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Physical Modeling of a Multisource System (Wind Turbine, Solar Panel) and Management with Simscape Language

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ABSTRACT: Being sustainable and producing little waste products, the renewable energy knows a rapid deployment. Unfortunately, the intermittent characteristic of these energies makes them difficult to control. The influence of this aleatory character can be reduced with the coupling of two or more sources of renewable energy and secondly with a sound management of storage systems. This new configuration of production and energy management is the target of our research.

The objective of this paper is to construct a model of a multi-sources system feeding a domestic house with the multi-physics approach which enables us to model, simulate and control all components and subsystems in our system consisting of wind turbine, solar panel and storage system with battery. This system feeds a domestic house.

To achieve this objective, firstly, a system description is presented. Secondly, a SIMSCAPE model for the multisource system is developed in the MATLAB/SIMSCAPE software. Finally, results are derived from simulations.

KEYWORDS: Multi-physic system; multisource system; wind turbine; photovoltaic panel; battery; SIMSCAPE

I. INTRODUCTION

For a system as complex as a hybrid system (wind turbine, solar panel), the ability to simulate the physical systems (mechanical, electrical, hydraulic, etc.) and control systems in a single environment is crucial to the development process.

This paper carried out a Matlab/Simscape model of a hybrid system (photovoltaic panel, wind turbine) which makes possible the prediction and the optimization of overall system performance.

The first part of this paper introduces the hybrid or multisources system. The system feeds a domestic house in Tetouan/ Morroco. The energy consumption of this house consumption is calculated and the hybrid system dimensioning is presented in the second part.Then, we model the system with MATLAB/Simscape software a powerful tool for physical modeling.

II. HYBRID OR MULTISOURCE SYSTEM

a. System presentation

Renewable energy is booming. Unlike fossil fuels, it is sustainable and generates a green power.

However, the intermittent nature of the power production of these systems prevents the massive application and use of those solutions.

To overcome this problem, the hybrid renewable energy system or multi sources system appears as a potential solution for the energy production thanks to the reliability of support whatever the weather conditions [1].

This system comprises more than one energy source, at least one of which is renewable. The hybrid system may include a storage device [2].

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Hybrid systems, even if they are very complex compared to current solutions mono source systems, are interesting due to their incomparable flexibility and their attractive cost price [3]. Also, a good system management minimizes the cost of energy storage and optimizes the production capacity.

There are several combinations of hybrid systems, namely: wind-diesel, photovoltaic-diesel, and wind-photovoltaic-diesel [4].

In our case, the system chosen to power a domestic home is the wind-photovoltaic system with battery storage. For this system, we distinguish between an alternate and a parallel system [5]. The alternate system is the combination of a wind system and a photovoltaic system connected by a system of switching between them depending on weather conditions. On the other hand the parallel one connects the two sources at the same time to the battery.

The system chosen in our study is the parallel one which is illustrated in the Figure 1 bellow.

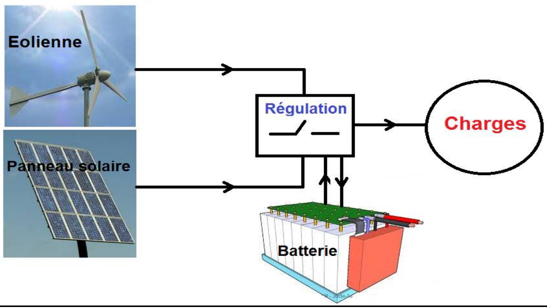

Figure 1. Hybrid system (wind turbine, solar panels, battery)

b. Wind energy systems

i. Wind energy basics

Wind turbines are systems that harness the kinetic energy of the wind for useful power. Wind flows over the rotor of a wind turbine, causing it to rotate on a shaft. The resulting shaft power can be used for mechanical work, like pumping water, or to turn a generator to produce electrical power.

There are two types of wind turbines : Horizontal Axis Wind Turbines and Vertical Axis Wind Turbines. Most wind turbines are built today with the horizontal-axis design, which offers a cost-effective turbine construction, installation, and control by varying the blade pitch.

ii. System components

The wind power system comprises one or more wind turbine units operating electrically in parallel. Each turbine is made of the following basic components as shown in Figure 2 bellow:

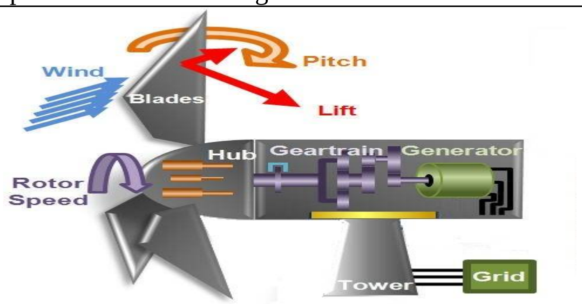

Figure 2. Wind turbine system [19]

- Tower structure

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• Rotor with blades attached to the hub. The three-bladed concept is the most common concept for modern wind turbines. It is dynamically more stable and has better visual impact. It converts the energy in the wind to rotational shaft energy.
The mechanical power available at the output of the rotor is given by the Equation (1).

