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RESEARCH NOTE

Physical Modeling of a Hybrid Wind Turbine-solar Panel System Using 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.

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1. 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.

In this work we 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. It differs from my previous papers called “physical network approach applied to wind turbine system with simscape language” [1] and “physical network approach applied to solar panel systems feeding a domestic house” [2] by coupling both systems and presenting a single model.

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 is calculated and the hybrid system dimensioning is presented in the second part. Then, we model the system in MATLAB/Simscape software, a powerful tool for physical modeling.

2. HYBRID OR MULTISOURCE SYSTEM

2. 1. System Presentation Renewable energy is booming. Unlike fossil fuels, it is sustainable and generates a green power. However, the intermittent nature of the energy produced by 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 [3, 4]. This system comprises of more than one energy source, at least one of which is renewable. The hybrid system may include a storage device [5]. 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 [6]. Also, a good system management minimizes the cost of energy storage and optimizes the

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production capacity. There are several combinations of hybrid systems. Namely: wind-diesel, photovoltaic-diesel, and wind-photovoltaic-diesel [7]. 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 [8]. 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.

2. 2. Wind Energy Systems

2. 2. 1. 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 working, like pumping water, or to turning 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 today are built with the horizontal-axis design, which offers a cost-effective turbine construction, installation, and control by varying the blade pitch.

2. 2. 2. System Components The wind power system comprises of one or more wind turbine units operating electrically in parallel. Each turbine is made of the following basic components as shown in Figure 1.

- Tower structure
- Rotor with blades attached to the hub. The three-bladed concept is the most common one for modern wind turbines. It is dynamically more stable and has better visual impact. The rotor converts the energy of the wind to rotational shaft energy.

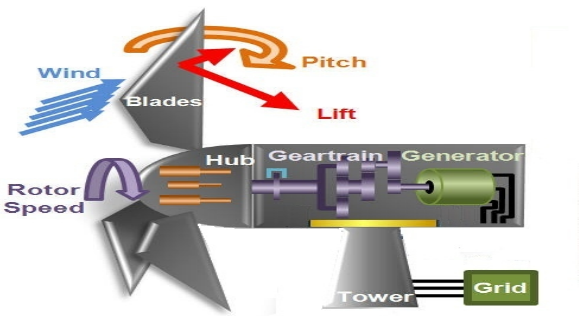

Figure 1. Wind turbine system [1]

[1] Mathworks guide (http://www.mathworks.com/help/physmod/elec/ref/solarcell.html)

The mechanical power available at the output of the rotor is given by the Equation (1).

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

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. The theoretical maximum coefficient of performance, 16/27, is never achieved by practical wind turbines due to the irregularities in the wind speed and other environmental factors. A more realistic value for the Cp for existing wind turbines range from 30-50% [9].

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.

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

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

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

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

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

where U is the tip speed of the blades, v wind speed, R the radius or length of the blades and ω 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 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 Equation (5).

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

where Ω is the mechanical rotational speed, Cr the load torque, J the moment of inertia of the rotating part and f 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[1]. To vary the positioning of the blades according to the wind speed, we can use a crank-rod system actuated by a hydraulic generator [10, 11]. The second solution which can be used is composed of a DC motor which rotates the blade when it gets an electrical command.

2. 3. Photovoltaic System

2. 3. 1. System Presentation Solar-electric-energy system has grown consistently and becomes a popular source of energy. The main reasons for this huge attention are: increase in efficiency of solar cells, recent technological improvements and green and environmental friendship [12]. It constitutes a primary and potential renewable energy source to all Cities in Morocco due to high irradiation in the region [13].

2. 3. 2. 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 which are the basic element of a photovoltaic generator.

A photovoltaic cell can be operated with many semiconductors. In reality, today there are three main technological fields: crystalline silicon, thin films and organic cells [14].

2. 3. 3. 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* [12, 15, 16] (as shown in Figure 2).

