SIMULINK MODEL FOR A BIO-DIESEL ELECTRICAL POWER GENERATOR USED INTO A FARM

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Abstract: The paper presents a Simulink model for a bio-diesel electrical power generator used to supply a farm. Considering that for a farm is too costly to connect to the national power grid, is taken into account electricity production using a diesel generator powered by bio fuel. Most systems of electricity generation using bio-diesel engine works all the time regardless of the rated electrical load. To avoid unnecessary fuel consumption when the electrical load is small was made an adjustment of mechanical power according with the electric load. For this purpose it was used a governor. As electric generator was used a synchronous machine because it can generate voltage with a constant frequency if the rotational speed of the rotor is constant. Electrical load was modeled using electric power consumption data collected from a real farm. Finally, a Simulink/Matlab model was created, which can be useful to engineers to design a real system.

Keywords: *bio-diesel, Simulink, synchronous machine, renewable energy.*

I. INTRODUCTION

In the current electricity networks continue changes occur such as: increasing energy consumption, aging networks and continuous emergence of new policies related to environmental protection. Distributed power generation systems are a possible solution for supplying electricity consumers. Mentioned systems are placed close to the user and differ by large central power generation systems by the generation method, transportation and distribution. Among the biggest disadvantages of renewable resources is their intermittent nature. To compensate and to extend the applicability of this type of resources are used with hybrid storage systems (batteries and supercapacitors).

Autonomous micro-power generation networks represent a new approach to the issue by means of an intelligent supply.

When a part of the grid is temporarily disconnected from the main power supply network and is supplied from own energy sources it is named an islanded grid.

Islanding can be of two types: intentional or unintentional. Unintentional islanding is when a disturbance of the grid occurs. Intentional islanding is used for customers in locations where the main power supply network is unreliable.

Electrical generators typically are of three types: synchronous generators, induction generators, and inverter-based systems. Each type has different characteristics which generate specific requirements to connect to the main power network.

Because a synchronous machine generates voltages at a frequency that is strongly dependent by the rotational speed of the rotor, the output voltage will have the same frequency if the rotor rotates with a constant speed. An important advantage of the synchronous machine is they do not require a supply of reactive power from the grid. This is the reason why these kinds of generators are very popular on islanded mini-grids. Another important advantage is the possibility of the synchronous machine to start without external reactive power. In comparison with induction generators, the synchronous generator is more reliable because it can control power factor by supplying reactive power to the grid when is necessary, which means additional voltage.

For an isolated farm, local generation of electrical power may be a better alternative that the connection to the national electrical power network. Major advantages consist not only in reducing the cost of electricity but also in reducing the cost of connecting to the electrical power supply network.

So, the idea of this paper is to propose a model for electrical power generator using a diesel engine. For small farms that can be a good solution do to a relative chipper equipment and fuel consumption. In addition, the farm where it is intended to be mounted can produce it-self bio-diesel fuel used in the power generator. In this way, it can be obtained a further optimization of energy production cost. The fuel consumption is also optimized by using a governor and a control system that is capable to adjust the mechanical power of the diesel engine according to the electrical load.

For conversion of the mechanical power to electrical energy a synchronous electrical machine was used. In the paper, the diesel engine with governor, synchronous machine and the control system is presented. The model was created using the Simulink/Matlab software package.

A model for electrical load was also created starting from measurements tacked from a real farm, during a complete day. We use measurements reported by the German Association of Electricity Business (VDEW, today's BDEW) [1], [2].

The operating principle is drawn in Fig. 1.

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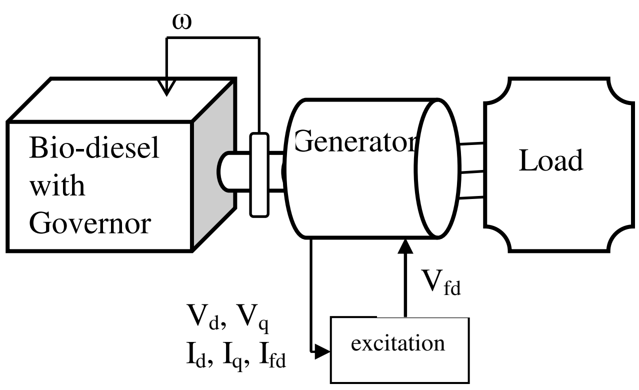


Figure 1. Diesel generator system principle.

