MANAGEMENT AND CONTROL OF A WIND-DIESEL HYBRID SYSTEM FOR ISOLATED SITE ELECTRIFICATION

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Abstract: *The Algerian south is very vast where the presence of a broad community seen far from the electric distribution several hundreds of kilometers .Currently the power is provided by generators for domestic consumption and the pumping for irrigation of farmland. This solution is not beneficial in the long term from the economic and technical point of view where the integration of a hybrid system will be useful by the diet based on wind power will be interesting because the wind speed covers the majority of these sites throughout the year as the city of Adrar. This article examines a strategy for the management of a system ensuring optimum use of renewable energy in a System of Energy Hybrid (SEH) using a wind turbine, a diesel generator and a battery storage system as bank representing a technology which the technical - economic aspects will be more profitable. Operating conditions depend on performance and weather conditions (wind speed, temperature, terrain) which have an influence on the performance of the wind turbine but the characteristics of other equipment (rectifier, inverter, controller, type filter, etc...); for this reason we present in this paper a suitable management of a hybrid system (SEH) having a strategy to balance the exploitation of these sources, and the permanent transfer of energy between the source and the load ensuring a continuity of adequate appreciable service at an economic cost.*

Key words: *Wind, Diesel generator, Battery, Energy management, Control, Inverter multi level.*

1. Introduction

The electric power is an essential factor for the development and the evolution of the human societies that it is in the field of the improvement of the living conditions that on the development of the industrial activities.Vis-a-vis at the request of electricity, always increasing nowadays, and far from the use of polluting fossil energies like oil and the gas, several countries turned to the new form of energy known as “renewable energies”. Indeed, a true world challenge is taken with serious today, as well on the policy of reduction of the gas emissions for purpose of greenhouse, [1], while bringing back them to a tolerable level according to the convention of Kyoto.

The evolution of technologies of the components returns the conversion of these energies increasingly profitable and thus their uses economically become competitive compared to the traditional sources [2].These energies are exploited in mono source or hybrid and mode autonomous or connected to the network [3, 4].The power plant by several sources must meet connection architecture. Similarly, proper management of production sources vis-à-vis the consumer to cover the energy needs of the facility and ensure optimal use of the energy produced. In this context, we propose a study for a judicious choice of the network architecture composed by an autonomous wind diesel generator, a storage battery.

After this introductory Section1, this article is organized as follows: a Section 2 present problem of the production of electricity in Algeria by the group diesel, Section 3 presents location of hybrid system and the good sites for implementing this system, Section 4 the component wind diesel generation system, Section 5 presents the control strategy of the isolated hybrid system, Section 6 shows the modelling of the Wind Diesel Hybrid System components, Section 7 presents the simulation and results. Conclusions have been made in section 8.

2. Problems of the production of electricity in Algeria

In most isolated regions in Algeria, the Diesel Generator (DG) is the main source of supply electrical energy Fig.1.

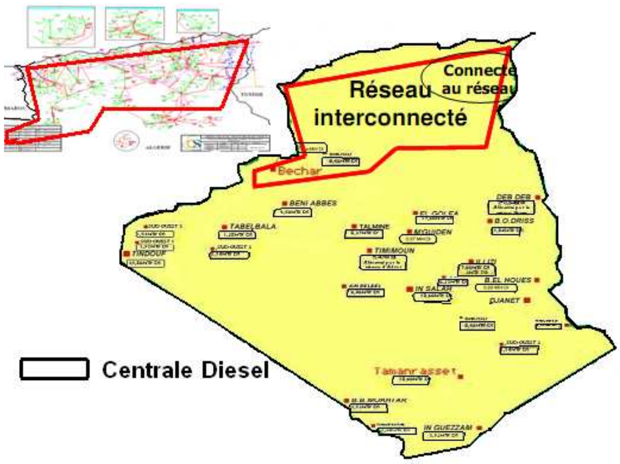


Fig. 1. Distribution of diesel generators in remote Algeria in the regions.

For these regions [5], the fuel is usually more expensive because it must provide additional transport costs to these isolated places, sometimes inaccessible. This is why the use of diesel generators combined with a renewable energy source and a storage system is recommended. It is with this objective that fits my article with the use of multiple sources for energy supply system adopted.

3. Location of hybrid system

Good sites for implementing this system in Algeria, we must choose a place which characterized (wind speed, power requirements).

For this study [6], a geographical localization is considered with the city of Adrar Fig.2, located at the Algerian western south with coordinates following: Longitude 0.28; Latitude 27.82 and covering a total surface of 427.968 Km^2.

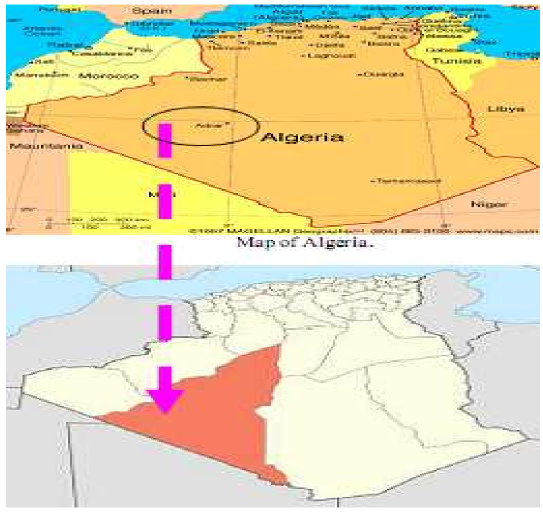


Fig. 2. Map geography of wilaya Adrar.