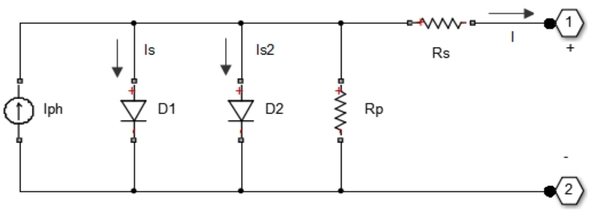

Figure 2. Equivalent circuit diagram of the SimElectronics solar cell [12]

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 3. Tetouan climate data [2]

2. 3. 4. Connecting Multiple Solar Cells There are three 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 voltage, we use the two types of combination.

2. 4. 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 storages. 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 compromises between cost and usable service rendered.

3. DIMENSIONING OF THE HYBRID SYSTEM FEEDING A DOMESTIC HOME

3. 1. Implantation Site The site chosen is in Tetouan/Morocco city. The climate data of this site (shown in Figure 3) which is the NASA data is obtained from Retscreen software.

3. 2. 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 daily energetic needs is presented in the Table 1. We multiply the total loads by 1.2 to get the total estimated consumption which must be provided by the system.

[1] Heliciel home page : http://www.heliciel.com/helice/helice-pas-variable.htm

[2] Climate database, Retscreen software.

The twenty percent extra energy is added to take into account the losses during storage and conversion of current.

3. 3. Dimensioning of the Wind Turbine

In our case, we chose a wind turbine with the following characteristics:

Diameter: 12 meters, Tower height: 12 meters and an asynchronous machine generator. Therefore, with an average speed of 4.3 m/s, we obtain an electrical power of 2210 watts.

3. 4. Dimensioning of the Photovoltaic Panel

To find out the sizing of the photovoltaic module, the total produced peak watt is needed. To obtain the total peak watt, we divide the total loads needed from the photovoltaic 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 [17]. 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 [17]. 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.

3. 5. 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. To size the battery, the calculation of the battery ampere-hour capacity factor is needed.

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

The required battery capacity is obtained from the following Equation (6):

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

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

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

4. 1. 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 [18, 19].

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 [20]. It includes a foundation library, which contains basic components for electrical, hydraulic, mechanical and thermal systems, and an utilities library which contains utility blocks. 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 [20].

4. 2. Hybrid System Model

Figure 4 represents the hybrid system block with the statefow chart. The hybrid block subsystem model is illustrated in the Figure 5 below. The wind turbine block generates the wind energy while the solar panel block models the photovoltaic energy source. The battery block stores the surplus of produced energy. This hybrid system feeds a variable charge modeled in Figure 15 below. The wind turbine produces 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.

4. 3. Wind Turbine Model Figure 6 represents diffent blocks of physical systems that constitute the wind energy system. The block 'wind couple' shown in Figure 7, 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 constitutes the rotor. This motion can be visualized in 3-D animation provided by Simmechanics environment in which the block 'rotor' is modeled (Figure 8). We can increase 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.

4. 3. 1. Model of Wind Couple Subsystem The calculation of the wind couple is based on Equation (1) which is linearized to form a transfer function.

4. 3. 2. 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 in Figure 8 below). 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).