II. DIESEL ENGINE MODEL

The diesel engine is equipped with a governor module that allows mechanical power control of the engine according with the load variations.

Governor role is to maintain the speed of the motor at a constant value. This is very important since the motor must rotate the shaft of a synchronous machine and is known that the synchronous machine works properly only at a constant speed.

The parameters of the motor are shown in Table 1. We use the diesel engine KDE 3500X, which is a component of the commercial electro-generator.

TABLE I. Engine parameters

Motor model	**KM178FG**
Nominal angular velocity [rpm]	3000
Cylindrical capacity [ml]	296
Nominal power [kW/rpm]	3.68/3000
Fuel consumption [g/kWh]	370

The transfer function for the control system of the governor is shown in equation (1), and the transfer function for the actuator is presented in equation (2).

$$H_c = 5 \cdot \frac{1 + 0.2s}{1 + 0.01s + 0.01 \cdot 0.02s^2} \quad (1)$$

$$H_a = \frac{1 + 0.25s}{s \cdot (1 + 0.009s) \cdot (1 + 0.0384s)} \quad (2)$$

III. SYNCHRONOUS MACHINE MODEL

Synchronous machine is called so because it rotates on a steady state with a constant speed called synchronous speed.

The rotational speed of the rotor is equal with the rotating speed of the air gap field which is the synchronous speed.

The stator current and rotor current generates fluxes which create also the air gap flux. The stator is coupled at alternative current network and rotor must to be excited by a direct current. This is the reason why synchronous machine is named doubly excited machine.

In the air gap appears a flux generated by the current that flows through the rotor. This flux is distributed sinusoidal. When diesel engine rotates the rotor of the electrical machine a revolving field is generated in the air gap. Because this field is generated by the excitation direct current, it is named the excitation field. The flux linkage of the armature windings is modified by the rotating field, and that follows in inducing voltages in stator windings [3].

Modeling is a very useful scientific method because reduce considerably the design process and permit to researcher to concentrate only on important values and issues. Working with models creates the possibility to generalize a piece of reality using defined laws. On this way, the complexity of the phenomenon is reduced and reality can became more understandable. After investigations of research object the mathematical model can be constructed to describe the behavior of the original. All essential parameters must be included on mathematical model. In many situations differential equations are used to create the model [4], [5].

Starting from the equivalent circuit of generator, presented in Fig. 2, the model can be developed [6].

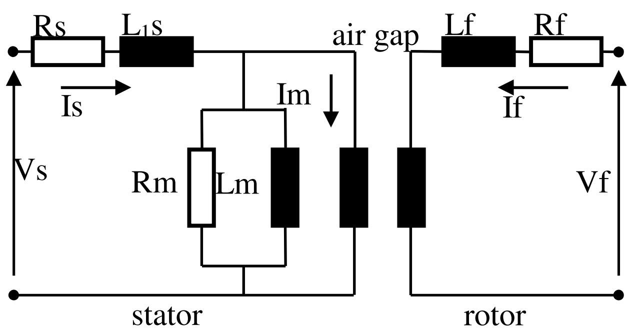


Figure 2. Equivalent circuit of synchronous machine.

Starting from this point we can write some equations. The synchronous machine rotates at synchronous speed which is dependent by the frequency of the supply network [7]. The stator has a three-phase type winding, and the rotor is supplied by a direct current. In equivalent circuit per phase of the generator, the moving rotor windings are connected with the stator. The equivalent circuit is composed by resistances of stator and rotor (Rs, Rf), leakage inductance of the stator and rotor (Lls, Llf), output voltage (stator) (Vs), excitation (Vf), currents of the stator and filed (Is, If), magnetizing current (Im), core-losses resistance (Rm), and magnetizing inductance (Lm) [8].