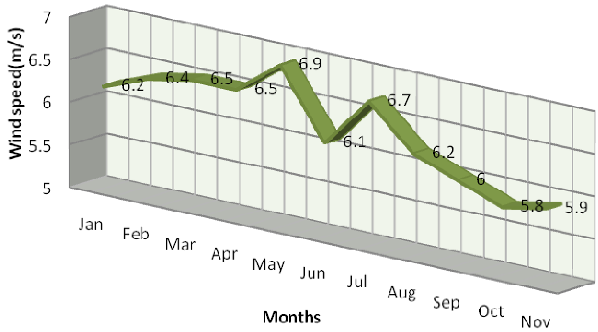


Fig. 3. Monthly averages speed of wind of Adrar [7].

The majority of sites in the city of Adrar could be regarded as isolated sites for the area is huge and their distance is far form one another. The weather conditions are extremely difficult which is another parameter to be considered, all these leads us to think of hybrid systems for feeding this region .

4. Schematic of the isolated power system

Fig.4 shows a remote area power system and its components. The Wind Diesel Hybrid System(WDHS) presented in this article consists of a Diesel Engine (DE), a Synchronous Machine (SM), a Wind Turbine Generator(WTG), the consumer load(P_L), a (Ni-Cd) Battery based Energy Storage System (BESS) [8].

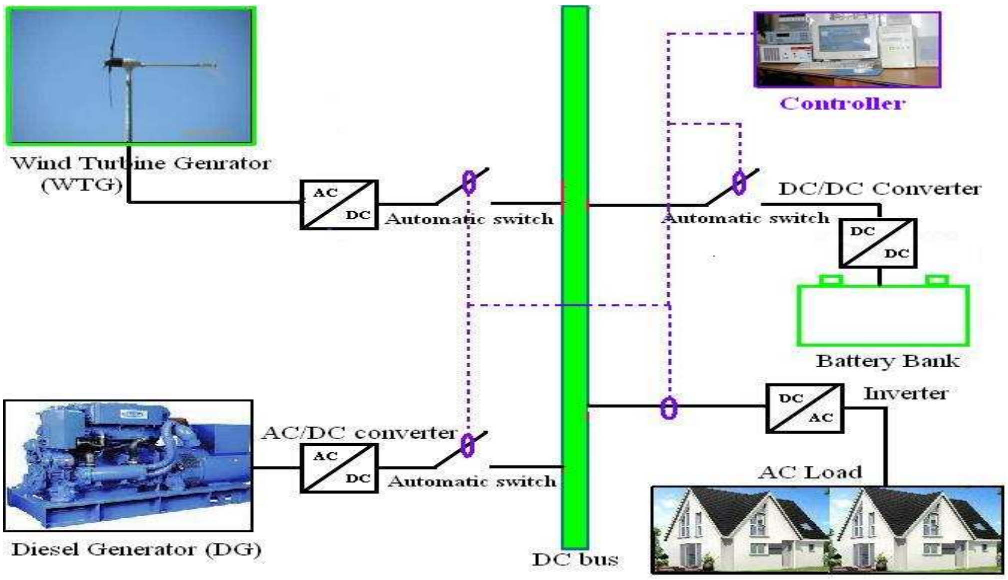


Fig. 4. Schematic diagram of (WDHS).

This system is classified as being High Penetration (HP) as shown in Fig.5 .Hybrid Wind-Diesel Systems with high penetration of wind power (HWDS-HP) have three plant modes: Diesel Only (DO), Wind-Diesel (WD) and Wind Only (WO).

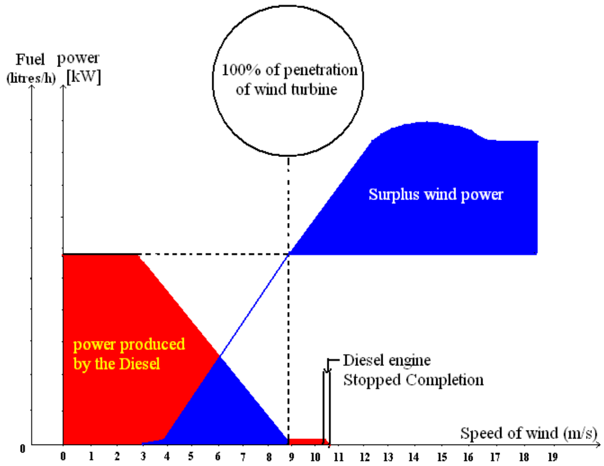


Fig. 5. Variation of energy covered by a system Wind-Diesel and diesel consumption as a function of wind speed[9].

5. The proposed control system strategy

For a multi-source energy system, a power flow management strategy is needed. According to wind speed values (V_m) and the power demanded by the consumer load. The power system has three operation modes, as follows [10].

- Weak winds ($V_m \leq 3$)*m/s* : (DO)in service
- Moderate winds($3 < V_m \leq 10$)*m/s* : (WD)in serviced
- Strong winds ($10 < V_m \leq 17$)*m/s* : (WO)in service

To adapt the production of the renewable source to the need for the load, we integrate a system of storage, such as the battery to ensure the continuity of service; that is necessary to feed the load, in case when the generator diesel fails and the wind is insufficient (low) for the operation of the wind turbine.