$Pm=1/2.\rho.pi.R^2.v^3.Cp(\lambda,\beta)$	(1)

Cp is the power coefficient or performance coefficient which indicates the efficiency with which the turbine converts the mechanical energy of the wind into electricity. This coefficient differs according to the turbines.
In our case, the coefficient is given by the relation in Equation (2). It is the most used formula.

$Cp=0.22(116/\lambda'-0.4a-5)*\exp(-12.5/\lambda')$	(2)

With a is the angle of attack of wind turbine and λ' depends on λ and a as shown in Equation 3.

$1/\lambda'=1/(\lambda+0.08a)-0.035/(a^3+1)\rho$	(3)

And λ is the specific speed witch is calculated by the Equation (4).

$\lambda=U/v=\omega.R/v$	(4)

with U is the tip speed of the blades, v is wind speed, R is the radius or length of the blades and ω is the rotational frequency of the rotor (in rad / s). β is the pitch angle of the blades
• Shaft with mechanical gear : The power from the rotation of the wind turbine rotor is transferred to the generator through the power train which increase the speed.
• Electrical generator :
The generator is what converts the turning motion of a wind turbine's blades into electricity. The two types of electric machines commonly used in the wind turbine industry are synchronous and asynchronous machines.
The mechanical equation that present the machine is given by the Equation (5).

$J\ d\Omega m/dt = Cem - f\Omega m - Cr$	(5)

Where Ω is the mechanical rotational speed, Cr is the load torque, J is the moment of inertia of the rotating part and f is the coefficient of viscous friction.
• Control mechanisms:
The wind turbine technology has changed significantly in the last 25 years. Large wind turbines being installed today tend to be of variable-speed design, incorporating pitch control and/or power electronics(electronic converters).

Pitch angle control system consists of varying the pitch angle (from a certain value to 0°) of the blades around the hub by a longitudinal axis to stop the blades if the wind speed is below the inflow speed (generally 4m/s) or above the rated speed in order not to destroy the system [6].
To vary the positioning of the blades according to the wind speed, we can use a crank-rod system actuated by a hydraulic generator [7][8].
The second solution which can be used is composed of a DC motor which rotates the blade when it gets an electrical command.

c. Photovoltaic system
i. System presentation

Solar or photovoltaic system energy is the most important renewable and sustainable energy system. Solar-electric-energy system has grown consistently and become a popular resource of energy. The main reasons for this huge attention are: 1) increase in efficiency of solar cells; 2) recent technological improvements; 3) green and environmental friendship [9].

ii. Principle of a photovoltaic cell

A photovoltaic cell is a sensor consisting of a semiconductor material absorbing light energy and transforming it into electrical current. The principle of operation of this cell uses the properties of light absorption by the semiconductor materials.

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It is the basic element of a photovoltaic generator.

A photovoltaic cell can be carried out with many semiconductors. In reality, today there are three main technological fields: crystalline silicon, thin films and organic cells [10].

iii. Solar/photovoltaic cell model

In Matlab/SIMELECTRONICS, a ready to use block 'solar cell block' is formed from a single solar cell as a resistances *Rs* connected in series with a parallel combination of a current source, two exponential diodes and a parallel resistor *Rp* [9], [11] [12] (as shown in Figure 4 bellow).

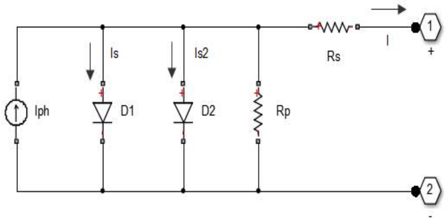

Figure 3. Equivalent circuit diagram of the SimElectronics solar cell [9][13]

iv. Connecting multiple Solar cells

There are 3 ways to connect solar panels; parallel, series, and a combination of both.
To increase the current, you can connect pairs of panels in parallel. In this case, all the positive terminals of the cells are connected together as are all the negative terminals.
To increase the voltage, you can connect pairs of panels in series by connecting the positive terminal of one panel to the negative of the next.
To increase both the current and the voltage we use the two types of combination.

d. Battery

Because the renewable energy source is intermittent, it is necessary to store it for times of low or no renewable energy production.
There are many types of energy storage. The most common is the batteries which store electricity in a chemical form.
There are many brands and types of batteries. Currently, Lead Acid batteries offer one of the best compromise between cost and usable service rendered.

III. DIMENSIONING OF THE HYBRID SYSTEM FEEDING A DOMESTIC HOME

a. Implantation site

The site chosen is in Tetouan city.
The climate data of this site (shown in Figure 5) which is the NASA data is obtained from Retscreen software.

