Abstract

Dual fuel technology systems (diesel-natural gas) to the commercial employment in diesel generator set has an innovative and relevant aspect. This project was developed in the state of Santa Catarina, by the Santa Catarina Gas Company - SCGÁS, CRW - Cesar Rafael Wilke EPP and SENAI Institute of Technology in Automation and ICT. This document addresses the experience and the final product achieved. During the project execution, computer simulations, tests and trials realized for the construction of the dual fuel system, the developed controller has achieved an average replacement rate of 61.5 %, and depending on the load this rate may reach 76 %, which meets the intended goals. Moreover, one can point out several features that make its use very attractive like the ease of installation, without the need for major changes in the generator, operational flexibility as it can operate in diesel mode or in gas-diesel mode and the ability to control a wide range of engines power.

1. Introduction

Currently the implementation of projects of power generation with natural gas in Santa Catarina meets obstacles in the high acquisition cost of natural gas generator sets, compared with diesel generators. As an alternative insertion of natural gas in power generation projects, and because of the dual fuel technology is still not produced for commercial use in Brazil, Companhia de Gas de Santa Catarina - SCGÁS, along with the company CRW - Cesar Rafael Wilke EPP and Senai Institute of Technology in Automation and Information Technology and Communication of Florianópolis, developed a dual fuel system for use in generators sets.

The Dual Fuel (Diesel / Gas) systems consist basically of a natural gas set injector, to inject gas into the air intake manifold of the diesel engine, and an electronic control system. The challenge focuses on developing electromechanical system of gas injection and in the respective electronics system control to the diesel and natural gas supply , in order so all devices can operate with stability, without technical-economic operational damages.

2. Conception of Dual Fuel System

The concept of the dual fuel system was developed for the conversion of diesel generator to dual fuel generator (operating with diesel and natural gas), by controlling the injection natural gas and air mixture in the intake system of the diesel engine, as illustrated by block diagram of Figure 1. The control is performed by an embedded controller, called dual fuel controller, which monitors a set of sensors diesel engine and the load calculating the amount of gas that must be mixed with air and injected into the engine. For this, the controller acts on a butterfly valve, controlling the amount of injected gas.

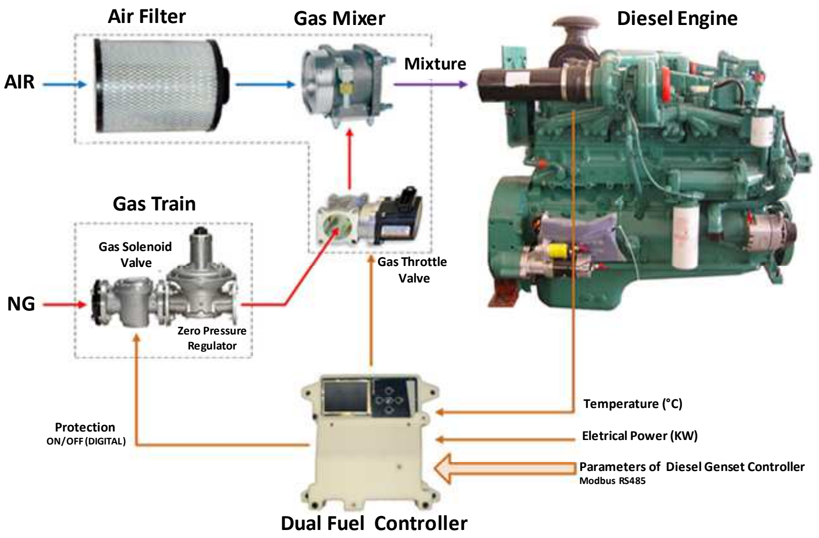


Figure 1 - Block Diagram of Dual Fuel System

Based on the design as this system was developed, if this is off, the power generator can only operate on diesel, as its former and original installation. This is due to the fact that no significant changes have been made in the generator, which will prevent operation in diesel mode. The advantage of this configuration is that it can be replicated in other gensets, by performing only a few adjustments of the control parameters and the design of electromechanical components.