The power management strategy used in this study is according to the flow chart shown:

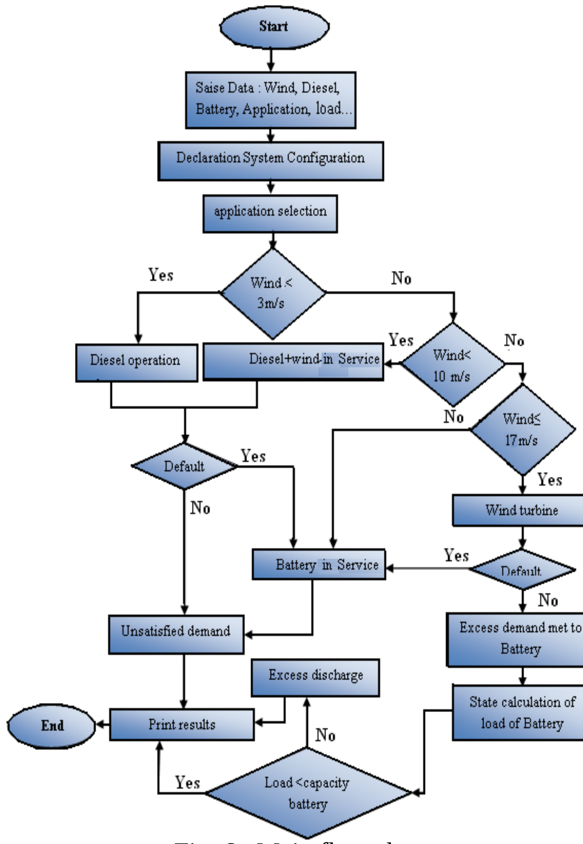


Fig. 6. Main flow chart.

6. Modeling of sources

6.1. Modeling of the turbine of the wind

Generator wind farm, consisting of a turbine at variable speed coupled with a synchronous generator with permanent magnets through a multiplier.

6.1.1. Model Wind

The wind speed is usually represented by a scalar function that evolves over time.

$$V_v = f(t) \quad (1)$$

The wind speed will be modeled in this part, as deterministic as a sum of several harmonics [11]:

$$V_v = A + \sum_{n=1}^{i} a_n.\sin(b_n.W_v.t) \quad (2)$$

Fig.7 represents the speed of the wind by a simulated random" (2)"

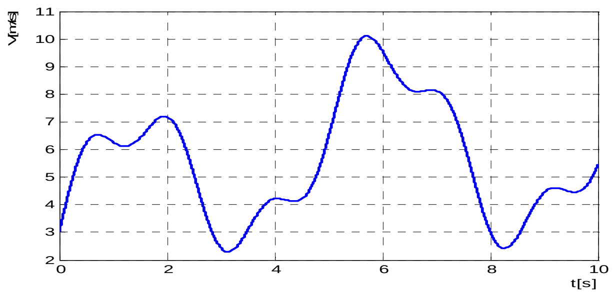


Fig. 7. Speed versus time.

6.1.2. Model of the turbine

Applying the theory of momentum and Bernoulli, we can determine the incident power (theoretical) due to wind [12, 13]:

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

S : The area swept by the blades of the turbine surface[m²].

ρ : the density of the air (ρ =1.225 (m^3/kg) at atmospheric pressure).

V: Wind speed [m / s].

In wind energy system is related to various losses, provided on the power extracted from the turbine rotor is less than the forward power. The power extracted is expressed by the following formula:

$$P_{extraite} = \frac{1}{2}.\rho.S.Cp(\lambda,\beta).V^3 \quad (4)$$

Cp (λ/β): power coefficient, which expresses the aerodynamic efficiency of the turbine. It depends on the ratio λ, which represents the ratio between the speed at the tips of the blades and the wind speed, and the angle of orientation of the blades β. The ratio λ expressed by the following formula:

$$\lambda = \frac{\Omega_t.R}{v} \quad (5)$$

The maximum power coefficient Cp was determined by Albert Betz as follows [14]:

$$Cp^{\max}(\lambda,\beta) = \frac{16}{27} \approx 0.593 \quad (6)$$

The power factor is the aerodynamic efficiency of the wind turbine. It depends on the shape of the turbine rotor and the angle of orientation of the blades *β* and the ratio of the speed λ. This coefficient can be written as follows:

$$Cp(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda i} - 0.4\beta - 5\right)\ell^{\frac{21}{\lambda i}} + 0.0068\lambda i \quad (7)$$

With:

$$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (8)$$

Fig.8 illustrates the curves of the power coefficient as a function of λ for different values of *β*.

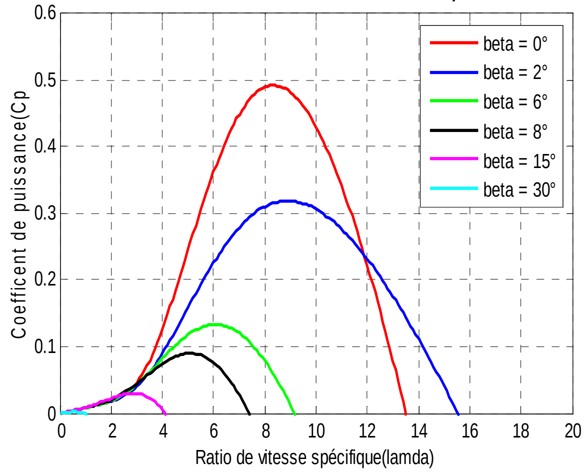


Fig.8. The characteristic of reactivity power coefficient according to λ and β.

The aerodynamic torque on the output shaft can be expressed by the following formula:

$$C_{al} = \frac{P_{eol}}{\Omega_t} = \frac{1}{2}.\rho.S.Cp(\lambda,\beta).V^3.\frac{1}{\Omega_t} \quad (9)$$

Ω_t : Rotational speed of the turbine.

C_{al}: Torque on the slow axis (turbine side).

6.1.3. Model multiplier

The multiplier is characterized by its gain ''G''. It adjusts the speed of rotation Ω_t of the turbine to the generator speed Ωg:

$$C_{aer} = G * C_g \qquad (10)$$

6.1.4. Tree model

The basic equation of dynamics applied to the shaft of the generator determines the evolution of the mechanical speed Ωm from the total mechanical torque C_m:

$$C_m = J \frac{d\Omega_m}{dt} \qquad (11)$$

J : total inertia that appears on the rotor of the generator:

$$J = \left(\frac{J_t}{G^2}\right) + J_g \qquad (12)$$

With:

J_g : the inertia of the generator.