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Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	13,2	75,7%	2,70	99,5	4,3	13,2	149	99
February	13,9	76,2%	3,58	99,4	4,7	14,2	115	109
March	15,2	75,8%	4,84	99,1	4,7	16,2	87	161
April	16,3	72,5%	5,98	98,9	4,9	18,1	51	189
May	18,7	72,3%	6,68	98,9	4,6	21,1	0	270
June	22,3	69,9%	7,54	99,0	5,0	25,0	0	369
July	24,8	68,3%	7,60	98,9	4,7	27,5	0	459
August	25,3	69,0%	6,90	98,9	4,4	27,1	0	474
September	23,1	73,4%	5,54	99,0	4,4	24,7	0	393
October	19,8	76,9%	3,95	99,0	3,9	21,1	0	304
November	16,5	76,4%	2,83	99,1	4,5	17,2	45	195
December	14,2	77,2%	2,30	99,4	4,4	14,4	118	130
Annual	18,6	73,6%	5,04	99,1	4,5	20,0	564	3 152
Measured at m					10,0	0,0		

Figure 4. Tetouan climate data [15]

b. Calculating domestic consumption

The first step in designing is to find out the total power of all loads that need to be supplied by the hybrid system.
Our hybrid system is supposed to supply a domestic house not connected to the power grid and equipped with required household appliances.
The estimation of the daily energetic needs is presented in the Table 1 below.

TABLE 1. Total consumption of the domestic charges

Equipement	**Power (W)**	**Service life**	**Daily consumption (Wh)**
Priority loads			
lighting (8 bulbs)	*80*	5	400
refrigerator	75	8	600
Computer	250	4	1000
Non-priority loads			
Television	100	7	700
Washing machine	450	2	900
Total priority loads			2000
Total non-priority loads			1600
Total loads			3600
Total estimated consumption=Total loads*1.2			4320

We multiply the total loads by 1.2 to get the total estimated consumption which must be provided by the system. The twenty percent of the extra energy is added to take into account the losses during storage and conversion of current.

c. Dimensioning of the wind turbine

In our case, we chose a wind turbine with the following characteristics:
Diameter: 6 meters
Tower height: 12 meters
Generator type: asynchronous machine
Therefore, with an average speed of 4.3 m/s, we obtain an electrical power of 2210 watts.

d. Dimensioning of the photovoltaic panel

To find out the sizing of PV module, the total peak watt produced is needed. To obtain the total peak watt, we divide the total loads needed from the PV panels by a coefficient called panel generation factor.
This factor is different from one location to another since it depends upon the climate of the site. For Morocco, the panel generation factor is 4. So, for our study, the size of the PV panel is 500 peak watts.
The number of cells in series n is obtained by dividing the module voltage by the cell voltage [20]. In our case, n=24/0.5.
The number of cells in parallel m is equal to the module current divided by the cell current [20]. The module current is equal to the total power divided by module voltage that is to say: 2000/24.
Then, the number of cells is 8064 and the module surface is 20 m².

e. Battery dimensioning

The battery should be large enough to store sufficient energy to operate the equipments when there is no power produced by the hybrid system at night and cloudy days.
To size the battery, the calculation of the battery ampere-hour capacity factor is needed.
The required battery capacity is obtained from the following Equation 7:

$$\text{Battery Capacity (Ah)} = \frac{\text{Total loads x Days of autonomy}}{(0.8 \text{ x nominal battery voltage})} \quad (6)$$

0.8 is the value of the depth of discharge.
Then, our battery has the capacity of 675 Ah rated at 24V for 3 days autonomy.

IV. PHYSICAL MODELING OF HYBRID SYSTEM (WIND TURBINE, PHOTOVOLTAIC PANEL) IN SIMSCAPE

a. Interest for multiphysics modeling of multisource system

The complexity of the hybrid system requires first a laborious design and rigorous management of electrical energy produced which can be provided only by a reliable modeling.
This is why in this paper, we chose the multiphysical modeling because of the necessity to model, simulate and controle the whole system in a single environment contrary to traditional modeling process in which the result can only be tested together when hardware prototypes have been produced since the various subsystems are created in separate software and simulation environments. Using this method, an engineer could build up a library of component models that could be reused in a variety of models in a variety of applications contrarily to the signal-based methods in which the mathematical model is dependent upon location in system making it difficult to reuse [16][17].
These advantages are due to the object oriented and non causal modeling which offers this approach.
The SIMSCAPE language is based in this appraoch. It is a toolbox developed by the MathWorks for Simulink, and it has been available since version R2007A of the MATLAB suite [18]. It includes a foundation library, which contains basic components for electrical, hydraulic, mechanical and thermal systems, and an utilities library, which contains utility blocks [19].
There are also more specialized toolboxes for physical modeling (such as SimDriveline, SimHydraulics, SimElectronics and SimMechanics) that now are considered as parts of the Simscape product family.
In R2008b, a major upgrade of Simscape was made, introducing the Simscape language which allows the users to create their own physical models, and even new physical domains [18].

b. hybrid system model

The Figure 5 below represents the hybrid system block with the statefow chart.