Matlab library SimPowerSystems use the seventh order model, which is considered the standard model. This model ignores the asymmetry of stator windings, parameters that are influenced by non-electric conditions (temperature), harmonics of flow in air gap, skin effect in rotor and stator windings, iron losses, and nonlinearity of iron magnetic characteristics. To can analyses and synthase the excitation system, the equations must be derived for some types of work conditions, which are presented in Fig. 3 [9].

$$u_s = -R_s \cdot i_s + \omega P \Psi_s + \frac{d}{dt}\Psi_s \quad (3)$$

$$u_r = R_r \cdot i_r + \frac{d}{dt}\Psi_r \qquad (4)$$

$$2H\frac{d\omega}{dt} = m_t - m_e \qquad (5)$$

$$\frac{d\delta}{dt} = \omega - \omega_s \qquad (6)$$

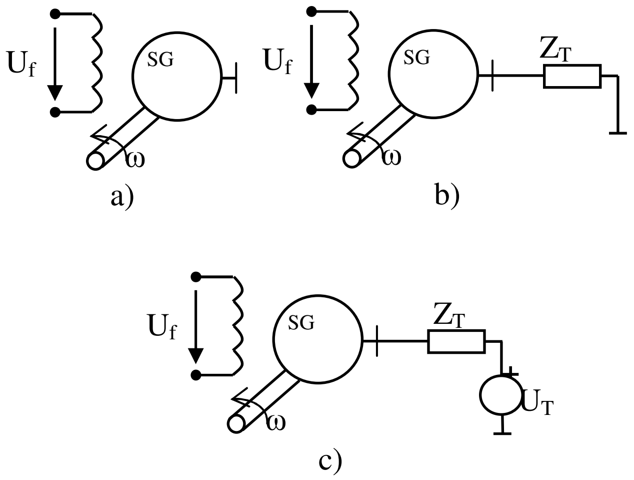


Figure 3. Equivalent circuit of the synchronous machine for different work modes.

Connection between fluxes, currents and electromagnetic moment are described by equations:

$$\Psi_s = -L_s \cdot i_s + L_{sr} \cdot i_r \qquad (7)$$

$$\Psi_r = -L_{rs}^T \cdot i_s + L_r \cdot i_r \qquad (8)$$

$$m_e = \Psi_d \cdot i_q + \Psi_q \cdot i_d \qquad (9)$$

Standard model is shown in Fig. 4.

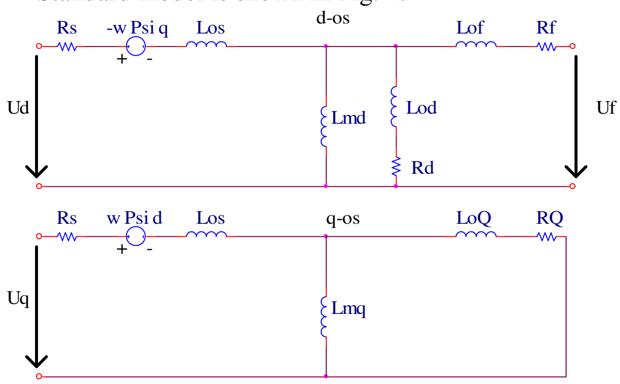


Figure 4. machine for different work modes.

The nonlinearity of the standard model occur from the equation (3) (product of angular rotor speed and stator flux) and equation (9) (product of currents and fluxes). This is the reason why the standard model cannot be used for synthesis of control system, but it can be used for analysis of dynamic and transient behavior. If the iron core nonlinearity is tacked into account, the complexity of the model increases too much. The model used for control system synthesis must to be linear [5], [10].

Fig. 5 presents all 6 models of three-phase synchronous machines that are available on Simulink/Matlab library. The parameters of the models are in pu or in SI. The first three models are simplified models of generators with permanent magnets on rotor. Synchronous machine operate in generator or in motor modes according with the mechanical power definition direction. In order to operate as a generator this data must to be a positive constant [11-18].