J_t : the inertia of the turbine.

The above equations are used to establish the servo block diagram of the turbine speed Fig.9.

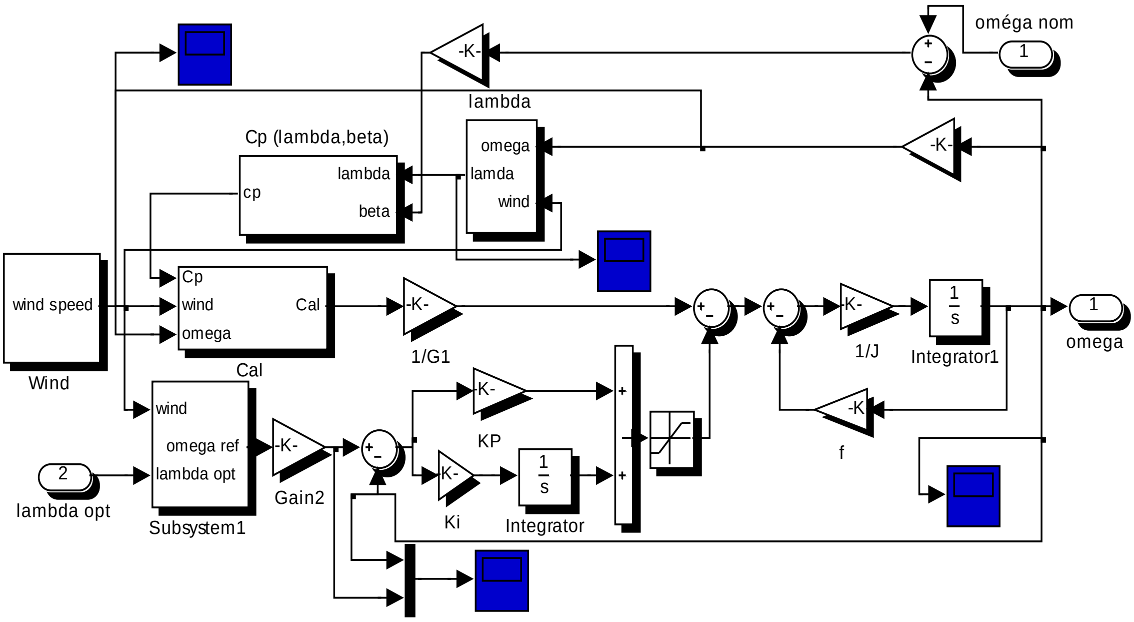


Fig . 9. Diagram of control of the speed of the turbine unit.

To capture the maximum power of the incident wind.It continuously adjust the rotational speed of the wind turbine. Optimal mechanical turbine speed is λopt and β = 0°. The speed of the Permanent Magnet Synchronous Generator (PMSG) is used as a reference for a controller proportional-integral type (PI phase lead). It be determined that the control target is the electromagnetic torque that should be applied to the machine for rotating the generator at its optimum speed. The couple that is determined by the controller is used as a reference torque of the turbine model Fig.9.

Variation of the system of the orientation angle of the blades (variation of the angle of incidence) to change the ratio between the lift and drag. To extract the maximum power (and keep constant), we adjust the angle of the blades to the wind speed.

6.1.5. Modeling of Permanent Magnet Synchronous Machine(PMSM)

Current machines alternating are generally modeled by equations nonlinear (differential equations). The non linearity is due to the inductance and coefficients of the dynamical equations which depend it is on the rotor position and time. In this article based on simplifying assumptions the model of the MAS which becomes relatively simple.

A three-phase transformation - two-phase is necessary to simplify the following model.

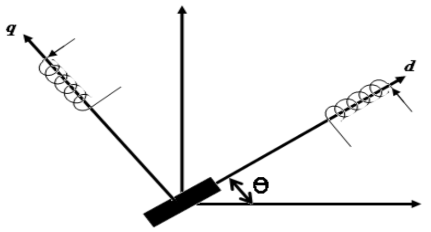


Fig. 10. Machine in two-phase model

The three fixed stator windings and rotor with permanent magnets are represented on the Fig.11. After simplifications there [15]:

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - \psi_q . w_r$$
$$V_q = R_s i_q + L_q \frac{di_q}{dt} + \psi_d . w_r \qquad (13)$$

With

$$\psi_d = L_d . i_d + \psi_f$$
$$\psi_q = L_q . i_q \qquad (14)$$

Ψ: flow of permanent magnets.
The relationship (13) becomes

$$V_d = R_s i_d + L_d \frac{di_d}{dt} - L_q . i_q . w_r$$
$$V_q = R_s i_q + L_q \frac{di_q}{dt} + (L_d . i_d + \Phi_f) . w_r \qquad (15)$$

The general expression of the electromagnetic torque and after simplification can be found:

$$Cem = P.(\phi_d i_q - \phi_q i_d) \qquad (16)$$

By replacing *Φd* and *Φq* with their values is:

$$Cem = P.((L_d - L_q) i_d + \phi_f) i_q \qquad (17)$$

The mechanical equation is written:

$$J \frac{d\Omega}{dt} + f\Omega = C_{em} - C_r \qquad (18)$$

$$\Omega = \frac{w_r}{P} \qquad (19)$$

With angular velocity *Wr* (electric pulse)

The permanent magnet synchronous machine (PMSM) is used in most conventional methods of electricity production. A PMSG is used to convert the mechanical energy of the wind into electrical energy.

The schema of the PMSG is represented in the following figure.

