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Hybrid Electric with a Smart Platform Source Modeling

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Abstract— *This paper develops how to manage and to save electric energy produced by hybrid sources. Research focuses on the detailed hybrid system component modeling. HOMER software is used for study feasibility and RETScreen software for results validation. Smart platform automatically chooses energy sources to be used by a home electric system in prioritizing renewable energy. Multi-sources system includes photovoltaic, wind turbine and generator. Switching and control between thermal and renewable energy sources are ensured by a microcontroller. Based on electric energy need, modeling can manage various energy sources by running each source independently showing its best performance. Therefore, this research allows the chosen villages to get out of blackout stress thanks to smart platform which is able to provide high availability of electricity from a hybrid system combined with battery storage.*

Keywords— ***Electric energy, renewable energy, thermal energy, battery storage***

I. INTRODUCTION

Nowadays, diesel generator is the most widely used technique for isolated sites electrification. However, access to these sites is usually long and difficult. Moreover, maintenance costs and fuel supply are very high. Solution consists to link hybrid system and diesel generator with two renewable energy sources (Wind Power, PV). Again, this solution is often the most cost-effective option. This paper focuses on providing permanent power supply of an isolated site which may be located on various sites in Madagascar. RETScreen software sized the system and detailed modeling of hybrid systems and its system components including the entire system study are presented.

II. METHODOLOGY

2.1. Hybrid systems overview

Hybrid systems are characterized by system function principle, by used various sources and whether exists storage device presence. Wind, solar or hydraulic energy are most frequently associated with a generator in hybrid systems involved a source of renewable energy. They are often autonomous, as they are made for isolated sites. The overall electric hybrid system can be structured as shown in figure 1. In this structure, sources and outlays can be added or removed according to the system topology. The power grid or the fuel cell could be for example the auxiliary source [1].

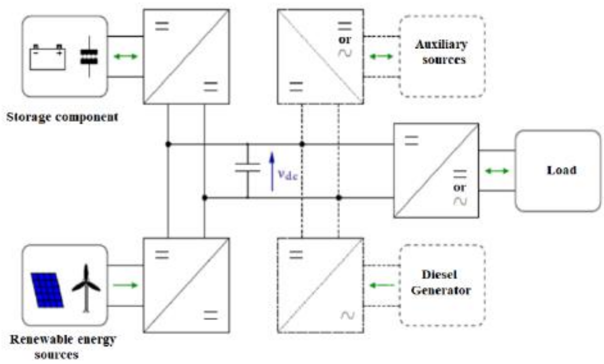

Fig 1: Hybrid system structure

There are three most popular hybrid systems in the world:

- Hybrid systems combining renewable energy sources: This option usually groups either wind combined with solar energy or hydropower with wind energy. Wind energy exploitation lays on its high availability whereas sun energy is available only few hours a day. Among these two options, the first option is more interesting in such way that many authors have conducted work and studied on the modeling of this system [2].

- Hybrid systems combining renewable energy sources with conventional energy sources: The electrical generation system using diesel generator as an additional energy is often the case in electric hybrid system. Conventional generators are used as backup generators in the system. Although, it is more cost-effective in isolated sites, model assessment can be more complex. Since, this system is conceived from the intermittency of renewable energy, it should use extra generators, [3].
- Hybrid systems combining renewable energy with storage systems: Associated with a storage system, this system reduces the problems related to climate variations. Studies made by several authors indicate that this system requires good management of these sources, [4]. Electric hybrid system configuration varies according to the process principle. Its configuration is based on buses (bus CC or CA or CC/CA). Some related study states configuration examples, [5], [6].

A. Photovoltaic cell modeling ***[7] [8]***

Figure 2 shows the basic solar cell model, [5]. This model represents the principle of sun light energy conversion into electric energy.