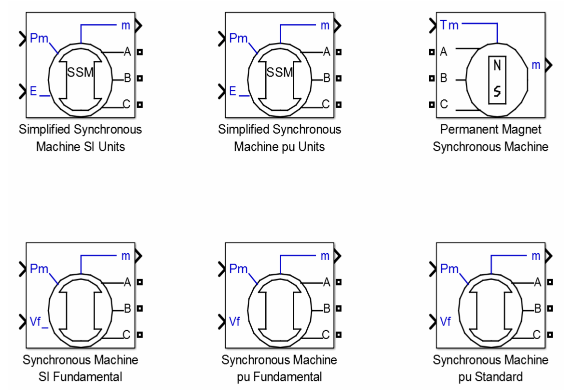


Figure 5. Different types of synchronous machines used in Simulink/Matlab.

For the excitation system of the synchronous machine we use a DC1A type which is recommended by IEEE 421 standard (Recommended Practice for Excitation System Models for Power System Stability Studies) [4]. The stator terminal voltage is a first order system which means it is a low-pass filter with time constant set to 20 ms. The exciter is also a first order system.

Using this type of excitation the control of the synchronous machine is done by the field voltage that is applied to the Vf input of the machine.

The waveform of Vd and Vq are shown in Fig. 6, and the currents Id and Iq are shown in Fig. 7.

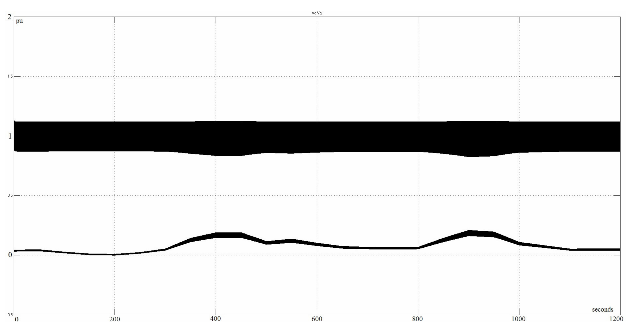


Figure 6. Vd and Vq voltages.

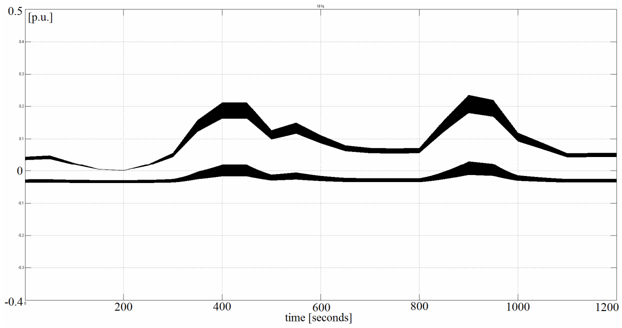


Figure 7. Id and Iq currents.

For modeling de synchronous machine a dedicated block from Simulink is used. The parameters for electrical machine are: 15 kVA, 400 V line-to-line voltage, and frequency is set to 50 Hz. Fig. 8 shows the parameters that are set on Simulink block.

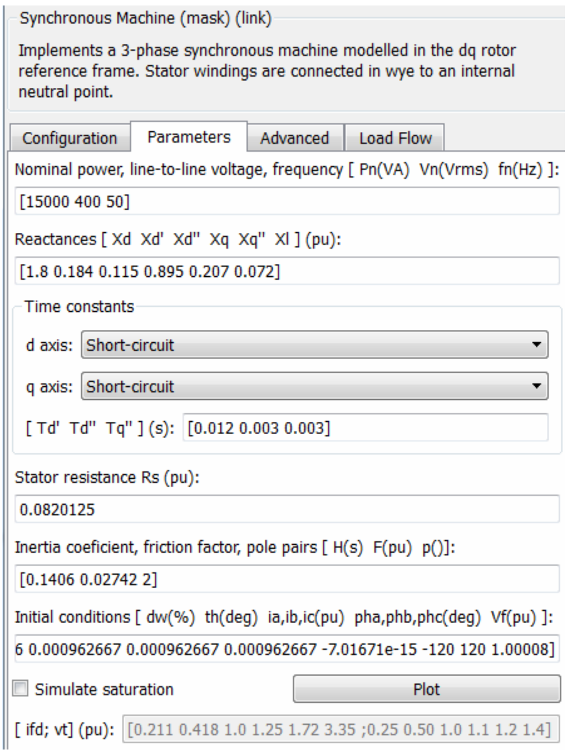


Figure 8. Synchronous machine parameters.