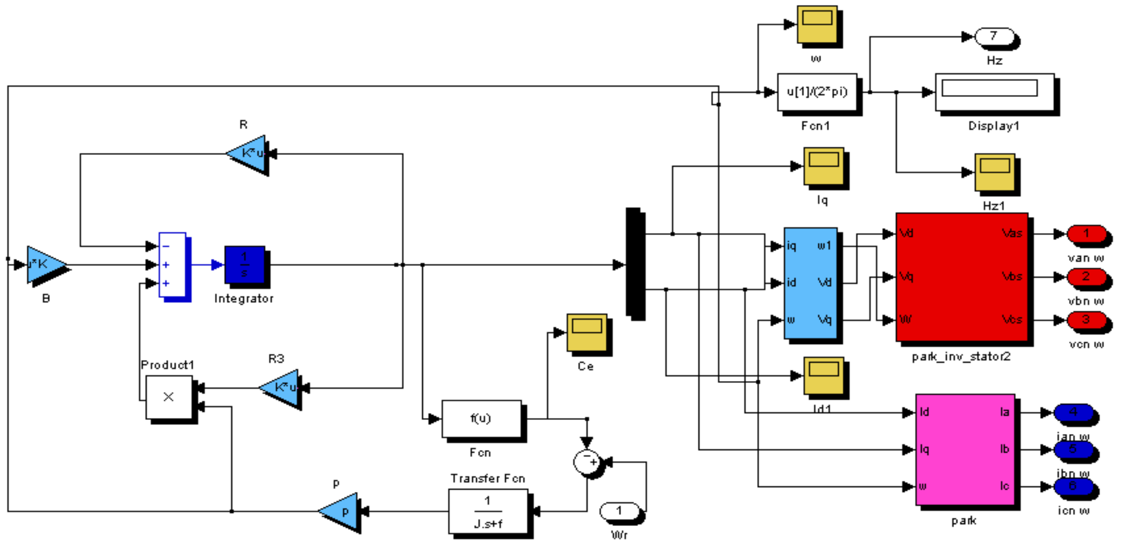


Fig. 11. Magnet synchronous machine standing

6.2. Diesel Generator (DG)

The generator consists of a diesel engine and a synchronous machine Fig.12 .The diesel engine produces mechanical energy by combustion of fuel. Synchronous generator converts mechanical energy into electrical energy [16]. The frequency is regulated through regulation of the speed of the diesel engine, as the amplitude is controlled via the excitation of the synchronous machine [17].

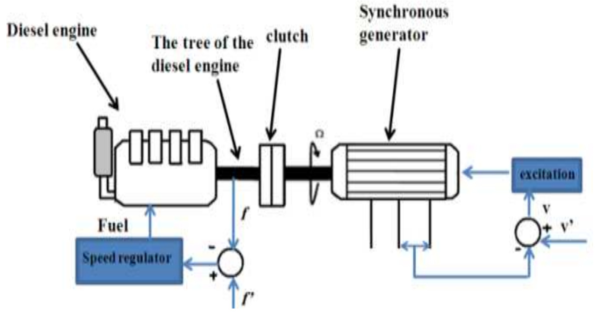


Fig. 12. Configuring the diesel generator (DG).

The torque developed by the diesel engine can be modeled in a simple way by a first-order time constant transfer function (τc) representing the constant combustion. Knowing that (τd) represents the delay on ignition there then this equation:

$$C_{diesel} = \frac{F}{1+\tau_c p} e^{\tau_d p} \qquad (20)$$

Or *F* is a relative gain of the fuel level.

6.3. Storage system modeling

There are three types of battery models reported in the literature, specifically: experimental, electrochemical and electric circuit-based. Experimental and electrochemical models are not well suited to represent cell dynamics for the purpose of state-of-charge (SOC) estimations of battery packs.

However, electric circuit-based models can be useful to represent electrical characteristics of batteries. The simplest electric model consists of an ideal voltage source in series with an internal resistance. In this work, a generic battery model suitable for dynamic simulation presented in [18] is considered. This model assumes that the battery is composed of a controlled-voltage source and a series resistance, as shown in Fig.13. This generic battery model considers the SOC as the only state variable [19].

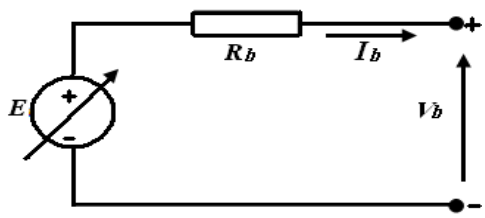


Fig. 13. Generic battery model

The controlled voltage source is described by the following expression [2]:

$$E = E_0 - \frac{V_p Q_b}{Q_b - \int i_b \, dt} + \tilde{A}\exp\left(-B_t \cdot \int i_b \, dt\right) \qquad (21)$$

When E is the battery constant voltage (V), E_0 is battery constant voltage (V); V_p is the polarization voltage (V), Q_b is the battery capacity (AH), i_b is the battery current (A); Ã is exponential zone amplitude (V), B_t is exponential zone time F constant inverse (AH^{-1}).Under Matlab/*Simulink* environment, the battery block, used in this study, is of Nickel-Cadmium (Ni-Cd) type Fig.14.

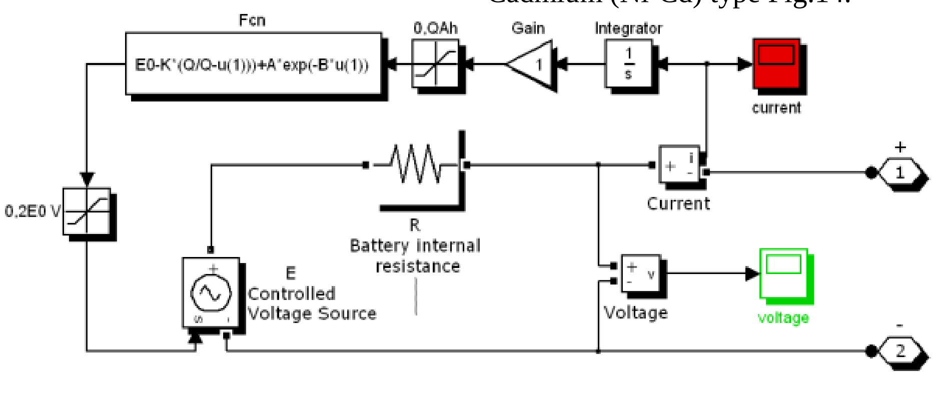


Fig. 14. (Ni–Cd) Battery Simulink schematic.