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The hybrid block subsystem model is illustrated in the Figure 6 below. The wind turbine block generates the wind energy while the solar panel block is the source of the photovoltaic energy. The battery block stores the surplus of produced energy.
This hybrid system feeds a variable charge modeled in the Figure 16 bellow.
The wind turbine produces an alternating current this is why the block universal bridge is used to convert the power.
This block implements a universal three-phase power using in our case the diodes power electronic devices.
the wind turbine and the solar panel subsystems are
connected with current sensor and voltage sensor blocks to measure the current and voltage across these subsystems.

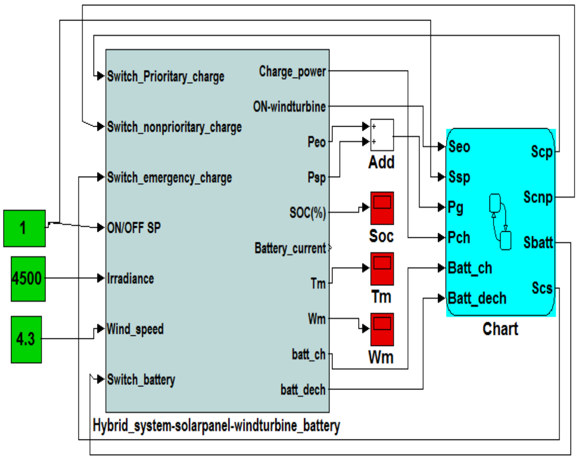

Figure 5. Hybrid system model in Simscape

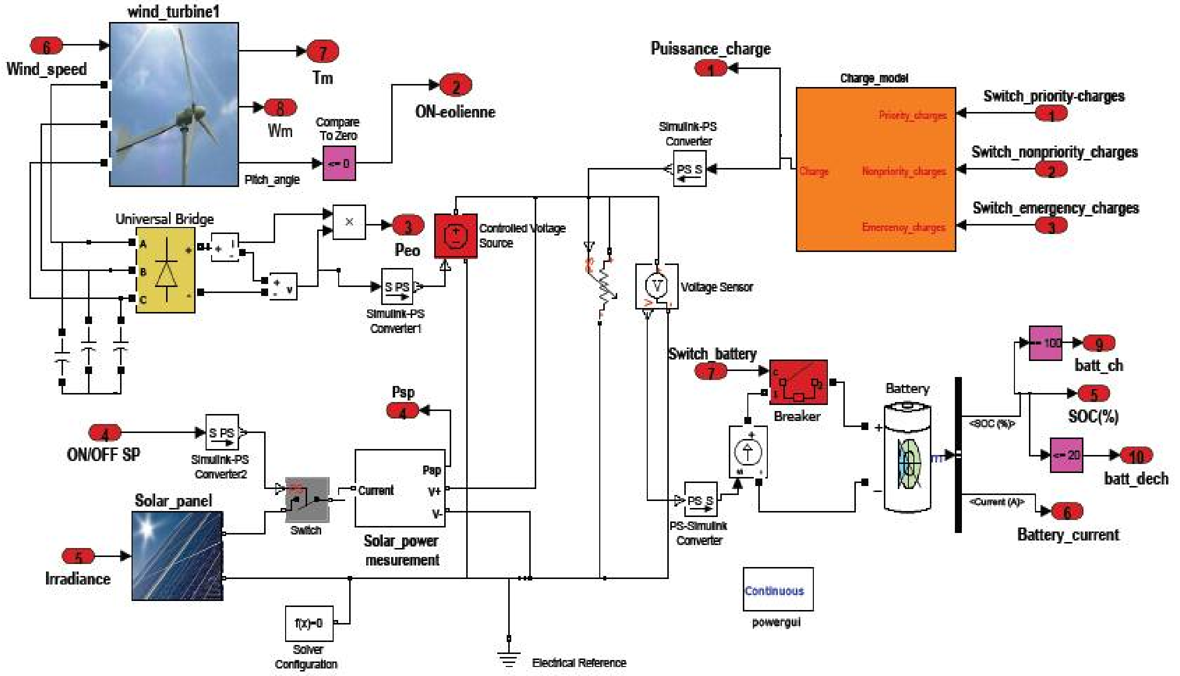

Figure 6. Hybrid subsystem block

c. Wind turbine model

The Figure 7 below represents diffent blocks of physical systems that constitute the wind energy system.

The block ‘ wind couple’ shown in Figure 8, calculates the aerodynamic torque applied to the blades. This torque depends on the wind speed, the speed of the generator and the pitch angle. It turns the blades and therefore the hub which constitute the rotor. This motion can be visualized in 3-D animation provided by Simmechanics environment in which the block ‘rotor’ is modeled (Figure 9).

We can multiply the speed of rotation of the wind turbine using a gearbox as shown in Figure 10. The SimDriveline tool enables modeling driveline systems which consist of one or more inertias and masses, rotating about or translating along one or more axes, constrained to rotate or translate together by gears, which transfer torque and forces to different parts of the driveline.

The torque at the output of the block gear_train is that applied to the generator’s shaft.

