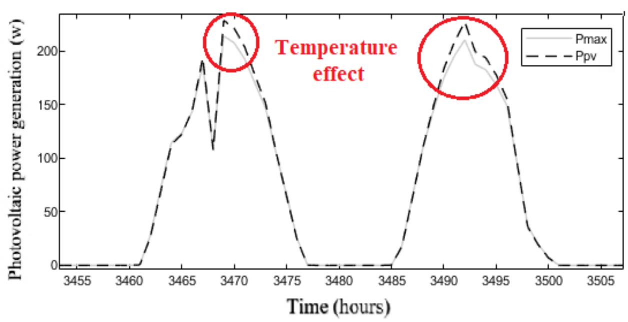

Fig. 15 Calculation of Ppv without temperature effect and Ppvmax with température effect for 48h

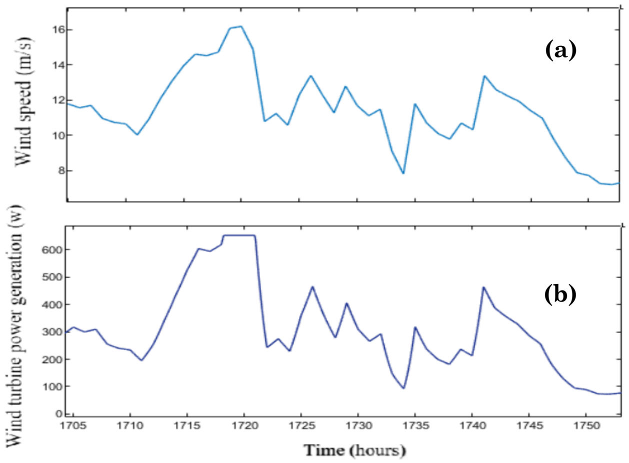

Fig. 16 (a) Wind speed input data, (b) Wind turbine power generation results during 48h

The temperature has a negative effect on the photovoltaic power, which allows performance decreases. Figure 15 shows a comparison of this reduction for P_{max} and P_{pv} production, which reach in 48h about 215 W with temperature effect, and 230 w without temperature effect. Therefore, it decreases by 7% according to the NOCT temperature considered in this case, compared to other studies in the literature, the effect of the temperature reduces the PV power by 7.8% (Aish, 2015) and also about 10% (Sun *et al.*, 2020) from experimental data too.

4.4 Wind turbine power results

The curve of Figure 12b shows the evolution of real fluctuation wind speed data for the year 2021 hourly, it can reach about 20 m/s in this case. Figure 16a presents one considered scenario for real wind speed data, which fluctuates between 7.2 and 16.2 m/s for 48 hours. The results of wind turbine power generation can reach more than 650 W during 48 h as shown in Figure 16b.

The changing of different wind speed values influence the wind turbine power generation in this same period considered. In addition, the influence of the vertical wind and wind direction on the power output has been experimented with a small vertical-axis wind turbine that is installed on the rooftop of a building, so when the wind speed is greater than 8 m/s, the power output becomes greater and reaching 400 W (Lee *et al.*, 2018).

4.5 Total power production results

After checking the weather conditions and calculating the possible energy production of both modes, the algorithm provides an output state system of PV or WT mode. The system states have an important role to select only the optimum powers from solar and wind sources, in calculating the total power output generation as shown in Figures 17 and 18.

The algorithm results depend on the input climatic conditions which are determined at the beginning, about the solar radiation, the ambient temperature, and the wind speed which are selected for this study. These input data allow us to get different values of PV and WT power generation, and also for system state for both modes of the invented system, to get the results of total power generation of the system. The curves representation of both results for the year 2021 (see Figure 17), then just for one representative scenario in 48h (Figure 18).