6.4. Model of the inverter PWM

6.4.1. Structure three levels inverter

The inverter on three levels is composed of three arms and two sources of Continue tension each arm of the inverter consists of four pairs bidirectional diode-switch and two median diodes make it possible to have level zero of the output voltage of the inverter. The middle point of each arm is connected to a DC supply following Fig.15 giving following schematic representation.

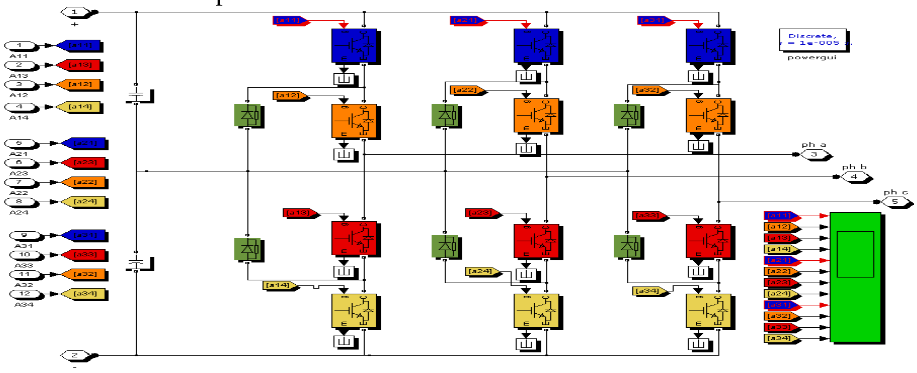


Fig. 15. The inverter Structure three levels

6.4.2. Control of static converters

A converter is said to order mode if the transitions between its different configurations depend on only the external command and no longer the internal commands.

6.4.2.1. Additional order

To prevent short circuits of the conduction voltage sources and to deliver the three desired voltage levels we must operate in its control mode.

Three additional commands can be applied on an arm of ups at three levels.

$$\begin{cases} G_{k3} = \overline{G}_{k1} \\ G_{k4} = \overline{G}_{k2} \end{cases} ; \begin{cases} G_{k2} = \overline{G}_{k1} \\ G_{k4} = \overline{G}_{k3} \end{cases} ; \begin{cases} G_{k4} = \overline{G}_{k1} \\ G_{k3} = \overline{G}_{k2} \end{cases} \quad (22)$$

With: G_{ks} control switch arm k T_{ks} trigger.

Table. 1. Excitation of switches

G_{k1}	G_{k2}	G_{k3}	G_{k4}	V_{ko}
0	0	1	1	V_{c2}
0	1	0	1	unknown
1	0	1	0	0
1	1	0	0	V_{c1}

In order to have full control of the three levels inverter must eliminate the case which gives an unknown response. By translating this additional order with the connection of the arm k switches functions, can be found:

$$\begin{cases} F_{k1} = 1 - F_{k4} \\ F_{k2} = 1 - F_{k3} \end{cases} \quad (23)$$

We define the function of connection of the semi-arm noted F_{km}^{b} with :

$$m = \begin{cases} 1 \text{ for the half arm top made up of } TD_{k1} and TD_{k2} \\ 0 \text{ for the half arm top made up of } TD_{k3} and TD_{k4} \end{cases}$$

Connection of the semi-arm functions are expressed using functions of the switches as follows:

$$\begin{cases} F_{k1}^{b} = F_{k1} F_{k2} \\ F_{k0}^{b} = F_{k3} F_{k4} \end{cases} \quad (24)$$

7. Results

To simulate the hybrid system (wind / diesel generator), we made the simulation scheme of Fig.6 in the *Matlab-Simulink 7.8* software Fig.16.

