Modeling and simulation of hybrid wind-diesel power generation system

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ABSTRACT

The increased environmental concerns after Kyoto Protocol and Copenhagen summit have led the development of renewable technologies. The renewable power plants are mostly implemented in rural areas as they cover large ground surface. The rural areas are far away from the main grid network and connection is possible through a weak transmission line. The concept of hybrid power system generation is proposed as effective solution for to meet our energy demands and to decrease the greenhouse gases emissions. The installation of hybrid power systems has known a constant growth in the last years. To improve the power quality of wind generation system a wind-diesel hybrid system is proposed in this paper. The simulation results confirm the smooth operations of the proposed wind-diesel system.

Keywords: *Renewable energy, Wind-diesel system, Asynchronous generator−Diesel generators*

1. Introduction

Global warming is one of the most serious environmental problems facing the world community today is interested in solving it. It is characterized by the increase in the average temperature of the earth and extreme weather conditions [1]. Plus of that, the rapid depletion of fossil fuels worldwide has necessitated an urgent search for alternative energy sources to meet the current requirements. Its renewable energy sources such as wind power have drawn attention to a large-scale [2]. The alternative energy sources are non-polluting, free in their availability, and continuous. These facts make the alternative resources attractive for many applications. Therefore, only 6.4% of total renewable energy sources available in the world are in use today. To get more consistent flow of energy to the user request, there has been a growing trend to combine renewable energy sources with diesel generators, giving a hybrid power generation system [4], they are activated to serve as electrical energy to relay telecommunications, border crossings, the isolated habitat, clinics..etc. The same systems are generally independent from large interconnected networks [5].

In the literature we find that hybrid systems have been studied for an isolated case or connected to a power grid. In [6] a study of a hybrid autonomous system was introduced, the same is presented in [7] for a power system in island in Bangladesh. Several parameters are enter in the study as well as the system design, but in the literature it is difficult to find how to size the various components of an autonomous system, most of them focus on the basic theory of technology but rarely the sizing of equipment. The variable parameter of most renewable energy often takes a complex control system [8]. In the same vision a design of a control voltage and frequency for a wind-diesel system is shown in [9]. In [10] P. S. Panickar et al study a strategy of adaptive control by a variable wind speed for an application for a wind diesel hybrid system. Modeling is also a major factor in studies developed to simulate a functioning system. Much software allows us to do that. In [11],[12] a modeling and simulation of various hybrid systems presented with MATLAB-Simulink software. In [13] a model of a hybrid power generation is made by the HOMER software.

In this study we propose a wind-diesel hybrid power system generation for to meet our energy demands and to decrease the greenhouse gases emissions. The simulation results confirm the good operations of the proposed wind-diesel system and shows the importance of the emergency generator in order to ensure the reliability and the economy of the system to reduce greenhouse gas emissions.

2. Structure of hybrid power system generation

The configuration of the hybrid system obviously depends on the availability and use constraints energy resources. This requires a measurement and a preliminary analysis of site conditions. There are several structures of an autonomous wind diesel hybrid system, wind-diesel system with short-term storage, wind-diesel system with long-term storage (batteries, compressed air, hydrogen, etc.) [14], wind-diesel system without energy storage.

The choice of a suitable structure of a hybrid system is depending to the satisfying the technical performance by respecting quality demands of electrical energy parameters and improving the economical performance by increasing the fuel savings and minimizing the electrical energy production costs in autonomous systems[15].

3. Wind-diesel system without storage

In our study we chose to work on the third structure of wind-diesel system without energy storage (Fig. 1)

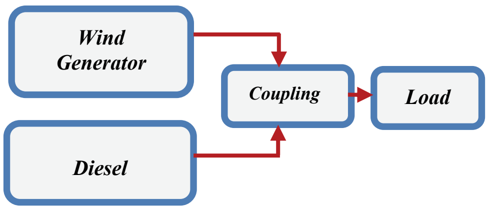

Figure 1 Simplified diagram of a wind diesel hybrid system

It is able to meet the need for electricity for consumers in isolated zones, it consists of the following subsystems: a wind generator and one diesel, both connect to a load.