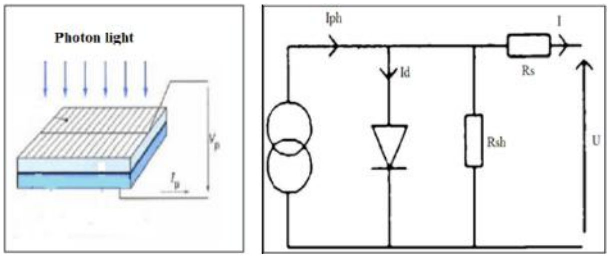

Fig 2: Photovoltaic cell equivalent circuit

By applying node's law to this circuit, intensities of circuit I and on diode I_d are given by:

$$I = I_{ph} - I_d \quad (1)$$

$$I_d = I_{od}.\left(e^{\frac{q.(U+Rs.I)}{k.T}} - 1\right) \quad (2)$$

where,

I_{ph}: electric power generated by the light [A]

I_{od} : Intensity of diode saturation power [A]

R_S: Resistance series [Ω]

k: Boltzmann constant ($k = 1, 38.10^{-23}$)

q: electron charge ($q = 1, 602.10^{-19}$ C)

T: Cell temperature [K]

B. Wind energy modeling

Wind turbines convert aerodynamic energy into electric energy. In a wind turbine two conversion processes take place. The aerodynamic power (available in the wind) is converted into mechanical power and then, again converted into electric energy. Wind systems facilities produce powers from kW (for mini wind systems) up to MW (for large wind systems). The kinetic energy in the wind is converted into mechanical energy by torque production. Since the energy provided by the wind is of kinetic energy, its amplitude depends on both air density and wind speed. Figure 3 shows a wind turbine model, [5].

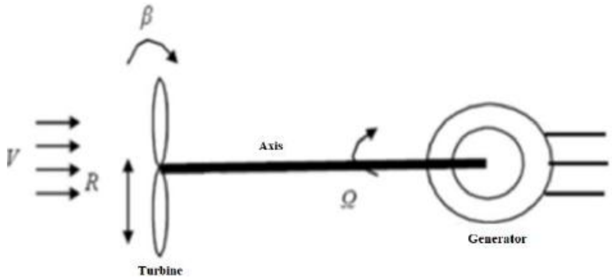

Fig 3: Wind turbine model

The wind kinetic energy is given by the formula:

$$CE = \frac{1}{2} mV^2 \quad (3)$$

where,

m: mass of air ($m = \rho.V.S.dt$) [kg],

ρ: density of the air [kg m^{-3}],

S: blades surface [m^2],

V: wind speed [m s^{-1}].

Knowing that P_w is the power developed by the turbine as

$$P_W = \frac{dE_C}{dt} = \frac{d}{dt}\left(\frac{1}{2}\rho.V^3.S.dt\right) \quad (4)$$

$$P_W = \frac{1}{2}\rho.V^3.S \quad (5)$$

Let C_p be the quotient between the mechanical power P_m and the power developed by the turbine P_w. The mechanical power is less than the developed power, and:

$$C_p = \frac{Pm}{Pw} < 1 \quad (6)$$

C_p depends on the speed ratio λ, the turbine rotation speed (which depends on specific speed), and blade inclination angle β. The mechanical power recovered at the wind turbine is given by:

$$P_m = \frac{1}{2} Cp.\rho.V^3.S \quad (7)$$

C. Battery model

The following electrical parameters characterize model battery:

- Ampere-hours (Ah) rated capacity C can be extracted from battery, under predetermined conditions of discharge.
- Charge status
- Charging (or discharging) plan which is the parameter reflected by the fraction between the battery nominal capacity and the electric power whether it is charged or discharged.

D. *Generator modeling*

A generator modelling takes account combustion engine and electric generator's association. The type of fuel and the power delivering ability make generators different from one another. In this study, Diesel Generator (DG) is used as its fuel consumption which varies linearly with consumed power as it refers in manufacturer data. The modeled generator is SIDERIS brand having power 2.5kVA with a range of 1.5 l/h, [9]. To model Diesel Generator, consumption-based simulation on the generator rated power is applied.

E. Microcontroller

According to BIGONOFF, microcontrollers are microprocessor type units for information treatment to which are added internal devices allowing their components to make edits deprived of adding internal components [10]. Today, they are located in most professional or public applications according to their need. Among the mostly used microcontrollers, there are:

- CMOS microcontrollers as the PIC 16F84A of Microchip [11],
- 16HC11 of Motorola with a large number of devices such as counters, PWM, digital analog converters, digital inputs and outputs, serial links, etc.
- Microcontrollers based on the 8051 architecture from Intel (ST, Atmel, Philips) with their advanced calculation capabilities. This family of microcontrollers has 8 bits and is an industry standard in its own right.
- Arduino microcontroller, FPGA and the raspberry. These are advanced platforms.