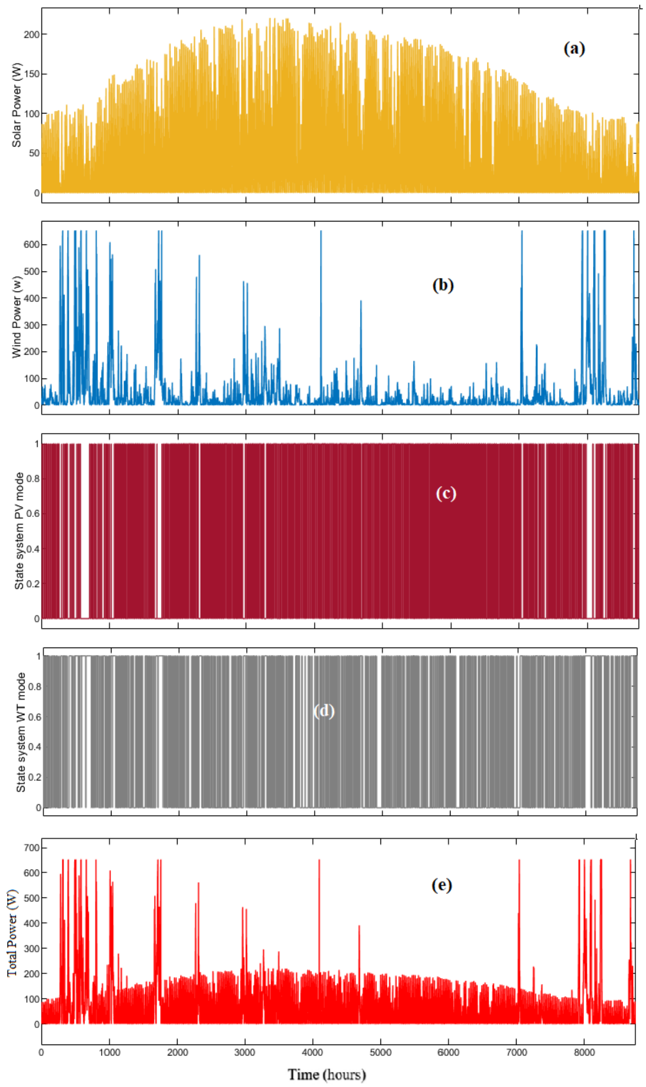

Fig. 17 Results calculation for 2021 of (a) photovoltaic power generation, (b) wind turbine power generation, (c) system state for PV mode, (d) system state for WT mode, (e) total power system generation.

The The hourly evolution of photovoltaic power generation is shown in Figures 17a - 18a, also for wind turbine power generation is shown in Figure 17b – 18b, then the system state for PV mode (Figure 17c – 18c) and system state for WT mode (Figure 17d – 18d), and finally total power system generation (Figure 17e – 18e) for the operating system respectively.

The behavior of the algorithm studied in the scenario is shown in Figure 18e for 48h. The invented system, from the beginning to the end generates energy by taking advantage of the best energy sources available and it is more effective when the climatic conditions are complementary. After calculation and comparing the generated powers Ppv and Pwt, the system states results are shown in Figures 17 – 18. The optimal operating mode is also obtained, when the state mode is "1" the mode is activated and when the level is "0" the mode is deactivated. The algorithm provides order to the invented system for transforming into operating mode may produce more electrical during that period. In this case study, we have the results plotted over the year 2021 for each hour (8760h) as shown in Figure 17e, to have a good comparison between conventional photovoltaic, and wind turbine powers and also between the total power generated by the patented system managed by this improved algorithm.