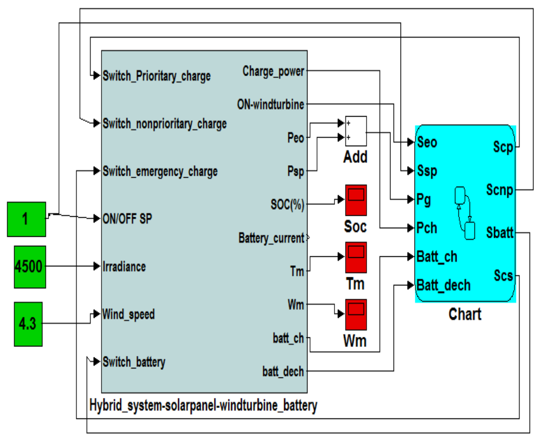

Figure 4. Hybrid system model in Simscape

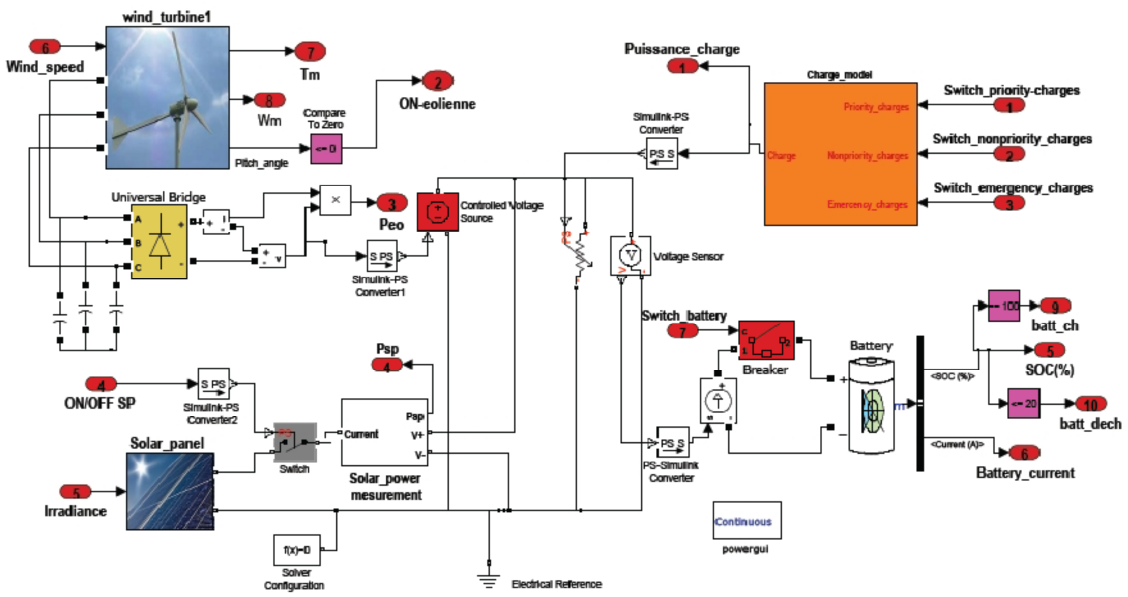

Figure 5. Hybrid subsystem block

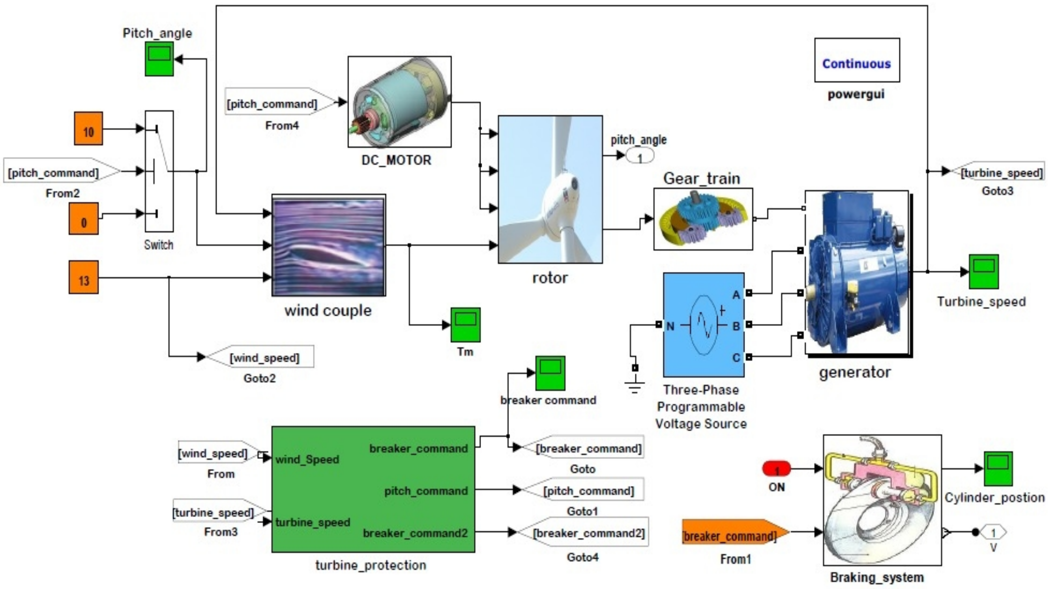

Figure 6. Wind turbine model in SIMSCAPE

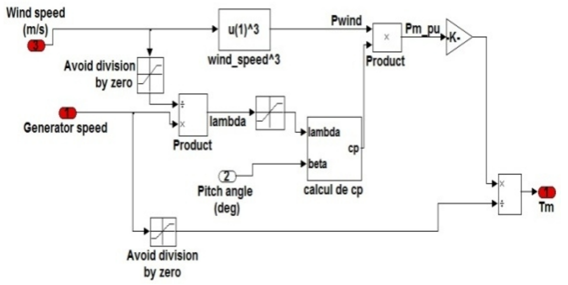

Figure 7. Wind couple model

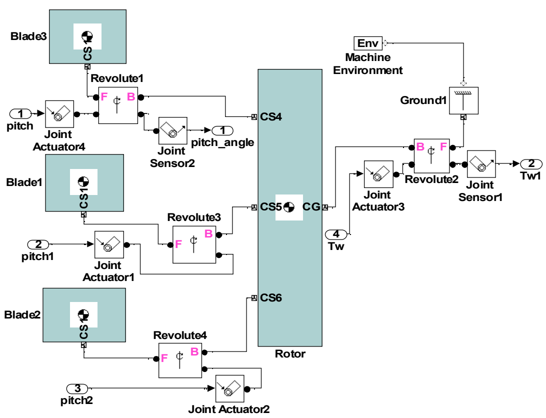

Figure 8. Rotor model

4. 3. 3. Model of Gear Train In the model shown in Figure 9, 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 over simple gear is made to have a greater gear ratio. Otherwise, we can settle for a simple gear.