III. RESULTS

Figure 4 displays the hybrid system configuration. The system uses battery as storage component.

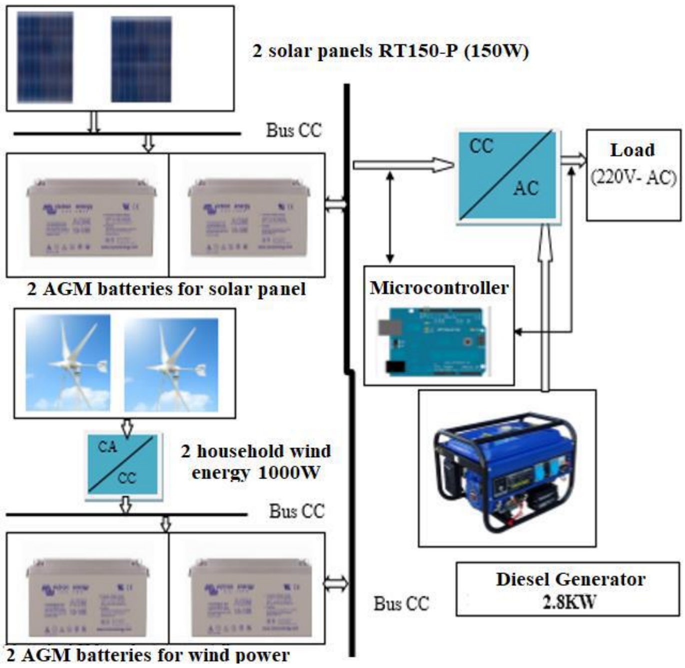

Fig 4: Hybrid system configuration

F. Hybrid system status representation

The hybrid system representation state is a powerful tool to model linear or non-linear system operation in continuous or discrete-time. It also has the advantage of maintaining the chronological representation of the phenomena [12], [13]. Figure 5 shows the hybrid system structure in smart platform.

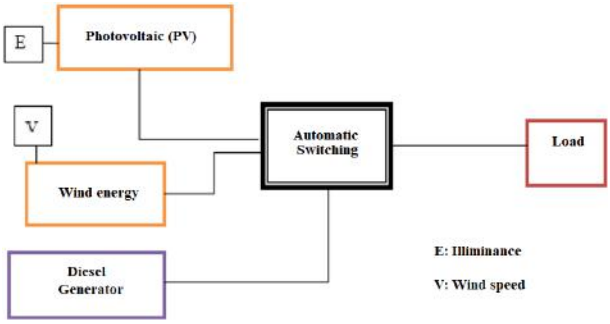

Fig 5: Hybrid system structure

The hybrid system consists of photovoltaic, wind energy, and diesel generators. Produced power by two renewable sources depends on the illuminance E and on the wind speed V. V_m and E_m are respectively the startup speed of the turbine and the minimum value of the illuminance. The renewable source stopped automatically when the sensor detects the electrical power line P_m corresponding to high values where power rises above the lower threshold. The switching system forms a dynamic system which in continuous evolution with power variation $P = x$, and in discrete evolution with transition running passage from renewable system to generator. Power curve $P = x$ according to type of load is modeled in Figure 6.

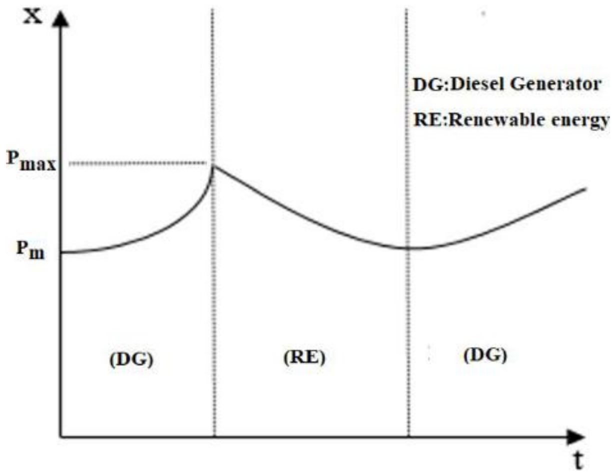

Fig 6: Renewable system power path

Power evolution can be modeled by the following differential equations:

$$\begin{cases} \dot{x} = -k_1 x + a & if\ generator\ DG\ works \\ \dot{x} = -k_2 x & if\ (PV + wind\ power)\ works \end{cases} \quad (8)$$

with a and k are two real positive nonzero constants.