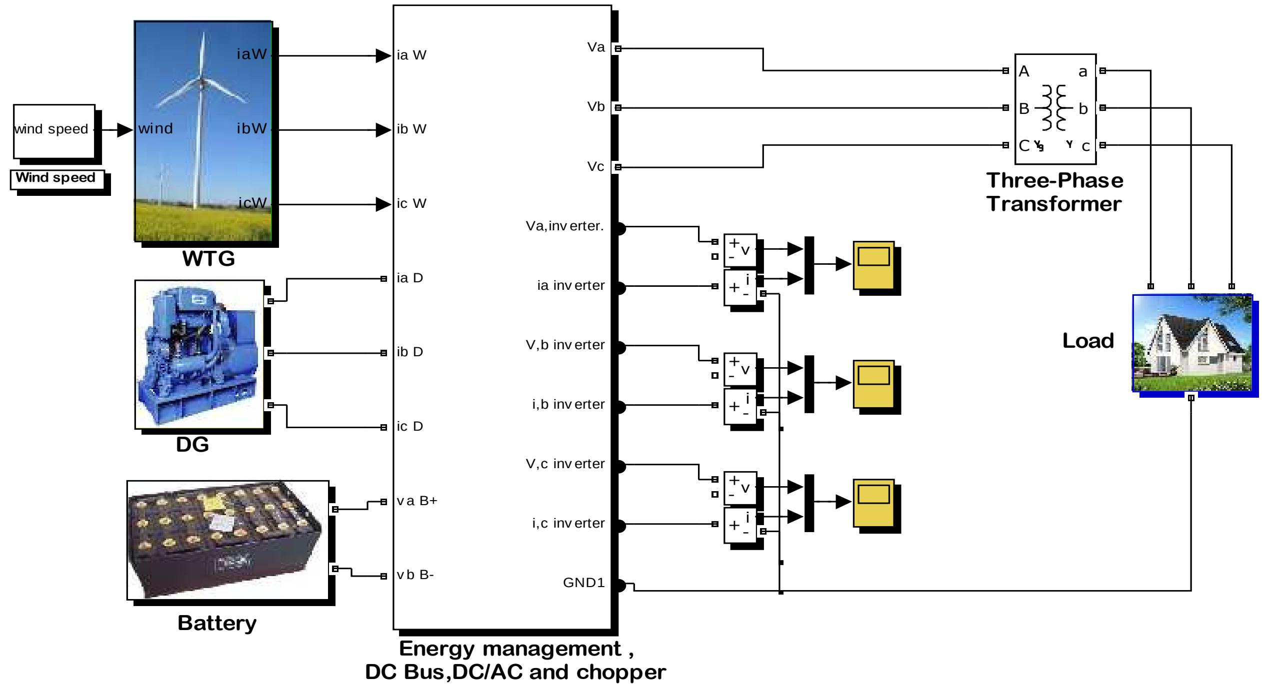


Fig.16. Renewable generation hybrid system

At ; t = 1.2s time coupling between two sources.

Shape of the current phase of two sources for the coupling is shown in Fig. 21. It is sinusoidal with an amplitude of ± 4.9 A, with a 20 ms period (50 Hz).

1. Wind turbine: 10≤V_m <17 (m/s)

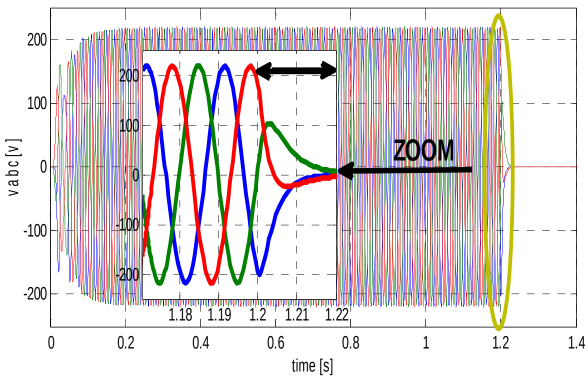


Fig. 17. The evolution of the stator voltages.

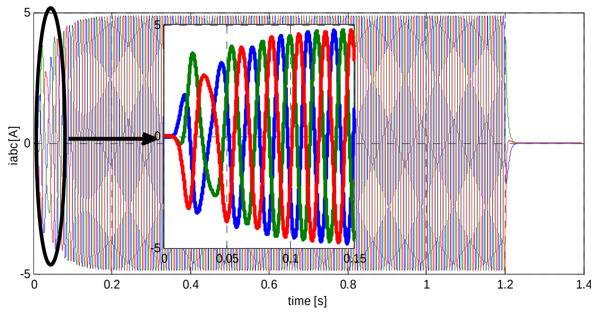


Fig. 18. The evolution of the stator currents.

2. Diesel group: V_m <3 (m/s)

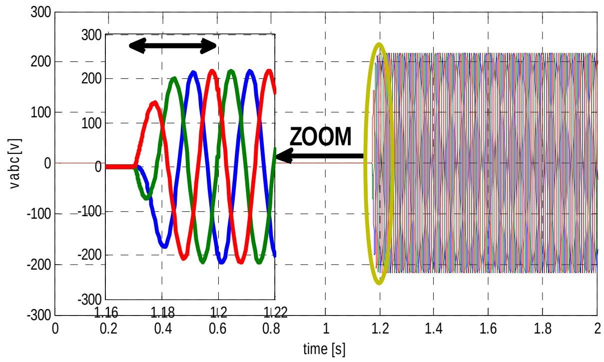


Fig. 19. Voltages produced by DG.

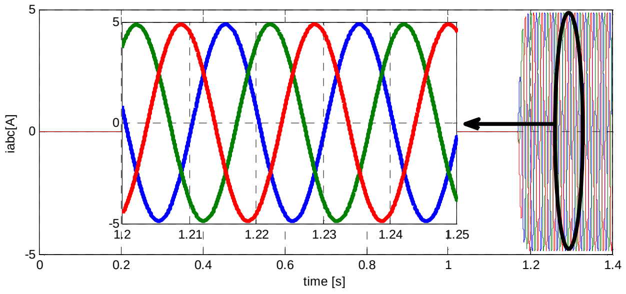


Fig. 20. Currents produced by DG.

3. Diesel Group /Wind turbine:3≤ V_m < 10(m/s)

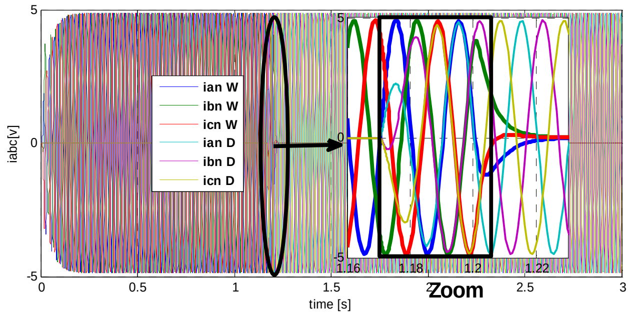


Fig. 21. Currents produced by DG/ WTG.