During the functionality of the system studied, if the electricity generated by the wind generator is sufficient for the load demand, the diesel generator is inactive produces reactive energy compensation. Except in the case where wind energy is insufficient to load demand, the diesel generator goes on to provide additional energy.

3.1 Wind generator

A wind turbine consists of four main components: a turbine which is the main tool for the conversion of wind energy into mechanical energy. An electromechanical system as a tool for transformation of mechanical energy into electrical energy, it includes the asynchronous generator and associated electrical components. An interconnect system and a control system [13].

The low cost and the standardization of the asynchronous machine that does not require a complex installation has led to a wide domination of this type of generators installed in a wind system. It is less demanding in terms of maintenance and has a failure rate very low. In the wind turbine consequent size, rotation speed is low. It is therefore necessary to insert between the turbine and the induction motor mechanical speed multiplier. In this work we will focus to study on an asynchronous machine squirrel cage self-excited. (Fig. 2)

PSM requires reactive energy to start (generation of rotating magnetic field). In a general case a capacitor connected in parallel with the stator circuit provide this energy [16].

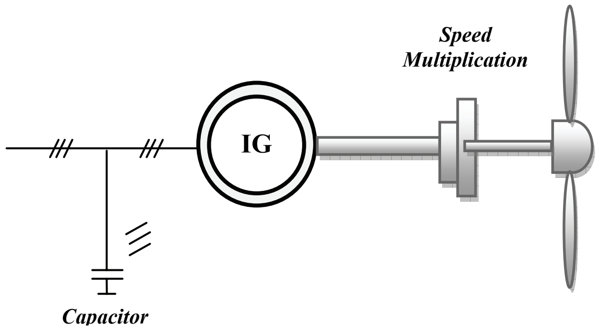

Figure 2 Wind system

3.2 Diesel generator

The diesel generator (Fig. 3) is generally composed of a synchronous generator coupled to a diesel engine. The frequency of the alternating output current is maintained by a speed regulator. The regulator operates by adjusting the flow of fuel to keep the engine speed and the speed of the generator constant. In the case of high speed wind, the clutch decouples the synchronous generator from the diesel engine, and the machine functions as a synchronous generator and provides reactive energy [16, 23].

Diesel engines are more efficient internal combustion engines. The speed of rotation of such generator depends on the amount of injected fuel and the load applied to the engine crankshaft. The diesel engine is a nonlinear system. It presents delays, which makes it difficult to control. Diesel engines are equipped with cruise control: mechanical, electromechanical or electronic. It carries out the automatic control of the speed of the diesel engine by adjusting the fuel injection depending on the load. It acts on the acceleration mechanism [16-23].

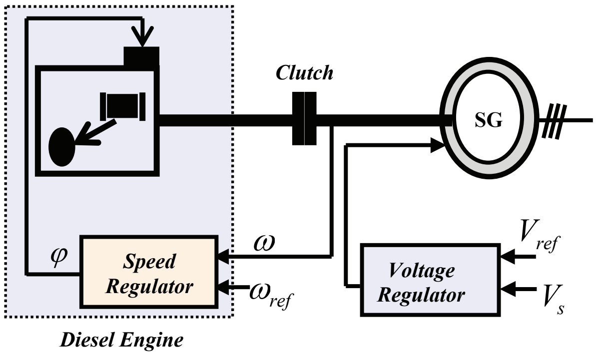

Figure 3 The diesel generator

4. Modeling of wind-diesel system

To optimize a hybrid power generation system, it is necessary to know the various elements of it. For this we will begin modeling the wind turbine with the asynchronous generator and as in a second step we model the diesel generator.

4.1 Modeling the wind system generator

In the literature, several studies have been devoted to the modeling of different components of a wind power system for a quality generated. A single wind turbine power small autonomous model was presented in [17]; the authors in [18] did an analysis of different modeling methods, the first deals with a theoretical model including a second based on the experimental data.