3. Methodology

Because it is a system that aims to replace the maximum diesel to natural gas by monitoring electronic sensors and action of electromechanical actuators, as shown in the block diagram of the dual fuel system (Figure -1), the methodology followed the following steps:

1. Development of electromechanical system gas injection;
2. Trials engine operating in open loop, in order to analyze the behavior of the diesel generator to be powered by natural gas;
3. Development of electronics and control algorithm, based on tests and computer simulations;
4. Tests engine operating in closed loop, in order to analyze the behavior of diesel generator with dual fuel (gas-diesel) system;
5. Development of features for the controller interface specification and manual;

For conducting performance tests and analysis of behavior in relation to computer simulations, the project acquired as shown in Figure-2:

• A generator of 100 kW, the C110 model, manufacturer Cummins, which has 5.9 6BT diesel engine model.
• A bench load of 100 kW, for the purpose of better control of load testing and plant safety by avoiding switching mains SENAI / SC;
• Set consists of 04 cylinders of natural gas totaling a volume capacity of 83.2 m³ of natural gas at a pressure of 200 kgf/cm², for purposes of this increased mobility generator, allowing operational testing in gas-diesel mode in places which the gas network has not yet been built.

Figure 2 - Facilities operating tests of the Dual Fuel system

3.1. Development of electromechanical system gas injection

The electromechanical system of gas injection was developed through the use of electromechanical valves, the same being composed of natural gas and electromechanical system air intake and mixes with natural gas ramp;

Slope natural gas

At the exit of the set of cylinders, the gas pressure is reduced to 0.15 kgf / cm ² by the gas ramp. The ramp consists of gas safety items as:

1. Gas filter : the component having taken to prevent the entry of impurities in the gas system;
2. Automatic shut-blocking overpressure (Shut off) valve that mechanically shuts off the supply of gas pressure and protects the rest of the equipment of the gas ramp;
3. Pressure regulator:. Valve that reduces the gas pressure to the working pressure of 0.15 kgf/cm ²;
4. Solenoid: electrically operated solenoid and electromagnet valve, used for electronic command turns on or off the gas supply. These solenoids operate with voltages from 12 V to 24 V drive;
5. Pressure Switches High and low: pressure sensor that operate through, normally open or normally closed electrical contacts;

Electromechanical system air intake and mixes with natural gas

Given that the system needs to perform dual fuel mixture of gas and air (atmosphere), controlling the flow of this mixture, the electromechanical system air intake and mixes with natural gas developed is composed of original motor devices such as filter and turbocharger air, together with the following components:

1. Gas Mixer: Liability item that uses the Venturi effect to create a depression and mix natural gas to the intake air;

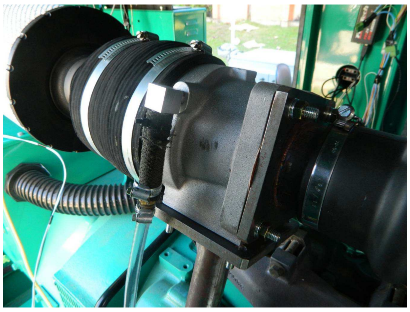


Figure 3 - Gas Mixer

2. Gas Throttle Valve: flow control that uses a butterfly type component to control the gas flow valve. The Gas throttle valve intake generates a depression to improve the performance of the gas mixer. This valve has a position sensor;

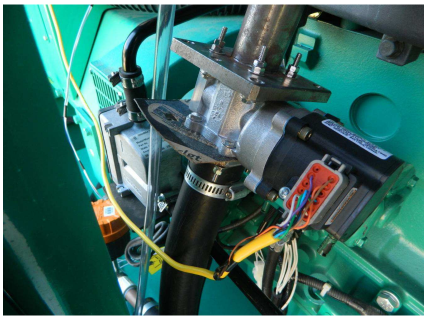


Figure 4 – Gas Throttle Valve

The blocks that have connection with block air intake are the building blocks of actuators, the diesel engine and the electronic control system. The following are the components of the air intake block having connections to other components of blocks:

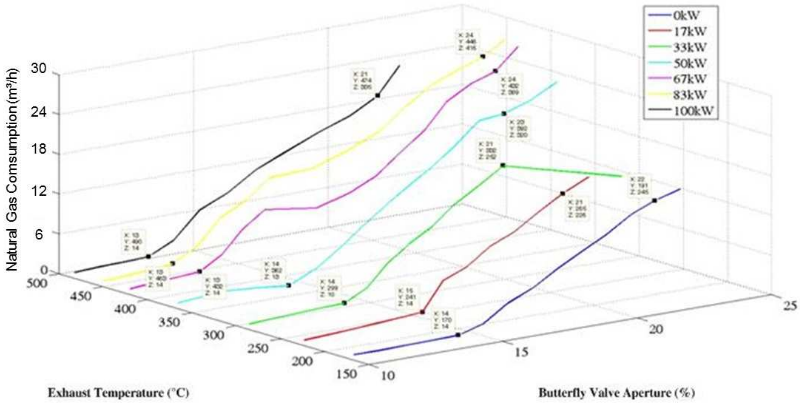
1. Gas mixer: an air inlet connection of the gas butterfly actuator block;
2. Gas Throttle Valve: has a sensor that uses a potentiometer (variable resistor) to inform the position. This sensor requires a 5 V power and informs the position with variation from 0 to 5 V to one of the sensor inputs of the electronic control system. This item also has a mechanical connection to the actuator that controls admission;
3. Pressure sensor and inlet temperature:. Both have a connection to an input sensors of the electronic control system.

3.2. Tests engine operating in open loop

Data Acquisition and Operating Limits

In order to analyze the behavior of the engine to be fueled with natural gas, tests engine operation, open loop, were performed. These tests were important for data acquisition in power generator for operation with natural gas and diesel, ensuring the maximum substitution of diesel by natural gas, so that operational problems and future damage to the generator are avoided . Moreover, the tests also possible to evaluate the ability of gas injection and mixing of the electromechanical system installed. During such tests and trials, open-loop, we observed the existence of some problems when the injection occurs in excess of natural gas in the engine.

The alterations of the normal functioning of the generator, include excessive vibration and temperature in relation to manufacturer specifications. Based on the monitoring of the variables and the behavior of the engine, it was found that the relationship between the defendant load to the generator, the temperature of the exhaust, the consumption of natural gas and the percentage of opening of the throttle valve present tendency of linearity, but with significant variations, as illustrated in Chart - I.



Graph I - Behaviour of variables in open loop.

3.3. Development of electronics and the control algorithm

<u>Simulation and Modeling System</u>

Considering the results obtained from tests for operation in open loop, a model plant was developed through modeling and simulation of control tools as simplified illustration of the Simulink block diagram below:

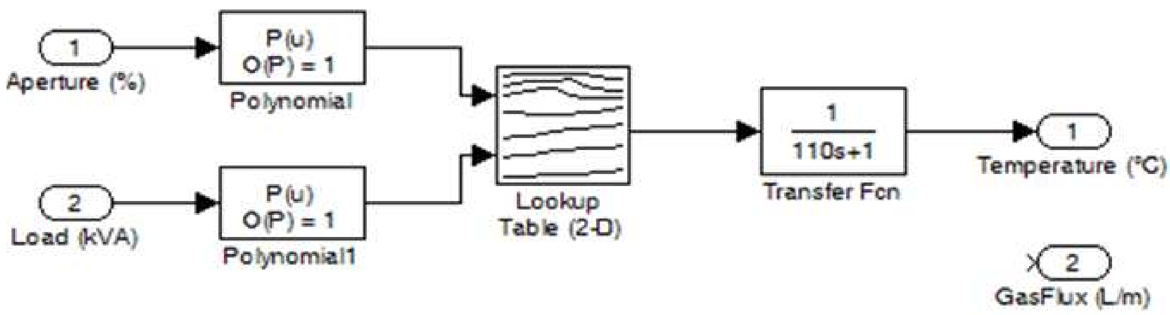


Figure 5 - Model of the plant

This model plant, represented in the form summarized in Figure 5, was structured to consider the behavior of the following input and output variables:

Input:

• Current Opening Butterfly (Positioning opening butterfly valve) Condition;
• Load Current Defendant (0 to 100kW).