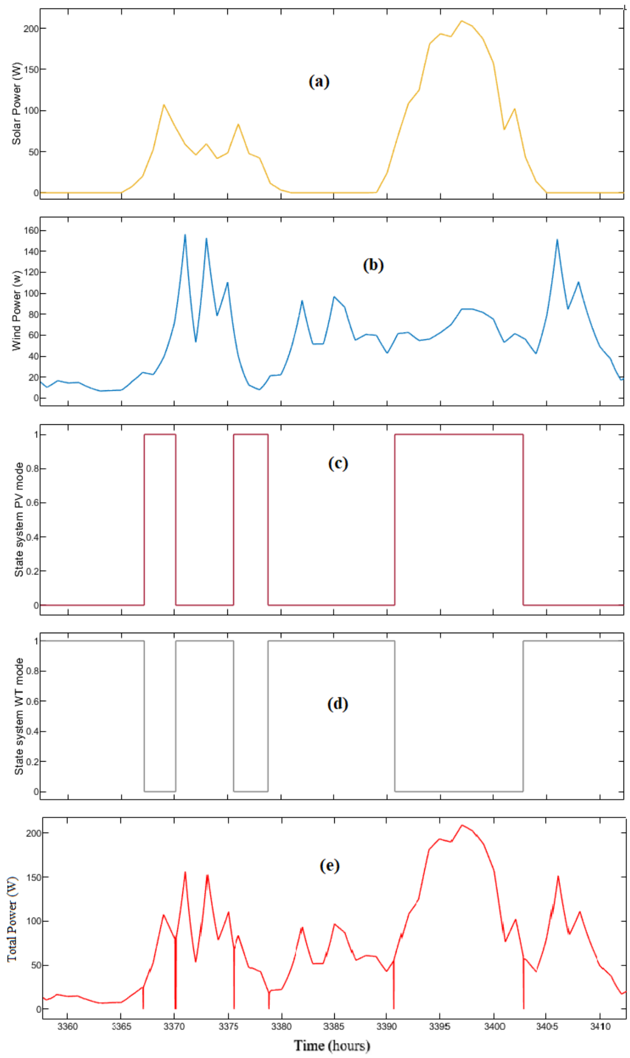

Fig. 18 Scenario results calculation for 48h selected of (a) photovoltaic power generation, (b) wind turbine power generation, (c) system state for PV mode, (d) system state for WT mode, (e) total power system generation.

The average value got from one year hourly, for both powers calculation Ppv reach 43.44 W and Pwt reach 41.61 W, and the average value of Pt is 73.05 W generated by the invented system in this case study. The Pt increases by 75.55% compared with Pwt and also the Pt increases by 68.15% compared with Ppv. The comparison rate between the invented system and photovoltaic, wind turbine conventional systems separately.

The invented system power generation represents 46.20% which is almost double compared these conventional systems separately, the photovoltaic rate has 27.48% and the wind turbine rate has 26.32%. The results obtained from the improved algorithm make it possible to show the added value of the invented system compared to traditional systems. This system also makes it possible to automatically switch to WT mode, during the night and even when the wind speed decreases to the minimum value.

5. Conclusion

The objective of this work is to improve the invented system operating with an optimal algorithm suggested especially for this case study with the weather conditions chosen. The system allows electricity generated with high efficiency, and also optimizes the space occupied, it is based on a flexible photovoltaic used also as blades. The system can switch between PV and WT modes to continue the production of electricity.

The algorithm developed has a major interest, especially to make the invented system adapted to different situations and according to climate change. To determine the most consistent mode, which provides more power generation in different scenarios, the operating mode will be selected after analysis of the input climatic data, and calculate separately the generated power of photovoltaic and wind turbine, then the algorithm compare to choose the optimal operating mode of the invented system, finally, the total power generated of this system will be got. We have obtained the results which are generated during one year for 2021, also for a selected 48 hours to better analyze and interpret the curves. We calculated the average value of power generated for all hours of the year to compare the performances of the conventional photovoltaic, conventional wind turbine with the patented system. The obtained results have an important contribution to the field of renewable hybrid energy systems. This system suggested has high efficiency, allows space-saving, and also has commercial potential, it has a power generated Pt increases by 68.15% compared with Pwt, and increases by 75.55% compared with Ppv, which is almost double (46.20%) compared to these conventional systems photovoltaic (27.48%) and wind turbine (26.32%) separately.

In the next work, we suggest a realization of a prototype on a pilot scale, to get practical results and to demonstrate the transformation step into the operation mode according to the case adopted.

Abbreviations

PV	Photovoltaic	WT	Wind turbine
P_{pv}	Photovoltaic power generation (w)	P_{wt}	Wind turbine power generation (w)
STC	Standard Test Condition	λ	tip speed ratio (TSR)
η	Photovoltaic efficiency (%)	A_r	area swept by the rotor blades (m2)
P_g	Generated power (w)	ρ	air density (kg/m3)
P_r	received power (w)	C_p	power coefficient
R_s	Solar radiation (W/m2)	ϑ	Wind speed (m/s)
A_s	area of solar panel (m2)		
NOCT	Normal Operating Cell Temperature (°C)		

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