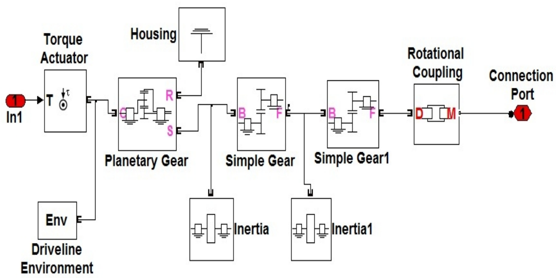

Figure 9. Model of gear train

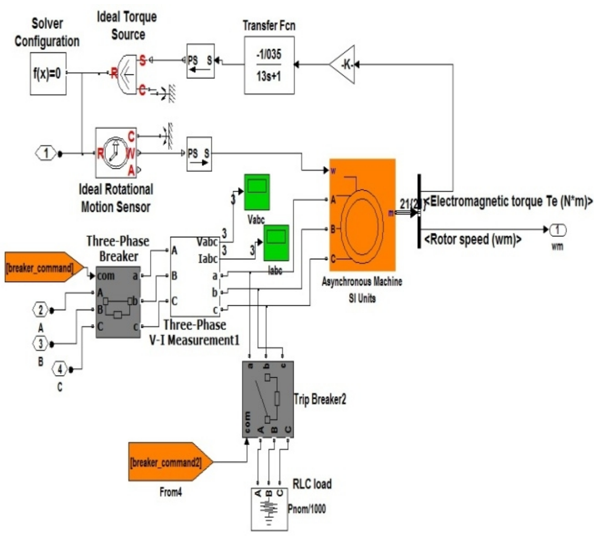

Figure 10. Model of generator subsystem

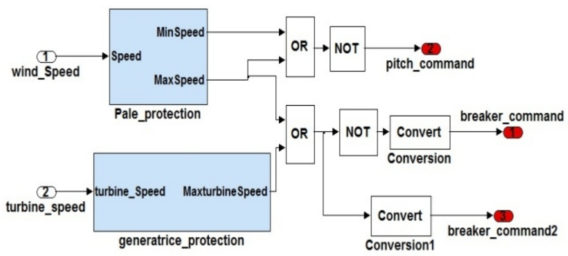

Figure 11. Turbine protection model

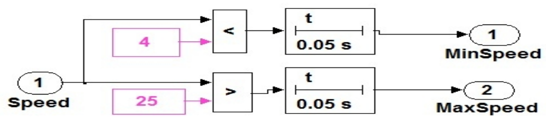

Figure 12. Models of blade protection

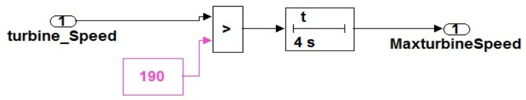

Figure 13. Models of generator protection

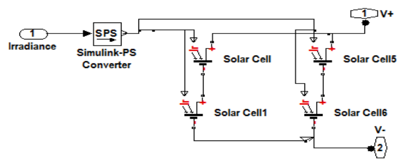

Figure 14. Solar panel model part

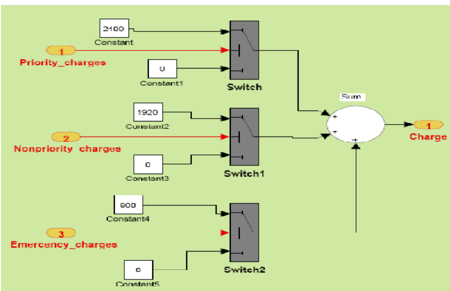

Figure 15. Charge model

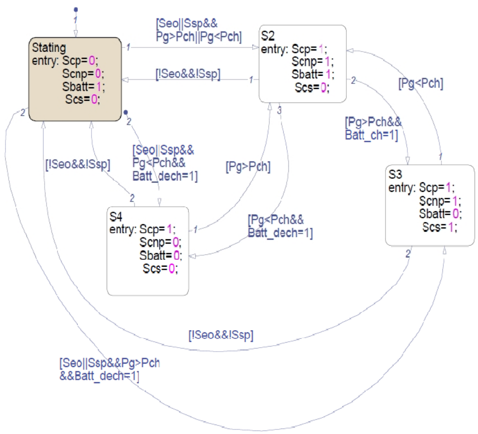

Figure 16. Control state flow chart model

4. 3. 4. Model of the Asynchronous Machine The model illustrated in Figure 10 consists of an asynchronous machine block ready to use and the loop speed command of the generator based on the Equation (7):

$$J\, d\Omega m/dt = \quad e - f\Omega m - \quad r \tag{7}$$

4. 3. 5. Model of Turbine Protection Protection system (modeled in Figure 11) 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 12). Also, in case of over speed of generator, it allows triggering the breaker in order to disconnect the wind turbine from grid (shown in Figure 13) and varying the pitch angle to 0. For the blade protection, if the wind speed is less than 4 m /s or above 25 m /s for 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. The choice of the value 0.05 is arbitrary for simulation.

4. 4. Photovoltaic Panel Model The solar panel modeled in Figure 5 is obtained by interconnecting in series and in parallel the solar cell block available in SIMELECTRONICS as shown in Figure 14. We have 8064 solar cells.

4. 5. Charge Model As shown in Figure 15, the charges are divided in three types:

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

4. 6. State Flow Chart In Figure 16, 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 produced power 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%.

5. RESULTS AND DISCUSSION

5. 1. Simulation Results For the wind speed equal to 4.3 m/s and the irradiation equal to 4500 W/m²/d, the produced power is greater than the loads consumption. Therefore, as it is shown in Figure 17, 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. Then, we switch off the battery (Figure 18) and we feed the emergency charges (Figure 19). In Figure 20, the value of the total charges passed from 4320 to 5220 at the time 300 s, the time of switching on the emergency charges.