Outputs:
• Temperature of exhaust;
• Gas flow defendant

Based on the data obtained from the exhaust temperature on the opening of the throttle valve and charge the defendant was generate a Look-up Table in the model, as shown in Figure 6.

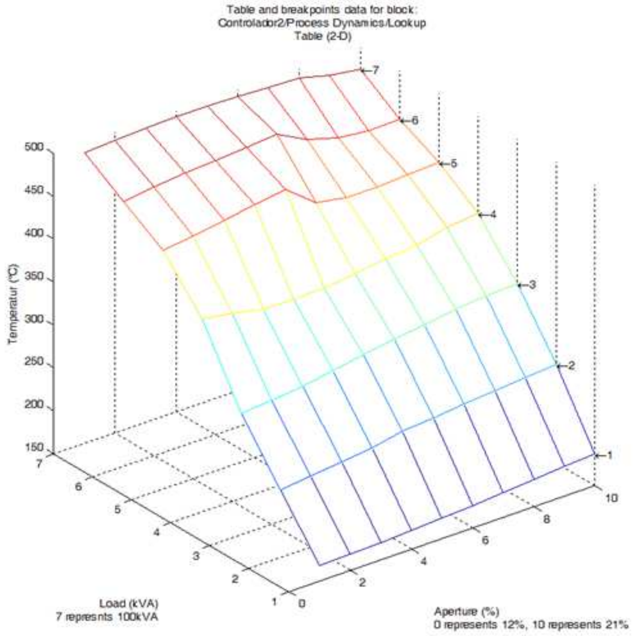


Figure 6 - Graphical Look-up Table

To test the control system during the simulations, a generator load is designed to create a loading ramp, as shown in Figure 7. This ramp is discretized using a zero-order hold, which can be adjusted, allowing the visualization of the behavior of system, snapshots intervals. The output of this subsystem indicates the current load demanded the power generator.

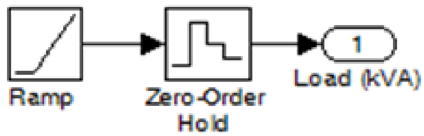


Figure 7 - Generator Load

Figure 8 presents, in summary, a model for obtaining the maximum temperature versus load defendant. Figure 9 illustrates the display of the look-up table, obtained in the tests.

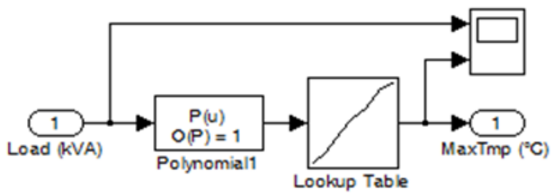


Figure 8 - Modeling of temperature

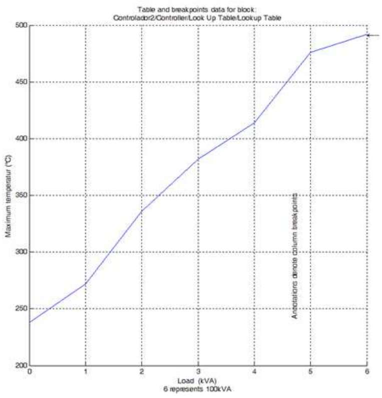


Figure 9 - Graphical Look-up Table

The strategy of the algorithm of the controller, in short, is to calculate how much the butterfly valve should open, upon receipt of information of the current position of the same, the defendant load and temperature. Therefore, the electronic control system modifies the action of the actuators by monitoring sensors and digital processing. Figure 10 shows the simplified model of the generator with dual fuel system installed.