Passage from one state to other is triggered by P_m value as it is shown in Figure 7.

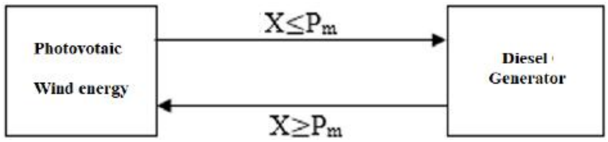

Fig 7: Condition swapping energy model

Since ideal condition for the system operation has been considered, evolution model can be determined. It requires very accurate sensor (power sensor) or gauge circuit to detect the switching threshold P_m and the energy used by the outlay P_{ch}. Once this threshold is detected, system state changes instantly.

System control

The system control model is described by equation (8) where:

- x = x1 when only Diesel Generator runs, and
- x = x2 when PV and wind power run.

The hybrid system control equation becomes matrix equation as follow:

$$\dot{x} = \begin{pmatrix} \dot{x1} \\ \dot{x2} \end{pmatrix} = \begin{bmatrix} -k_1 & 0 \\ 0 & -k_2 \end{bmatrix} \begin{pmatrix} x1 \\ x2 \end{pmatrix} + \begin{pmatrix} a \\ 0 \end{pmatrix} \quad (9)$$

Assume that $B = \begin{pmatrix} a \\ 0 \end{pmatrix}$ and $A = \begin{bmatrix} -k_1 & 0 \\ 0 & -k_2 \end{bmatrix}$, the command matrix $[A]\ (B)\ [A]^2\ (B)\ldots,\ [A]^{n-1}\ (B)$ are of full rank. And if this command matrix is linearly independent, then the electric hybrid system is completely controllable [12].

G. Switching

The autonomous switching is characterized by the phenomenon where the system state changes discontinuously when the power produced by renewable source reaches a threshold or is less than the energy required by the load. Switching system function displays on Figure 8.

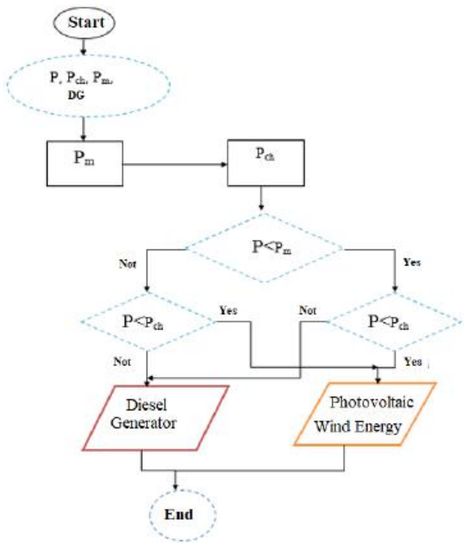

Fig 8: Switching system function

H. Modeling with simulink

a. Photovoltaic generator

Photovoltaic generator simulation uses mathematical equation to build simulink model to characterize a photovoltaic cell. Model corresponding Simulink block diagram is shown in Figure 9.

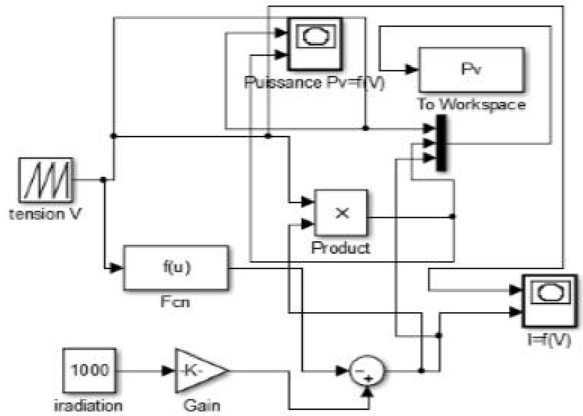

Fig 9: Block diagram of a photovoltaic cell.