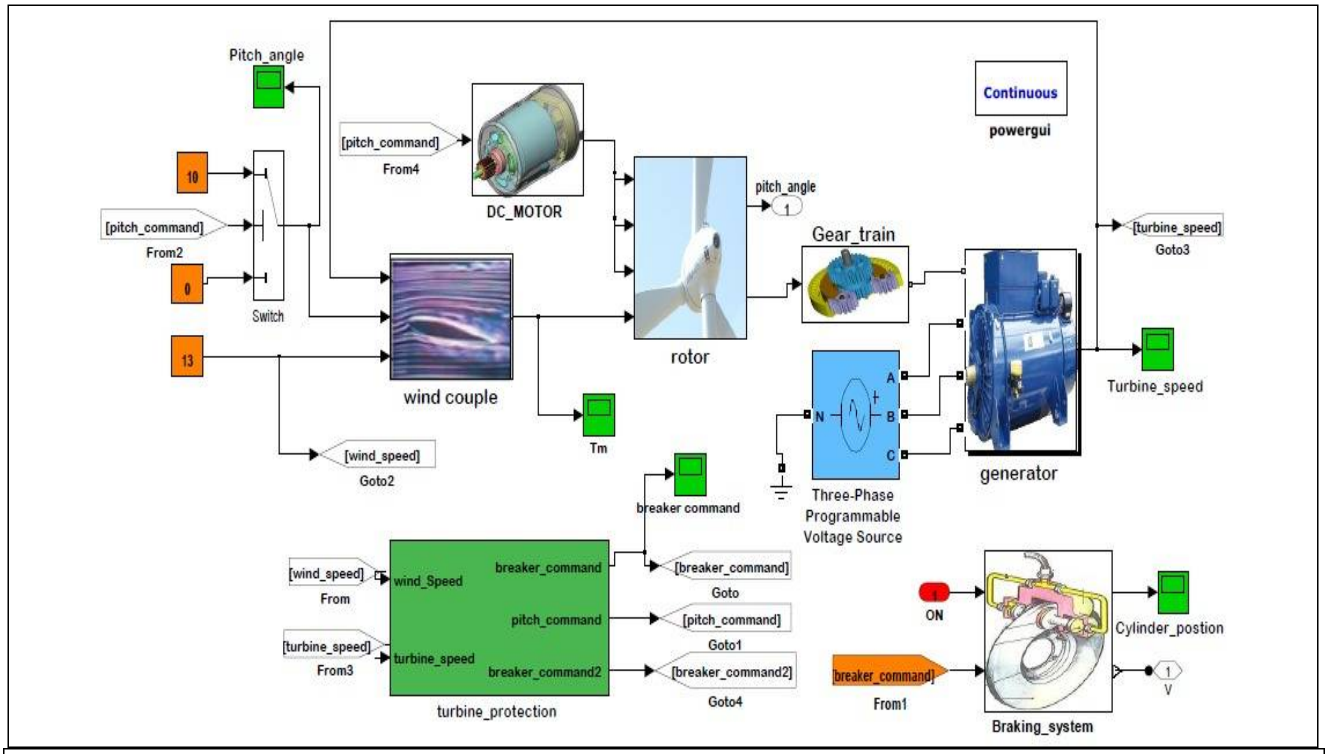

Figure 7. Wind turbine model in SIMSCAPE

i. Model of wind couple subsystem

The calculation of the wind couple is based on Equation (1) which is linearized to form a transfer function.

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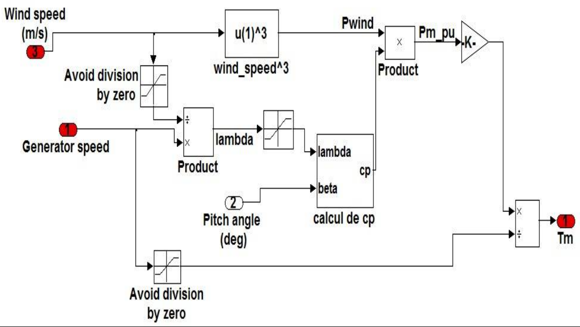

Figure 8. Wind couple model

ii. Model of rotor subsystem in SIMMECHANICS

The blades and the rotor are represented by bodies connected by joints representing the possible motions of bodies relative to one another (shown inFigure 10).

The rotor and blades can rotate relative to ground.

Also, the blades can make a rotational movement relative to the hub to vary thereby the pitch angle.

The bodies are modeled with Body blocks specified by their masses, inertia tensors, and attached Body coordinate systems (CSs).

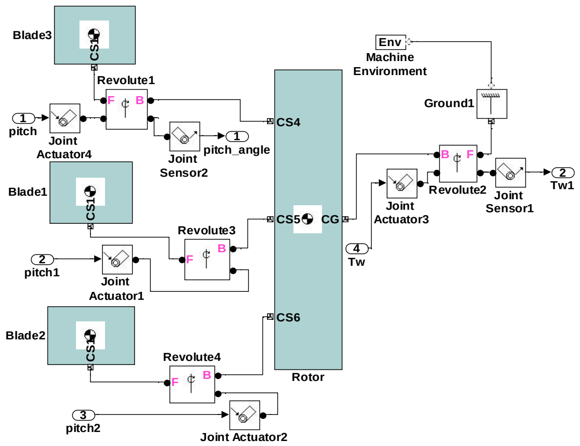

Figure 9. Rotor model

iii. Model of gear train

In the model below (shown in Figure10), simple and planetary gears are used to transfer torque up and down the driveline axes. The Inertia block represents a rotating body specified by its moment of inertia. The choice of planetary gear and simple gear is made to have a greater gear ratio. Otherwise, we can settle for a simple gear.