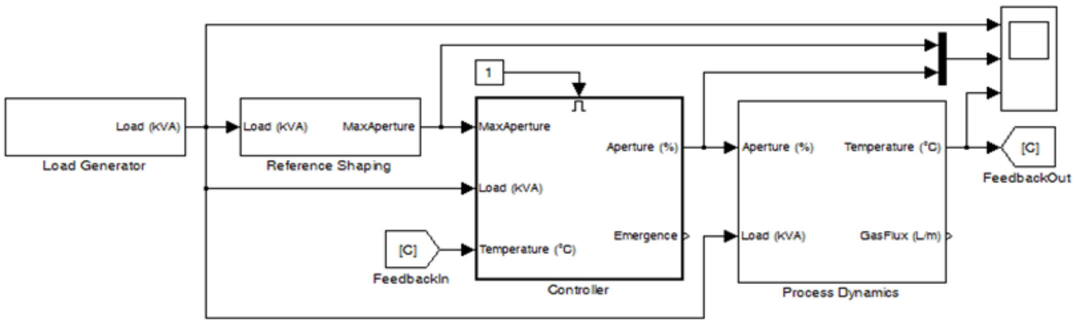


Figure 10 - Model of the generator with the Dual Fuel system

Table I displays the list of components that can be connected to the control electronics as well as the essential components of the system.

Sensor/Actuator Component	**Significância**	**Subsistema**	**Interface**
Gas Solenoid valve	Very High	Gas Train	Digital
Gas Throttle Valve	Very High	Gas Inlet	Analogical
High Pressure Sensor	Low	Gas Train	Analogical
Low Pressure Sensor	Low	Gas Train	Analogical
Position of Gas Throttle Valve	Very High	Gas Inlet	Analogical
Air Inlet Pressure	Low	Engine	Modbus RS485
Air Inlet Temperature	Low	Engine	Modbus RS485
Coolant Temperature	Low	Engine	Modbus RS485
Oil Temperature	Low	Engine	Modbus RS485
Oil Pressure	Low	Engine	Modbus RS485
Engine Temperature	Low	Engine	Modbus RS485
Exhaust Gas Temperature	Very High	Engine	Analogical
Knock Sensor	Very High	Engine	Analogical
Oxygen Sensor (Exhaust)	High	Engine	Modbus RS485
Speed Engine	Low	Engine	Modbus RS485
Eletrical Power	Very High	Generator	Analogical

Table I - List of sensors and actuators Dual Fuel System

The results generated by the model developed can be seen in Figures 11, 12 and 13, and the upper graph represents the respondent burden, the intermediate graph represents the control action on the opening of the throttle valve and the bottom graph represents the temperature of the system.