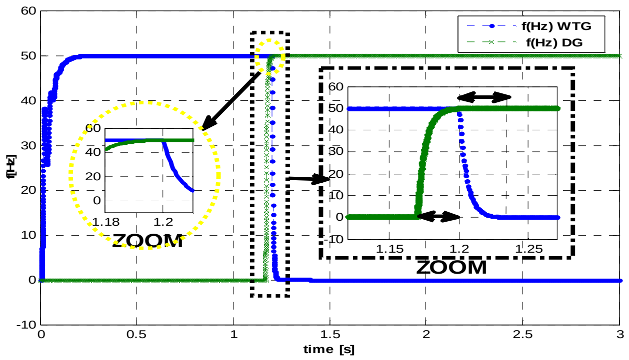
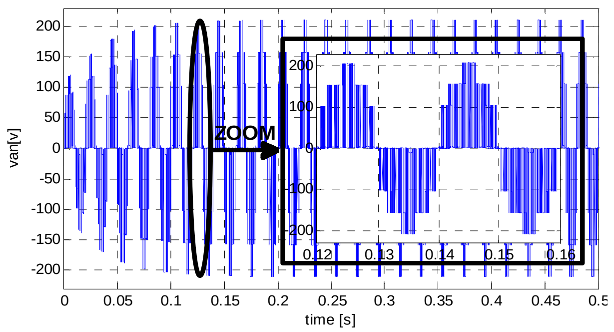
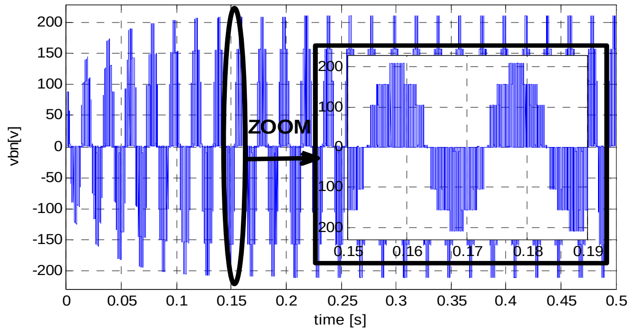


Fig. 22. Overview of frequency.





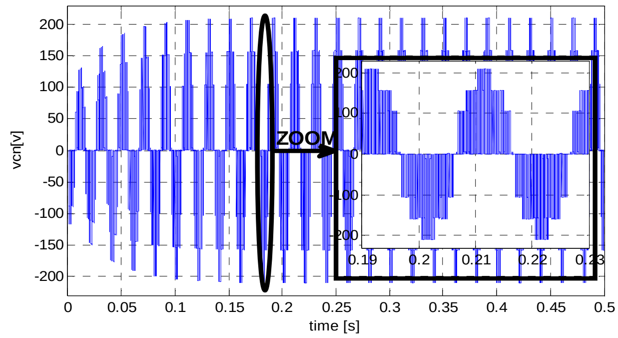


Fig. 23. Simple tensions of phases "A,B,C" generated by inverter NPC.

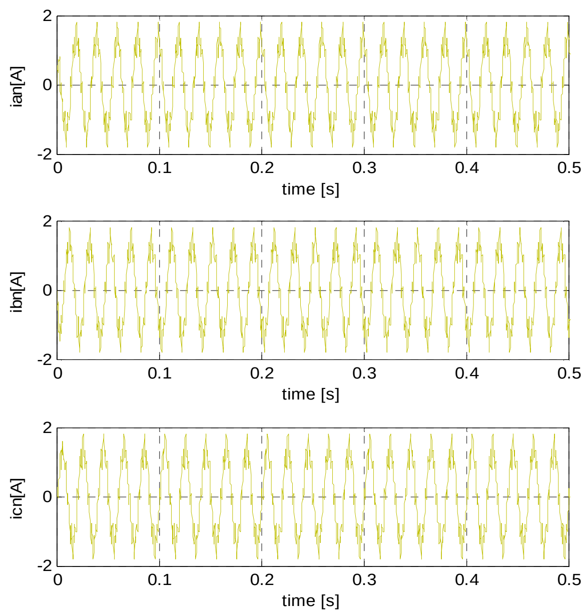


Fig.24. Simple currents generated by inverter

According to Fig.17 representing the three-phase simple tensions where the feeding of the consumers is only assured by the wind generator(WO), when the speed of the wind is included [10m/s with 17m/s] until the time(t=1.2 s) according to the condition of adapted management; for this mode, I note that a surplus of wind power which can stored be in the battery with a system of regulation to ensure the continuity of service: this is necessary to feed the load of which in the case when the power generator unit falls down and the wind insufficient for operation of the wind(see it Fig.23 and Fig.24) .

In case where (t≥1.2 s) the DG ensures only the feeding of the load concerned, knowing that the speed of the wind is lower than 3m/s (see Fig.19 and Fig.20).

8. Conclusion and perspectives

In my research, I have based in the integration of a hybrid system with a storage facility located in a remote site. The hybrid system includes a variable speed wind turbine which is controlled by the MPPT (Maximum Power Point tracking) command, a diesel generator and battery as an electrochemical storage system. Simulation management system has been applied in Adrar site where meteorological data (wind speed, temperature, relief) are available. According to the results, management has enabled us to obtain a technical and economic gain fuel, longevity of the generator, an assurance of service continuity and removing a portion of greenhouse gas emissions during operation in wind.

To have a permanent solution is power problems in isolated perspective (technical, economic and environmental) in Algeria the country is moving towards a new form of energy called "renewable energy" by launching an ambitious program of these energies and including energy efficiency will have a strategic role. The program is to install a renewable power in the order of 22,000 MW between 2011 and 2030 to meet national demand for electricity. In this context, the city of Adrar has received a draft wind farm power generation capacity of 10 MW, the first of its kind nationally and 2020, the province of Adrar will be reinforced with a new 175 MW power plant which is in progress, and whose studies are in progress, too.

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