Diesel engine, the governor, and the synchronous machine with excitation system are shown in Fig. 9.

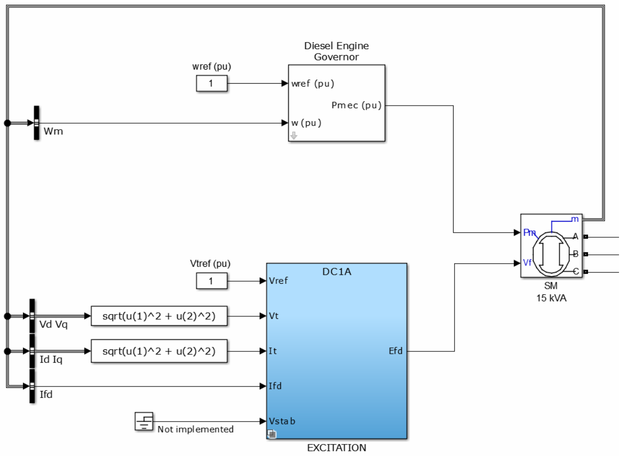


Figure 9. Electrical diesel generator with governor.

IV. REMOTE FARM ENERGY CONSUMPTION MODEL

A Simulink model of a remote farm was created starting from the measurements presented by BDEW. The profile duration was scaled to 1200 seconds for reducing time simulation and to avoid convergence errors that can appear in Matlab environment [1]. The power demand of a farm is shown in Fig. 10.

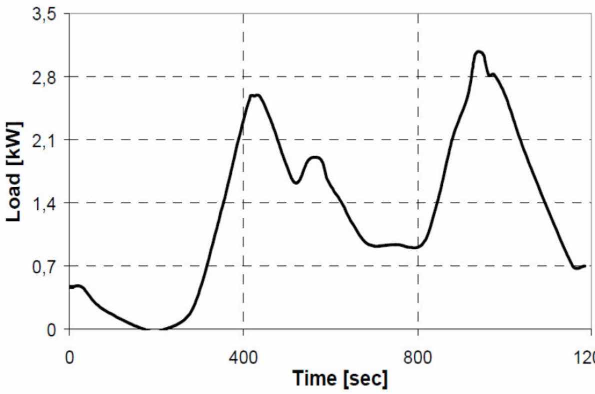


Figure 10. Remote farm profile [1].

V. RESULTS

The entire system is shown in Fig. 11. The simulation step-size was set to Ts=0.2 ms. The running time of the simulation was set to 1200 seconds which represents a compression of the load profile. This method was also used by authors of the paper [2].

To ensure the functioning of the system was necessary to introduce an additional 500 VAR capacitive reactive load in parallel with active load represented by farm consumption.

The main idea of our work is to control the mechanical power of diesel engine in order to reduce the fuel consumption. For this reason, a diesel electric generator was modeled using a governor to control the mechanical power of the diesel engine, but maintaining a constant angular speed [1], [2]. The reason why we need to maintain the angular speed at a constant value is because we use a synchronous electrical machine which can be operated only at a constant angular speed.