We can say that a wind system transforms wing energy of the air mass to a mechanical power, characterized by the speed of rotation and mechanical torque. (Fig. 4)

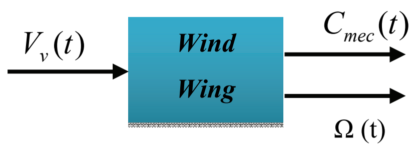

Figure 4 Model of the wing

In our case the turbine is formed with a horizontal axis, the principle of wind conversion was established by Betz it assumes that the blades are placed in a lively air to infinity upstream speed V_1 and downstream of an infinite speed V_2 with an air mass moving through the density ρ with surface S of the blades [19]

$$m = \frac{\rho.S.(V_1 + V_2)}{2} \quad (1)$$

The power p_m ; extracted is expressed as half the product of the mass and the change in wind speed.

$$P_m = \frac{m.(V_1^2 - V_2^2)}{2} \quad (2)$$

By replacing the expression of m in the equation!(2)!

$$P_m = \frac{\rho.m.(V_1 + V_2)(V_1^2 - V_2^2)}{2} \quad (3)$$

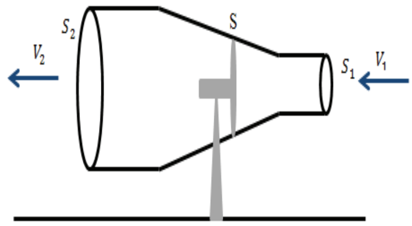

Figure 5 Tube of the current around the wind system

Undisturbed wind theoretically pass through the same area S with no variation in speed V_1 , the total power p_{mt} would be written:

$$P_{mt} = \frac{\rho.S.V_1^3}{2} \quad (4)$$

The ratio of the power extracted from the wind and the total power available is:!

$$C_p = \frac{P_m}{P_{mt}} = \frac{\left(1 + \left(\frac{V_1}{V_2}\right)\right).\left(1 - \left(\frac{V_1}{V_2}\right)^2\right)}{2} \quad (5)$$

Where C_p : The power coefficient

If we represent the corresponding feature in the equation above, we see that the power coefficient C_p has a maximum of 0.59, see Fig. 6. This theoretical limit called Betz limit which determines the maximum extractable power for a given wind speed. The evolution of the power coefficient is a specific data for each wind. [20]

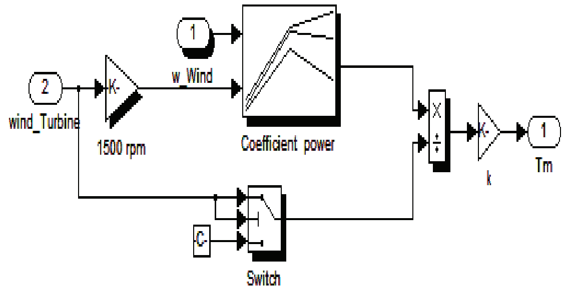

Figure 6a Bloc of Wind turbine

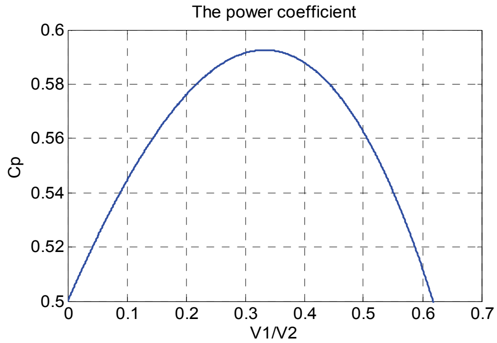

Figure 6b Power Coefficient

With the combination of the equations (1), (4) and (5), the mechanical power p_m available on the shaft of a wind turbine is expressed by [19]:

$$P_m = \frac{P_m}{P_{mt}}.P_{mt} = C_p.P_{mt} = \frac{1}{2}C_p(\lambda).p.\pi.R^2.V_2^3 \qquad (6)$$

The specific rate λ is written as follows

$$\lambda = \frac{\Omega_1.R}{V_1} \qquad (7)$$

Given the ratio of speed multiplier K, the mechanical power p_{mg} available on the shaft of the electric generator is expressed by:

$$P_{mg} = \frac{1}{2}.C_p\left(\frac{\Omega_2 R}{KV_1}\right).\rho.\pi.R^2.V_1^3 \qquad (8)$$

With:

- ✓ R : Radius of the wind turbine
- ✓ Ω_1 : Rotational speed before the multiplier
- ✓ Ω_2 : Rotational speed after the multiplier

4.2 Modeling the diesel generator

Modeling of the diesel engine must consider the moving parts of the engine, the power output p_i and the total power dissipated p_{diss}. The motor runs at constant speed for a given order to maintain the voltage and frequency of the current supplied by the alternator constant load. The principle of energy conversion can be written as follows [21]:

$$P_i - P_{diss} = 0 \qquad (9)$$

The power delivered can be represented by the following expression:

$$P_i = P_{ci}.n_i.m_f \qquad (10)$$

With

- P_{ci} : The calorific value of the fuel
- n_i : The indicated engine performance
- m_f : The flow of fuel injected into the combustion chamber

The total dissipated power includes on the effect of friction of the moving parts as (rods, pistons, crankshaft), and that of the load applied on the engine, can be expressed by the following formula:

$$P_{diss} = P_{mf} \cdot \frac{C_y}{4\pi} . \omega + C_r . \omega \tag{11}$$

- P_{mf} : The average pressure of the friction losses
- C_y : The total displacement of the engine
- C_r : The resistive torque to the applied load

The modeling of friction at different parts of the engine was the subject of numerous studies that lead to a variety of forms. Given the complexity to treat each element separately, it was preferred to use the comprehensive assessment of the losses [22] formulas.

The most accurate formula which represents the variation of the power of friction depending on the speed and pressure of the intake air of the engine as follows:

$$P_{mf} = (1 + \omega . S_{eng} . \left(K_{f1} + K_{f2} . \frac{P_{in}}{P_a} \right) + K_{f3} \omega^2) . P_a . \frac{C_y}{4\pi} . \omega \tag{12}$$

The rural areas are typically fed by conventional diesel power stations. Suitable dynamic models are included in hybrid power system generation for all important elements of conventional diesel power stations, namely the diesel engine, speed governor and permanent magnet synchronous generator [16].

For the diesel generator, simple or more sophisticated models available in the literature are employed, depending on the data available [24]. However, experience has shown it is often sufficient to use the simple model of Fig. 7, where the speed governor is represented by its droop and integral gain (PI controller), along with a first order lag for the valve actuator mechanism[16].

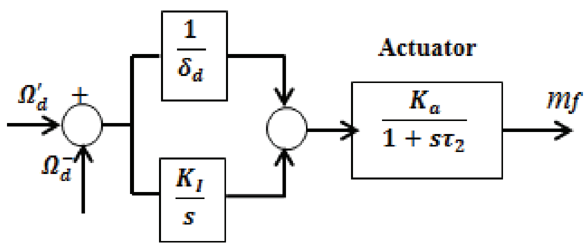

Figure 7 Speed governor block diagram of the diesel engine

5. Simulation of the wind diesel system

The general structure of the wind diesel power system is shown in Fig. 8.

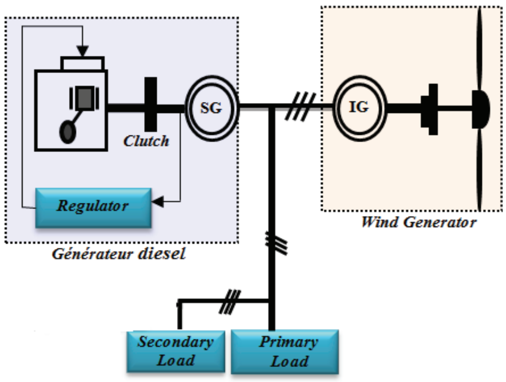

Figure 8 Diagram of a wind-diesel system

The hybrid power system generation presented in this study uses a 380 V, 300 kVA permanent magnet synchronous generator, a wind turbine driving a 380V, 250 kVA induction generator, a 100 kW customer a variable primary load and a variable secondary load (0- 400kW). In this load center, we used two circuit breakers for connecting and disconnecting a (150KW) auxiliary load and secondary load. When we want to control the frequency we close the circuit breaker of secondary load and vice versa.