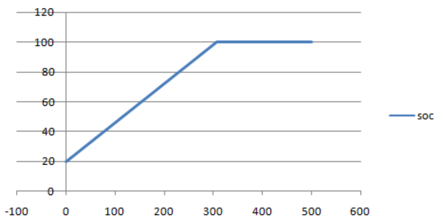

Figure 17. Battery charged state switcher

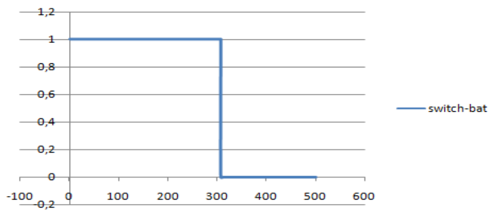

Figure 18. Battery switcher

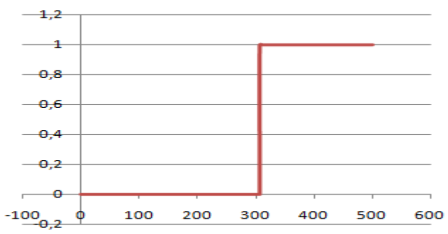

Figure 19. Emergency charge switcher

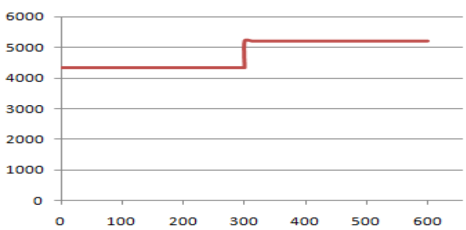

Figure 20. Total charge power

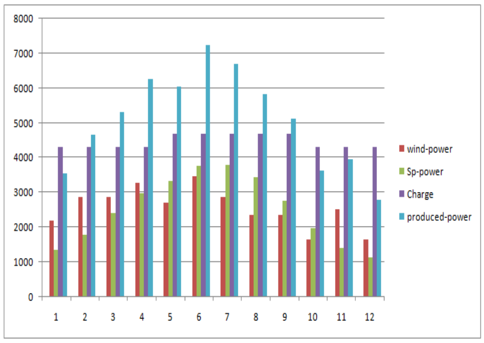

Figure 21. Charge distribution and annual energy production of wind turbine and solar panel

5. 2. Annual System Performance Figure 21 shows the monthly energy production of the wind turbine and solar panels and the monthly charge distribution. In this figure, the charge increases 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. Also, we find that the system covers all needs demand during the period from February to October. For the remaining months, the total system production is less than the total loads because the wind speed and the irradiation decrease. A goog power management as proposed in the paragraph 4.6 may solve this problem.

6. 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 modeling. The performance of the system shows that it is not necessary to couple the wind turbine with the solar panel because the two systems can meet the requirements and have the same deficits during the same period for Tetouan site. Therefore, it is better to settle for a photovoltaic system because of its low costs compared to a wind turbine.

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Physical Modeling of a Hybrid Wind Turbine-solar Panel System Using Simscape Language

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چکیده

از آن جا که انرژی‌های تجدیدپذیر پایدارند و پسماند زاید زیادی ندارند، به سرعت استقرار یافته‌اند. متاسفانه، ویژگی متناوب این انرژی‌ها کنترلشان را دشوار ساخته است. تاثیر منفی این ویژگی را می توان با جفت کردن دو یا چند منبع از انرژی‌های تجدیدپذیر و در مرحله دوم با مدیریت مناسب سیستم‌های ذخیره‌سازی کاهش داد. این پیکربندی جدید تولید و مدیریت انرژی هدف پژوهش ماست. هدف از این مقاله ساخت یک مدل از یک سیستم شامل چند منبع برای تغذیه وسایل خانگی با رویکرد چند رشته‌ای فیزیکی است که ما را قادر به مدل‌سازی، شبیه سازی و کنترل همه اجزا و زیرسیستم متشکل از توربین بادی، پانل‌های خورشیدی و سیستم ذخیره سازی با باتری می‌سازد. این سیستم تغذیه برای یک خانه است. برای رسیدن به این هدف، ابتدا، شرح سیستم ارائه شده، سپس یک مدل SIMSCAPE برای سیستم چندمنبعی در MATLAB نرم افزار SIMSCAPE / توسعه یافته است. در نهایت، نتایج به دست آمده از شبیه‌سازی مشتق شده است.

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