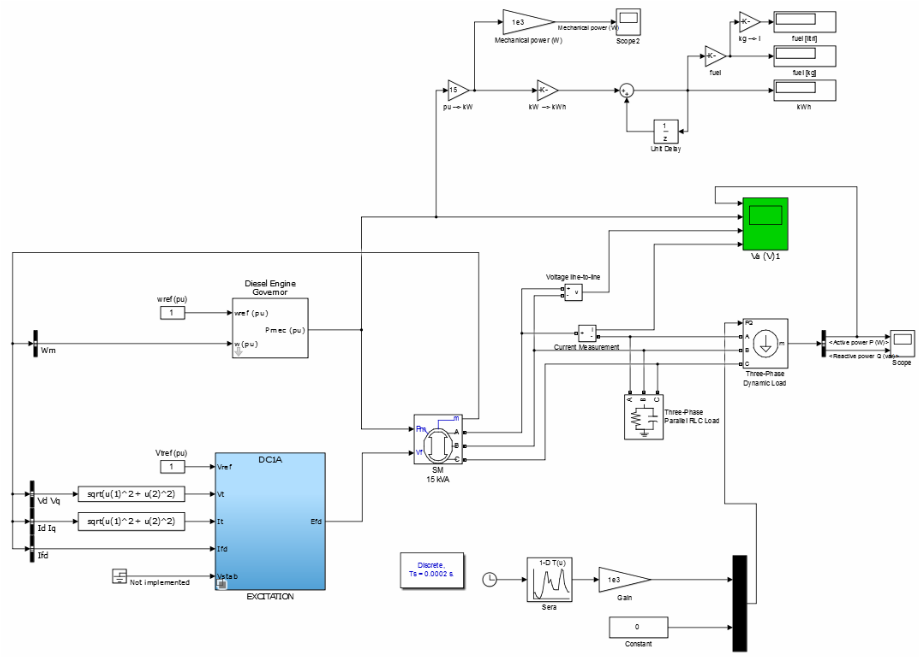


Figure 11. The entire system implemented in Simulink/Matlab.

As it can be seen in Fig. 12 this requirement was achieve. Rotational speed has only some very little variations that not exceed 0.4% of the nominal rotational speed. The rotational speed is expressed in rpm (rotates per minute).

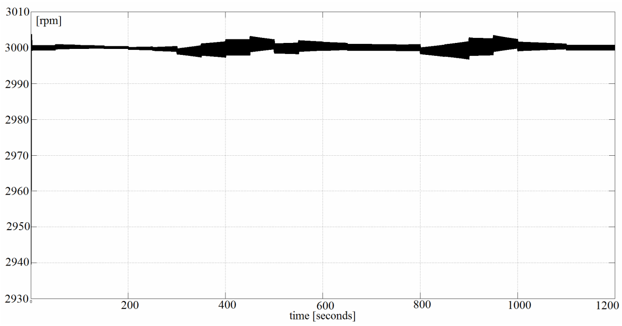


Figure 12. Rotational speed of the engine.

The mechanical power developed by the diesel engine is shown in Fig. 13. As you can see the mechanical power variation is very similar to the electrical load.

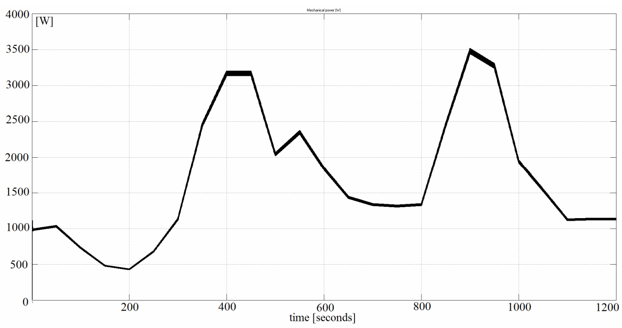
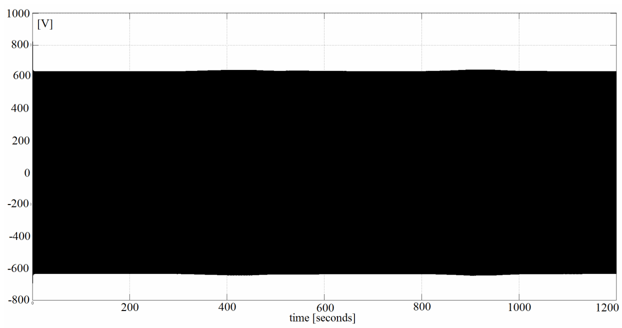
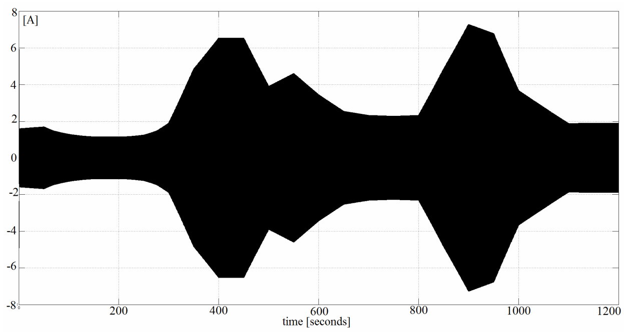