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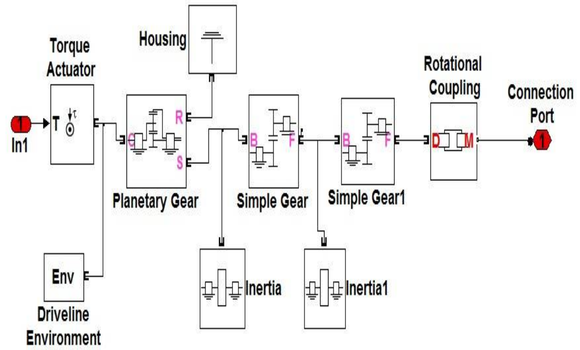

Figure 10. Model of gear train

iv. Model of the asynchronous machine

The model illustrated in the Figure 11 below consists of an asynchronous machine block ready to use and the loop speed command of the generator based on the Equation (7):

J dΩm/dt = re –fΩm-rr	(7)

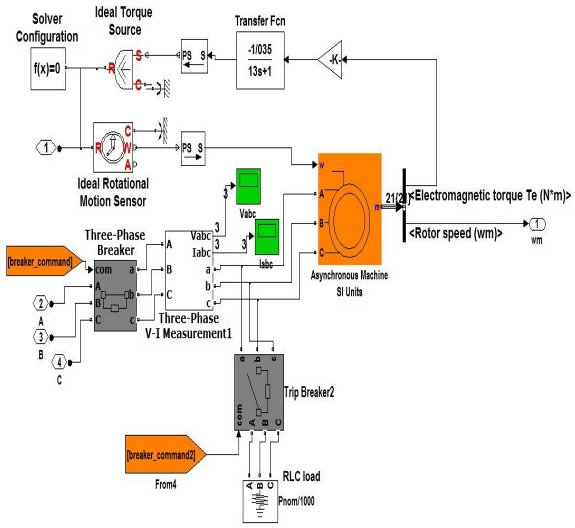

Figure 11. Model of generator subsystem

V. MODEL OF TURBINE PROTECTION

Protection system (modeled in the Figure 12 below) permits immobilizing the wind turbine when the wind reaches a certain strength or when the wind speed is below a certain value by changing the pitch angle of the blades for zero engine torque (beta = 0) (shown in Figure 13). Also, in case of over speed's generator, it allows triggering the breaker in order to disconnect the wind turbine from grid (shown in Figure 14) and varying the pitch angle to 0.

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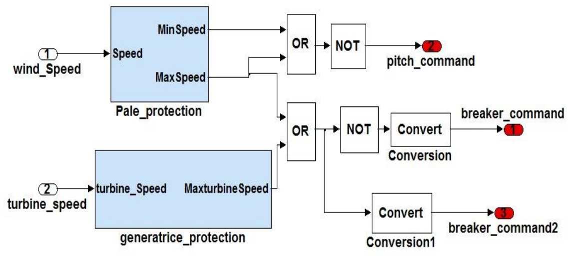

Figure 12. Turbine protection model

For the blade protection, if the wind speed is less than 4 m /s or above 25 m /s for a time of 0.05 seconds, the pitch angle value switches from 10 to 0.
In order to protect the generator, we switch the pitch angle to 0 and trigger the circuit breaker if the generator's speed exceeds the rated speed by 20% for a period of 0.05 seconds.

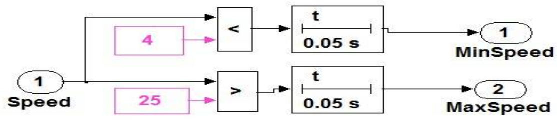

Figure 13. Models of blade protection

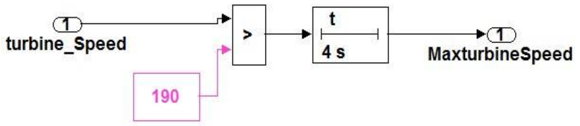

Figure 14. Models of generator protection

a. Photovoltaic panels model

The solar panel modeled in the Figure 6 above, is obtained by interconnecting in series and in parallel the solar cell block available in SIMELECTRONICS as shown in Figure 15 below.
We have 8064 solar cells.