The simulation time is 20s with a sampling period of 1ms. In t=5s a 150KW auxiliary load is added in the primary load change show figure.9. The simulation results are shown in the figures below. From the simulation results it is noted that, the turbine connected to the induction generator operates at a speed which is slightly greater than the synchronous speed (Fig. 9).

We note that at t=5s the primary load power is 250kW and according to the characteristic of the turbine for a wind speed 8m/s, the power generated by the wind turbine is 100kW is less the total primary load, in this instant the power generated by the diesel generator increases (Fig. 11) to meet the demand.

In the same figure at time t=10s, we note that if the wind speed increases (10m/ s), the wind power exceeds the load demand, it is possible to shut down the diesel generator the power supplied by diesel generator decreases, which leads to a decrease the fuel consumption is accompanied with a proportional reduction in toxic emissions and greenhouse gas emissions. A secondary load bank is used to regulate the system frequency by absorbing the wind power exceeding consumer demand.

Consequently at low wind speeds both the induction generator and the diesel-driven synchronous generator are required to feed the load show figure.

Fig. 11 shows the required reactive power generated by the diesel system to initiate the asynchronous generator. The voltages and currents of the load are in sinusoidal forms are shown in Figs(13- 15).

Frequency is maintained constant by using diesel governor which senses the change in speed and acts according to it show Fig.16.