Based on the photovoltaic cell model in Figure 9, RT-150P module composed by 4 groups block model of 9 cells connected in parallel (36 cells) displays in Figure 10. This model is based on an equivalent electrical circuit with the Matlab/Simulink software

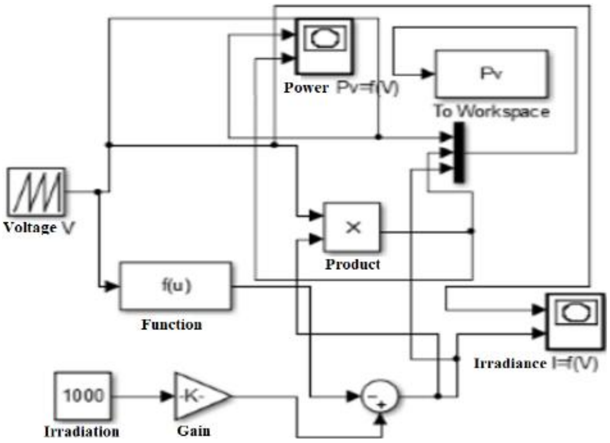

Fig 10: Solar panel RT-150P model

Using 36 photovoltaic cells, Figure 11 shows solar irradiation *I(A)* and Power-voltage pace *Pv(W)* characterizing photovoltaic cell. These curves are obtained from *Pv = f (V)* and *I = f (V)* at medium irradiance 1000W/m^2 and temperature T = 25ºC.

The characterization of the photovoltaic cell has been defined for illuminance E = 1000W/m^2 and temperature T = 25 ° C. Power curve characterizing a photovoltaic panel depends on the variation of current-voltage (Figure 12(a)). Power reaches a maximum peak 140W when current-voltage at 12V. Besides, the current is maximum at the open circuit (voltage zero) and zero at the maximum voltage (Figure 12(b)).

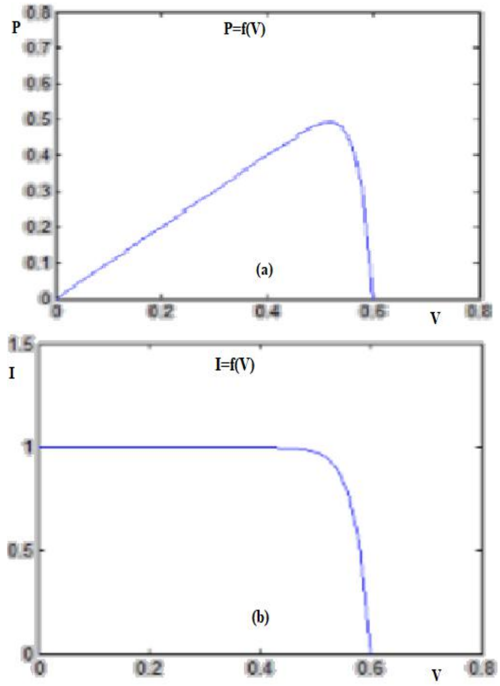

Fig 11: Characteristics of a cell for solar irradiation of 1000W/m2 at 25 ° C: (a) P = f (V), (b) I = f (V)

According the curves in Figure 11, a photovoltaic cell provides 1A electric current and voltage 0.6V at the cell terminals. Using module RT-150 P composed of 4 x 9 cells, Figure 12 shows voltage and power characteristics.

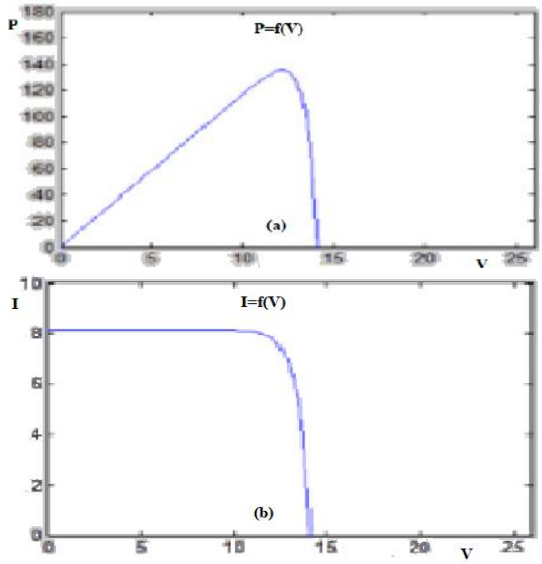

Figure 12: Module RT-150 p features: (a) power-voltage, (b) current-voltage

b- Wind turbine

Figure 13 shows the block pattern of the wind turbine to simulate its operation.