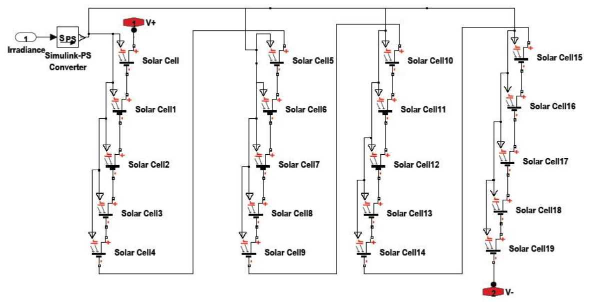

Figure 15. Solar panel model part

b. Charge model

As shown in Figure 16 below, the charges are divided in three types:

- Priority charges which must not be triggered unless there is no energy production

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- Non priority charges: when the energy production is lower than the loads consumption, an unballasting of these charges is made to avoid tripping the circuit breaker on all load.
- Emergency charges which must be switched on when there is an overproduction and the battery is totally charged.

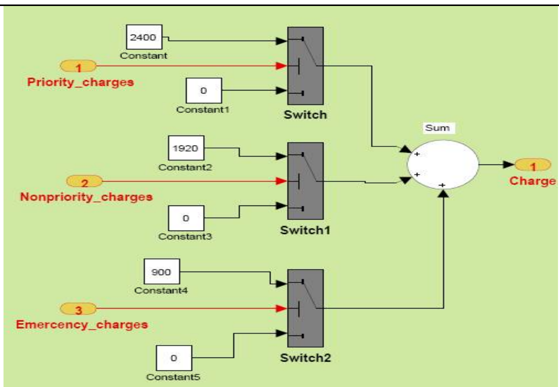

Figure 16. Charge model

c. Stateflow chart

In the Figure 17 below, Scp is the priority charges switch, Scnp is the non priority charges switch, Scs is the emergency charge and Sbat is the battery switch.
If the system is on (the wind turbine and or the solar panels are on, Seo and or Ssp are closed) and the power produced (Pg) is greater than the charge power (Pch), all loads are fed except the emergency one which is switched on if the battery is charged (Batt_ch is true).
The priority charges are switched off if the power produced is less than the total charges consumption and the battery is discharged (Batt_dech is on).
In order to protect the battery against deep discharging, we switch it off if the SOC is less than or equal to 20%.

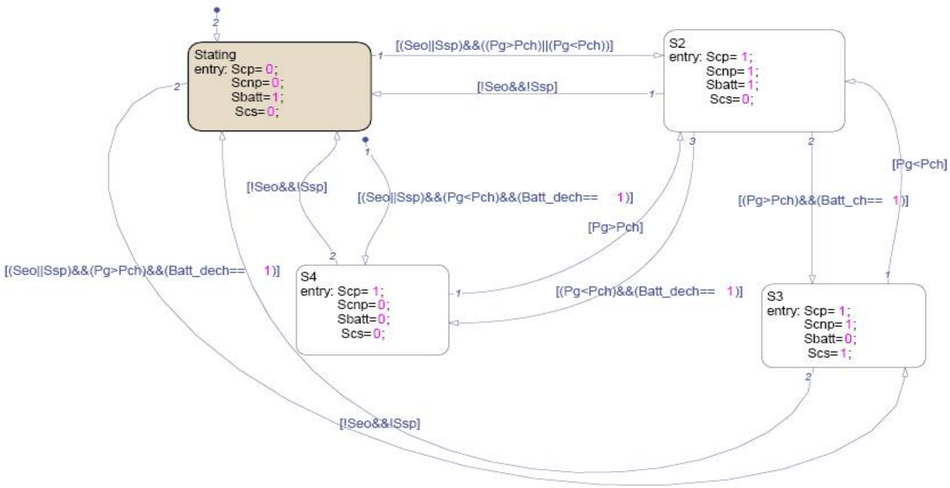

Figure 17. Control stateflow chart model

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VI. SIMULATION RESULTS AND DISCUSSION

For the wind speed and the irradiation chosen, the produced power is greater than the loads consumption. Therefore, as it is shown in the Figure

18a below, the battery is totally charged at the time 300s. So, in this time, the state of battery Batcharg which indicates that the battery is totally charged is on (Figure 18b).

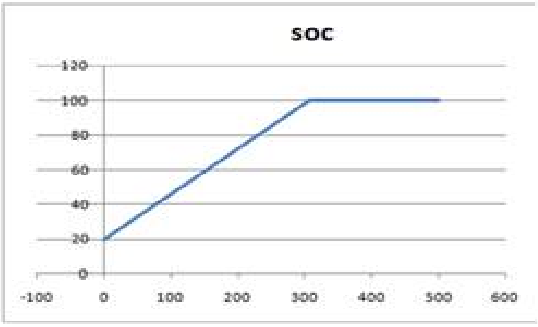

Figure 18a. Battery state of charge

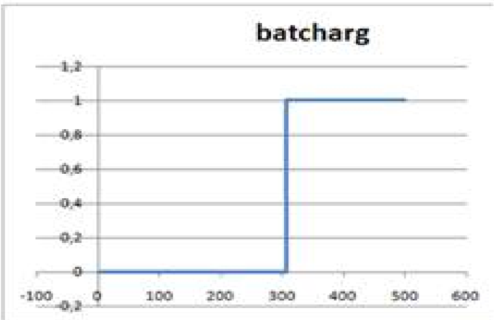

Figure 18b. Battery charged state switcher

Then, we switch off the battery (Figure 19a) and we

feed the emergency charges (Figure 19b).