Figure 13. Mechanical power.

The next two images (Fig. 14 a) and b)) are shown the line-to-line voltage and current that flow through one line of the three-phasic electrical system. It can be seen that the voltage amplitude is constant at approximately 690V ($400 \cdot \sqrt{3}$), and current amplitude is varying according with the power variations.



a) Line-to-line voltage.



b) Current through the line

Figure 14. Line-to-line voltage and current through the one of the three-phasic electric system.

For a better view of the voltage, Fig.15 is showing a zoom of the voltage. The frequency of the voltage is stabilized at 50 Hz, as we proposed at the start of our work.

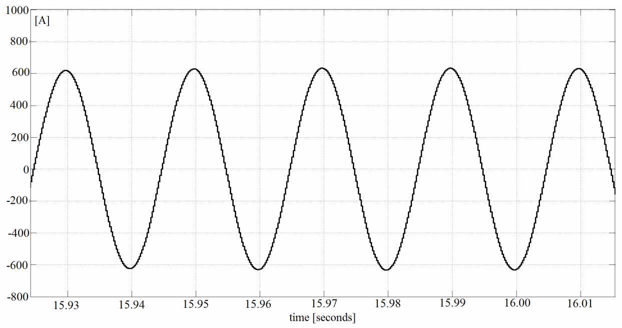


Figure 15. Line-to-line voltage zoom.

The principal objective of our work was to control mechanical power of diesel engine according with the electrical consumption of the farm. This target is confirmed by Fig. 16, where you can see that that mechanical power follows the variations of the electrical load.

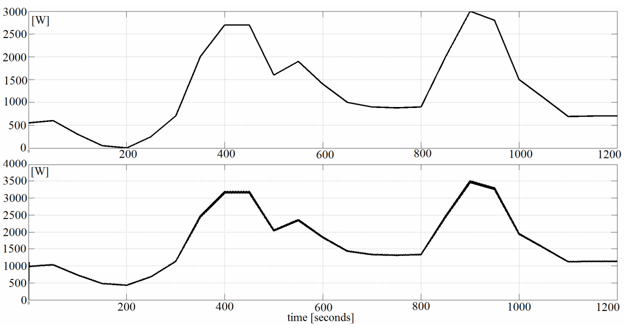


Figure 16. Electrical power (first) and mechanical power (second).

The engine was modeled starting from a commercial generator with a nominal power of 3000 W and 3000 rpm rotational speed. The fuel consumption of the engine is 370 g/kWh, so the total consumption during a day can be estimated.

Total electrical energy consumption during a day, for farm consumption load model, was computed to 64.43 kWh. The fuel consumption of the engine is 370 g/kWh, so we can evaluate the fuel consumption approximately 23.83 kg during a single day. The fuel density is 85%, so the fuel consumption can be expressed also to 28 liters. If the optimization system presented in this paper is not used, the diesel engine will function on nominal power (3680 W, from datasheet) during the complete period (24 hours), so the energy consumption on this way will be 88.32 kWh. Comparing the energy consumption of an optimized system (64.43 kWh) with energy consumption for non-optimized system (88.32 kWh) we can conclude that a value of 27% of energy is saved. This energy economy means a fuel save of 10.4 liters.

Another important goal of our work is that the CO_2 emission is also reduced considerably.

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