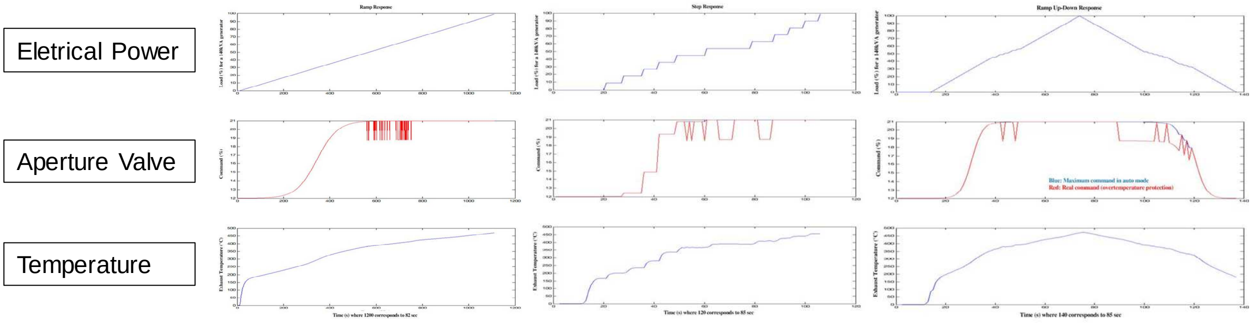


Figure 11 Figure 12 Figure 13

Figures 11, 12 and 13 show the operation of the controller, respectively, when the demanded load varies almost linearly with small increments (Figure 11) when the demanded load varies more sharply (Figure 12) and when the demanded load sense changes increase to decrease (Figure 13). The simulation results indicate that the controller has been satisfactory behavior occur to stabilize the system at both the opening and closing of the throttle valve opening. From the definition of the control algorithm and computational simulations, the algorithm was implemented in embedded controller for field testing be performed in motogenerator.

Figure 14 - Embedded Controller

3.4. Tests engine operating in closed loop

Field tests had significant rapprochement with the results of computer simulations.

The replacement rate ranged from 54.25% to 76.07%, growing to obtain an average replacement rate of 61.5%, which meets the expected results in this first prototype.

3.5. Development of features for the controller interface and manual

The dual fuel system developed has four main features, which can be observed in the main interface of the controller and selected on the main interface command, as Figures 15 and 16.

Figure 15 - Main Interface Controller

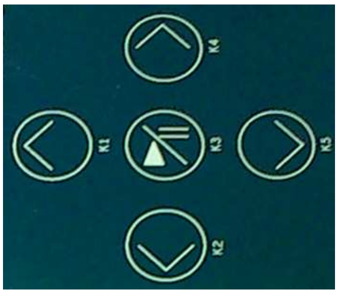


Figure 16 - Main Command Interface

The control function of the gas is the main function of the control unit, it is responsible for gas injection in order to ensure system security. Here view of the gas control interface in Figure 17.

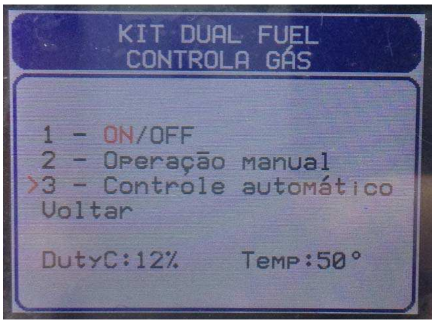


Figure 17 - Control of natural gas interface

The second function of the control unit refers to the observation of the process variables. When you select option 2 on the main interface of the controller (Figure 15), the user is taken to the monitoring interface. The monitoring interface, shown in Figure 18, shows the main sensors interfaced with the controller. In the current version of the product, such parameters are:

- Exhaust Temperature (° C);
- Lambda Sensor;
- State Controller: ON / OFF;
- Voltage at the output of the generator;
- Current at the generator output.

Figure 18 - Monitoring Sensors

The function configuration (Figure 19) of the controller allows adjustments for handling this equipment, how to change the screen brightness and the sensitivity of the touch buttons.

Figure 19 - Configuration Function Controller

The function "4 - Advanced" from the main interface of the controller, illustrated in Figure 20, refers to the use of advanced settings designed for specific applications, among which include sending information to other devices via the communication interface RS-232, the transmission speed of 9600bps.

Figure 20 - Advanced Settings screen.

4. Conclusion

The results of tests and trials show that the dual fuel system developed meets the desired goals in this first prototype, since it presents the following advantages:

• Operating Economy of 24.6% compared to diesel generator sets (Natural Gas: U.S. $ 0.60 per cubic meter, Diesel: U.S. $ 1.00 per liter).
• Ease of installation, no need for big changes on the generator;
• Operational flexibility can operate on diesel or gas-diesel mode mode;
• Ability to control a wide range of engine power;
• Manufacture and national support;
• Replacement rate ranging from 54.25% to 76.07% as respondent burden;
• Average replacement of diesel with natural gas rate of 61.5%.

5. References

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