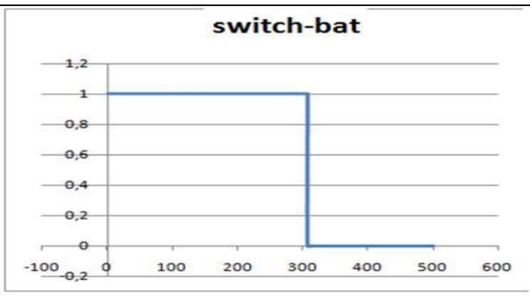

Figure 19a. Battery switcher

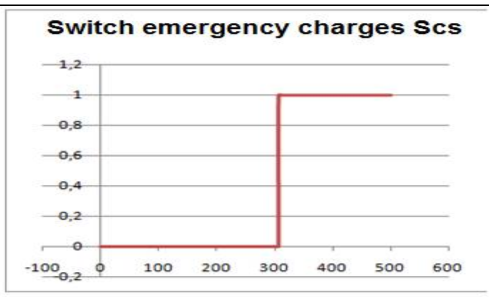

Figure 19b. Emergency charge switcher

In the Figure 20a below, the value of the total charges passed from 4320 to 5220 at the time 300s, the time of switching on the emergency charges.

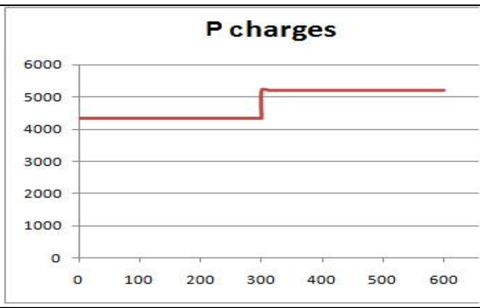

Figure 20a. Total charge power

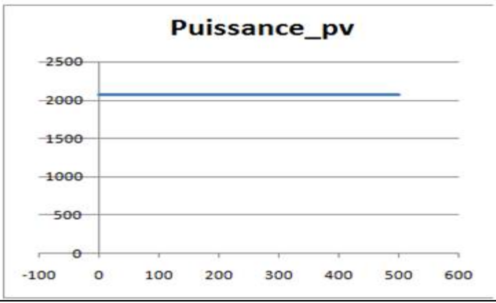

Figure 20b. Solar panel produced power

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The total produced power of the solar panel is shown in the Figure 20b above and the generator speed is shown in the Figure 21 below. This speed stabilizes at the rated speed 148m/s (the generator rated speed is 157m/s +/-10%).

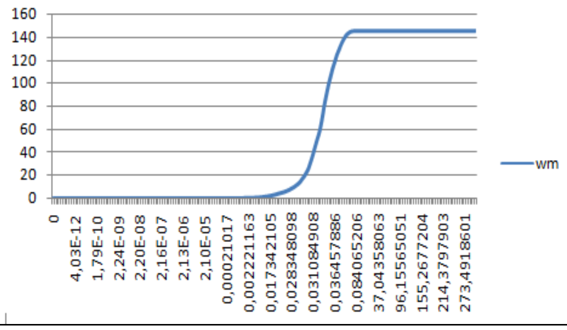
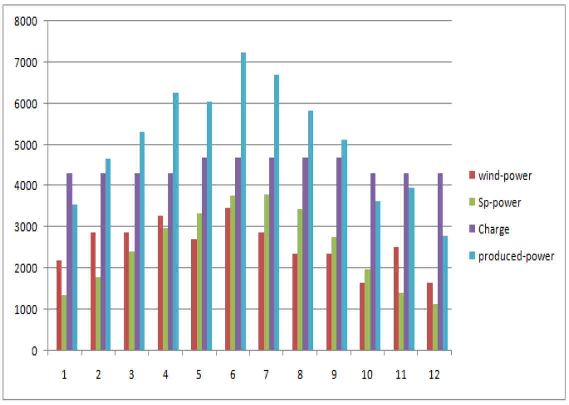


Figure 21. Wind turbine generator speed



The figure above shows the monthly energy production of the wind turbine and solar panels and the monthly charge distribution. In this figure, the charge presents an evolution during the summer period from May to September. This variation is due to the increased consumption of the refrigerator which is supposed to work 12 hours per day during the summer period instead of 8 hours.

We also find that the system covers all needs demand during the period from February to October. For the remaining months, system production is low due to low wind speed and low irradiation. A good power management as proposed in paragraph 1 may solve this problem

VII. CONCLUSION

In this paper, a Matlab/SIMSCAPE model for a hybrid system (wind turbine, photovoltaic panel) was presented and developed. A calculation of the consumption of a domestic load is made in order to size our system supposed to feed a domestic house.
The whole system model was simulated and the results show how powerful is the Simscape language for multiphysics and multidomain modelling.
The performance of the system shows that it is not necessary to

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