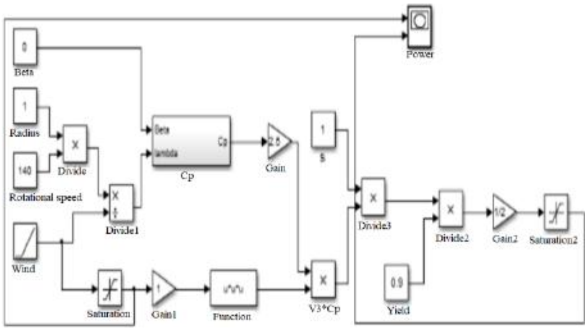

Fig 13: Wind turbine block diagram

For the wind turbine, electric power production rises with wind speed till it reaches the highest threshold 1000W, (Figure 14).

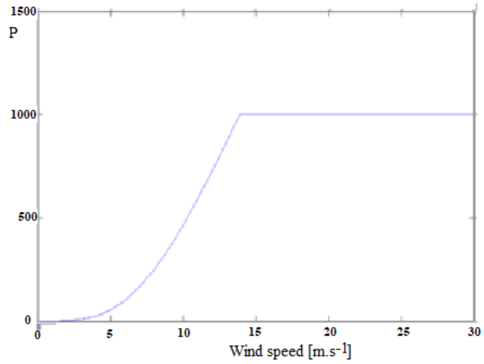

Fig 14: Wind turbine power variation over wind speed

The maximum power or nominal power P_n produced by the wind generator is obtained from nominal speed $V_n \approx 14$ m.s^{-1} (50.4 km.h^{-1}). The startup speed V_d is 2 m.s^{-1}.

c. Battery model

Figure 15 shows a battery model under Matlab/Simulink platform.

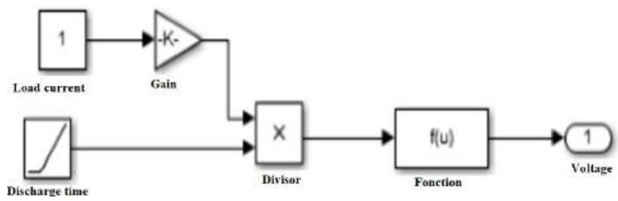

Fig 15: Battery block model

b. Diesel Generator model

Diesel Generator model under Matlab/Simulink platform is given in Figure 16.

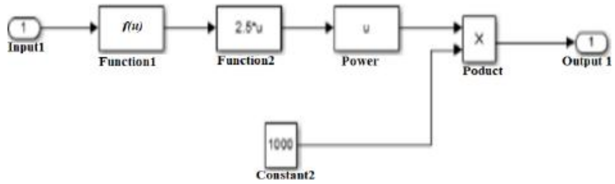

Fig 16: Diesel Generator block model.

c. Arduino microcontroller model

Arduino microcontroller is used for switching circuit command. Its block model under Matlab/Simulink that represents the system (sensor - Arduino-Relay) is shown in Figure 17.

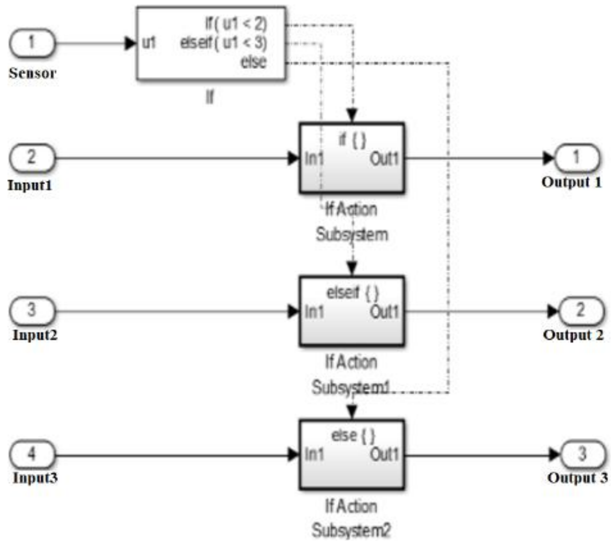

Fig 17: Arduino-sensor model

Arduino output values of Arduino-sensor model (Figure 17) according to data delivered by current sensor is represented on table 1.