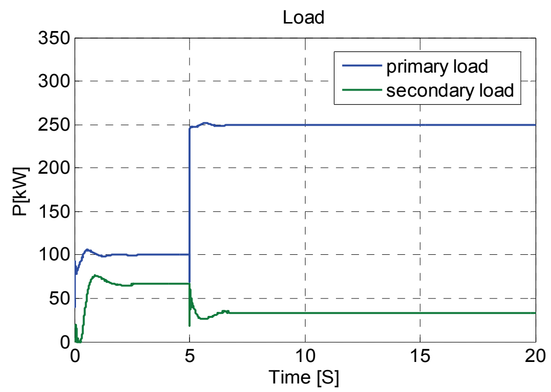

Figure 9 Load in the system

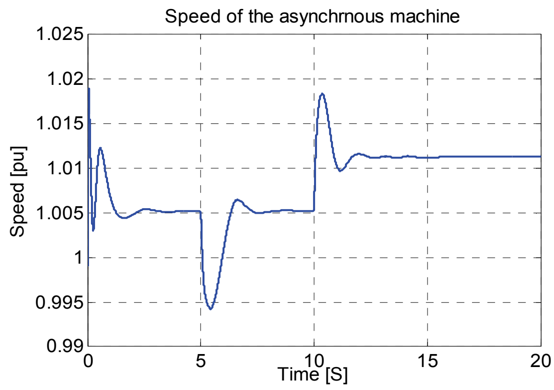

Figure 10 Speed of the asynchronous generator

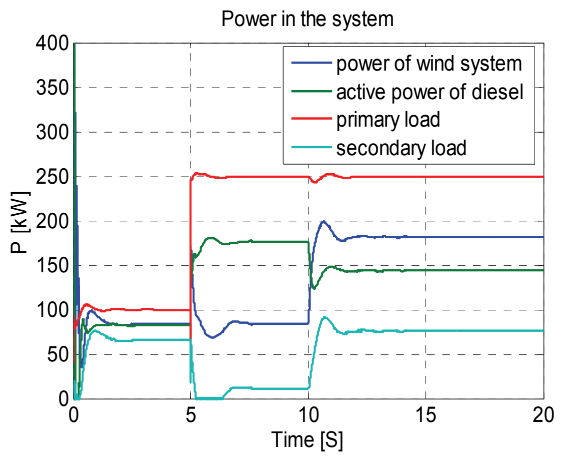

Figure 11 Power in the hybrid system

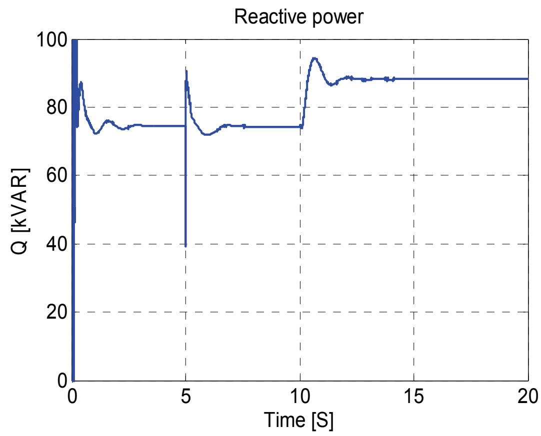

Figure 12 Reactive power of the diesel generator

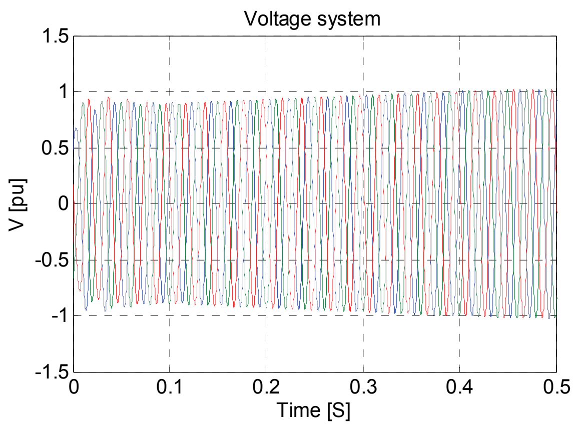

Figure 13 Load Voltage

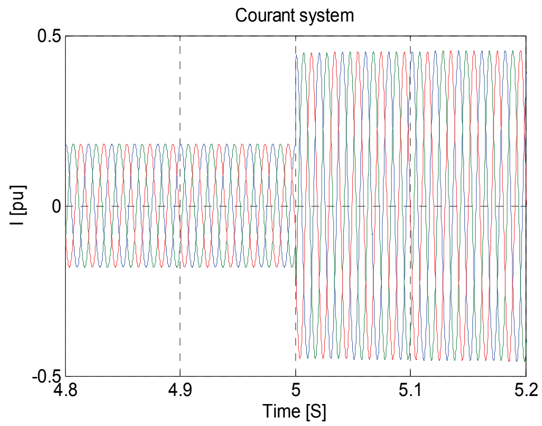

Figure 14 Load Current

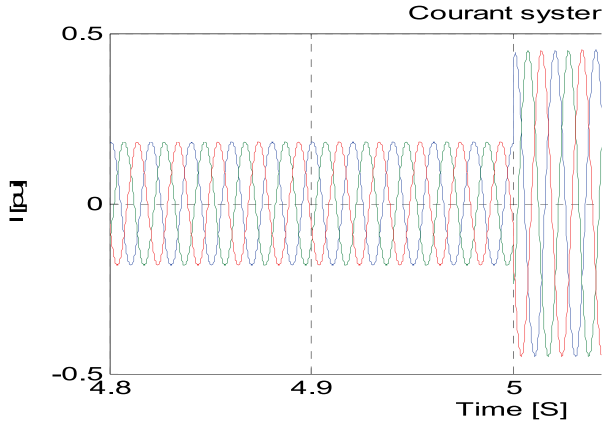

Figure 15 Zoom of the load Current

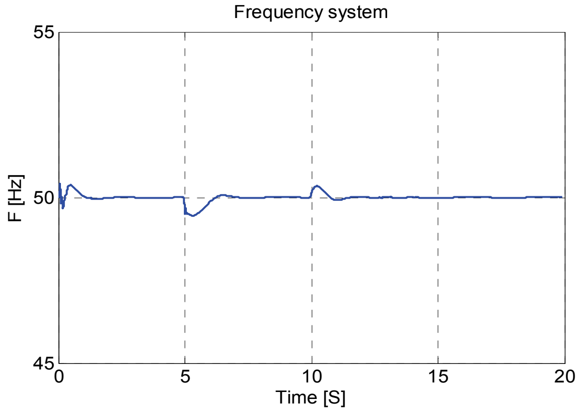

Figure 16 Frequency system

6. Conclusion

In this paper simulations under Matlab \ Simulink of a wind-diesel hybrid system were presented. The simulation results show the importance and flexibility of operation of diesel generator and wind generator to reduce fuel consumption are associated with a proportional reduction in toxic emissions and greenhouse gas emissions.

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