Table 1: Arduino output values

Current intensity	Output 1	Output 2	Output 3
I<4A	5 V	0 V	0 V
I<6A	0 V	5 V	0 V
I>=6A	0 V	0 V	5 V

Using the Arduino model, current intensities are displayed on microcontroller digital output. Time offset was set to 0. Captured graphs of output 1, output 2 and output 3 with current intensities I<4A, I<6A and I>=6A are shown in Figure18 (a), (b), (c) respectively.

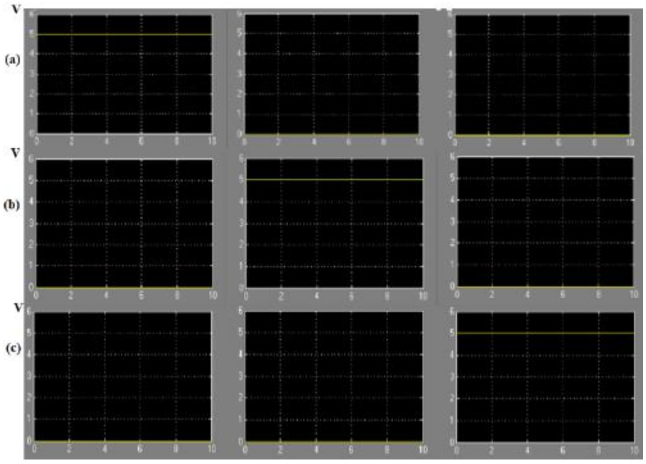

Fig. 18: Microcontroller model output voltages: (a) I<4A, (b) I<6A, (c) I>=6A

I. *Modeling of the electric hybrid system*

After developing all components of hybrid system like hybrid source and switch module, it remains to connect these components to find out overall system functioning and carry out an analysis according to various parameters related to the system (load, battery state, climate data, etc.). Figure 19 illustrates the whole block model of the hybrid system on Matlab/Simulink platform.

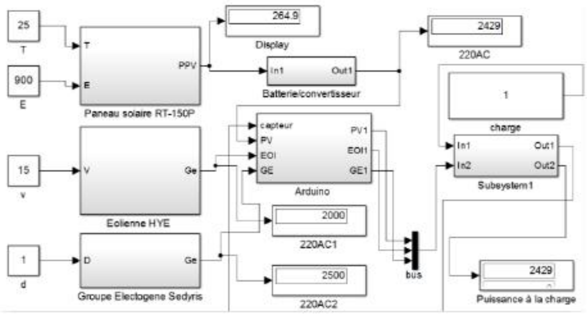

Fig 19: Block model of hybrid system on Matlab/Simulink

Block model of hybrid system analysis is performed through simulation in varying load power. When power load grasps 500W (Figure 20 (a)), hybrid system connected load is average. Similarly, if power load rises up to 1000W (Figure 20 (b)), connected load is still considered to be average. In these cases, renewable sources itself fits to ensure the power supply in order to satisfy load capacity. But if power load becomes greater than 2000W (Figure 20 (c)), energy needs have to be powered by Diesel Generator.

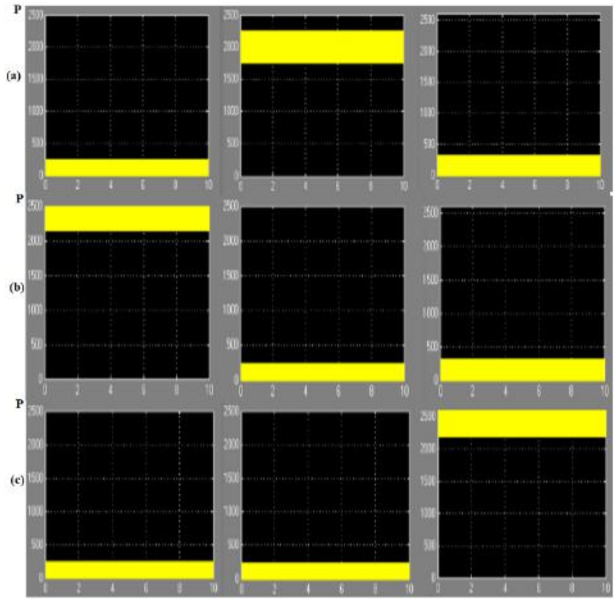

Fig 20: (a) load <500W, (b) load < 1000W, (c) load >= 2000W

Daily Load profile

During the day, load electric power varies and is not constant throughout the day. Table 2 presents estimate daily energy needs of a given household. It describes electricity demand from the site that includes light and other electrical devices. The daily energy consumption E_c of a household estimate about 2332W.

Table 2: Estimate daily energy consumption of a household

Devices	Number	Power unit (W)	Daily use delay (h)	Power (W)	Energy (Wh/d)
LED lamp	4	18	6	72	432
Radio	1	8	15	8	120
TV set	1	20	6	20	120
Load speaker	1	250	6	250	1500
Laptop	1	50	3	50	150
				Total	2332

Assume that the daily load distribution is given by the Table 3.

Table 3: Daily load profile

Hours	Power (kW)	Hours	Power (kW)
0 h - 1h	0	12h - 13h	0.270
1h - 3h	0	13h - 14h	0.278
3h - 4h	0	14h - 15h	0.320
4h - 5h	0.432	15h - 16h	0.013
5h - 6h	0.552	16h - 17h	0.014
6h - 7h	0.580	17h - 18h	0.200
7h - 8h	0.730	18h - 19h	0.500
8h - 9h	0.028	19h - 20h	1.123
9h - 10h	0.063	20h - 21h	1.123
10h - 11h	0.060	21h - 23h	0.200
11h -12h	0.270	23h - 0h	0.008

Figure 23 shows the daily functioning distribution of three generators according to the daily load profile.

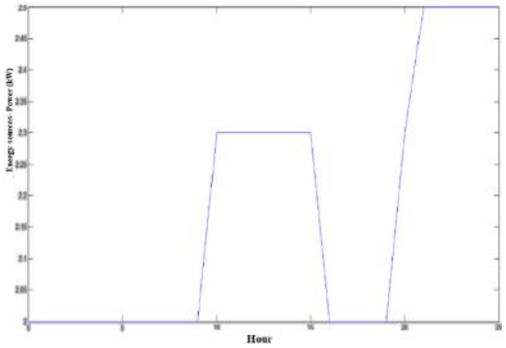

Fig 23: Daily functioning distribution of three generators according to load profile

IV. DISCUSSION

The use of multiple technologies offers the best method to determine each system characteristic. Hybrid electric system performance is influenced firstly by its design the component dimensioning, secondly the component type, architecture and thirdly, the choice of process strategy. To evaluate efficiently the system performance, parameters such as fuel economy, kilowatt hour cost, outages number and duration, stops number for maintenance need to be investigated. C. Darras suggested that the optimal configuration for hybrid systems should be determined by minimizing the kilowatt hour cost [14]. Ashok has developed a reliable system model based on a hybrid optimization model for renewable electricity production [15]. For example, to find an optimal hybrid system among various combinations of renewable energy, minimizing the cost of the entire life cycle leads to a good result.

In this study, the current system formed by multiple hybrid electric source designed in Matlab/Simulink. This smart platform technology connected power to the various loads where its value served as trigger parameter for switching energy sources. As long as the load is less than 2000W, only renewable can be enough to supply the energy need. In case that the load requires a lot of energy more than 2000W, Diesel Generator intervene to power the load. The platform chooses automatically the source depending on loads capacity. In fact, according to the daily load profile, photovoltaic generator dominates at noon. In the evening, Diesel Generator provide power in the system because the load requires considerably more electric. Since renewable energy such as solar energy and wind energy are available and inexhaustible, this study allows to reduce fossil energy dependence and contribute to the sustainable development.

V. CONCLUSION

Hybrid system modeling on Matlab/Simulink can represent system diagram in blocks and simulation under this software allows system analyses. According to the results, the combination of the two energy sources connected to a secondary system (generator) creates a substantial energy profit (daily presence of food). To sum up, this paper develops electricity power system combined with autonomous process. The used hybrid system brought significant development essentially to the power supply diversification that may affect positively the environment.

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