Automating, monitoring, and control of an ICE based micro-CCHP system using LabVIEW and Android

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***Abstract*—A methodology to automate and control a small-scale combined heat and power system (micro-CHP) is proposed. The contribution of this design is to extend the original plant toward micro-CHP system modeling, thus allowing flexible and efficient system through graphical programming. The automation involves the synthesized system analysis; thereby, human intervention is reduced. It builds on LabVIEW™ software that takes the model architecture to monitor and control de plant. Measured signals and parameters (SQL database) managed by LabVIEW™ are used to issue remote control communication. An Android application was developed to communicate with the database. The integration methodology of automation, monitoring and control energy variables in real-time may be extended to study failures and possible improvements on micro-CHP systems.**

***Index Terms*— Automatic generation control, Cogeneration, Energy measurement, Mobile communication.**

I. INTRODUCTION

Energy demand is often required in many different ways. Those generally include a combination of heating, air conditioning, mechanical power and electricity. Often, these types of energy are generated using a combustion engine with a heat source at high temperature. A heat engine always dissipates thermal energy to a low temperature thermal sink, which are usually the surroundings. This thermal energy is commonly known as secondary heat or waste heat. This heat is useful for most heating applications; however it is not suitable to transport thermal energy over long distances, as electricity and fuel are.

Waste heat recovery for local applications is an example of a more efficient use of energy. Therefore a more efficient energy system must generate electricity close to the places where the waste heat can be used. This technique is known as a combined heat and power system (CHP), or cogeneration. Cogeneration systems are able to increase the total energy extracted from primary energy sources, such as fuel and solar thermal energy. In a traditional power plant - that provides electricity to consumers -, about 30% of energy content of the primary energy source - such as biomass, coal, solar thermal, natural gas, oil or uranium -, is used by the consumer. The efficiency can be 20% for very old facilities and may reach 45% for new gas plants. By contrast, a cogeneration system converts between 10% and 40% of the primary energy into electricity, and most of the remaining heat is used for hot water or heating. Totally, up to 90% of the heat from the primary energy source is used when heat production is less than thermal energy demanded [1].

Small-scale CHP systems are commonly known as micro-cogeneration or micro-CHP (micro combined heating and power). During the last three decades high power cogeneration systems have been economically more justifiable than micro-CHP, due to economies of scale. After 2000, micro-CHP has become profitable in many markets around the world, due to rising energy costs.

Several definitions have been used for micro-CHP in the past. The publication of the Cogeneration Directive 2004/8/CE of the European Parliament (February 2004) definitely unifies the situation in Europe with the following definitions: a micro-CHP unit is the cogeneration unit with a maximum electrical power less than 50 kW; a small-scale cogeneration unit with a maximum electrical power less than 1 MW. Some authors limit the definition of a micro-CHP unit to a system that produces an amount of electrical power lower than 5 kW [2].

Micro-CHP systems are usually designed to meet the thermal energy demand, providing heating and domestic hot water (DHW) in residential or commercial buildings, as a conventional boiler would do. Unlike a boiler, a micro-CHP unit generates electricity from the heat produced at high temperature and thus helps to save fuel, reduce emissions of greenhouse gases and reduce electricity costs. Most units operate in parallel with the mains and can even export some electricity to the grid. The most used technologies for the development of micro-CHP systems are reciprocating internal combustion engines, Stirling engines and fuel cells.

The use of small scale trigeneration equipment or micro-CCHP (micro combined cooling, heating, and power), for home use has also achieved great interest in recent years. One of the most commonly used technologies is the conventional vapor compression refrigeration system as the thermal driven systems (mainly absorption and adsorption), which are still in development stages [3].

Because the conventional refrigeration requires mechanical or electrical energy to drive the compressor, this cooling technology fits perfectly to trigeneration systems during the summer season. Some authors argue that the use of non-fossil fuels in combination with cogeneration or trigeneration technologies are the best solution to mitigate CO_2 emissions [4]. The system presented by Parise et al uses a heat engine to drive an electric generator and produces cooling power using a vapor compression refrigeration system; a very similar system to the one proposed in this paper.

In order to reduce human intervention dependency, and develop more sophisticated and efficient systems, new energy system models are supported in computational instruments, such as automation [5, 6]. The two main keystones of automation are sensors and actuators. That is, the "nerve cells" of the grid [7]. Therefore, in general, the automation process is divided into two independent phases: acquisition and control. It is for this reason that recent advances focus on the generation and processing databases or remote control systems.

When designing and creating automated energy grids, the possibility of manual and/or automatic operation models has to be taken into account. In other words, the user does not lose the control over the system, and manual operation must be also available [8]. Moreover, existing energy technology at home and industry is continuously advancing, at the same time as the user requirements are increasing and changing at a similar or slightly faster pace. Thus, nowadays the principal goal of this research area is the smart concept (i.e. domotic field).

Energy system automation research trend is following visual programming approach. Thus, graphic programming language is becoming increasingly important [9]. LabVIEW™ (Laboratory Virtual Instrumentation Engineering Workbench) development environment is one of the most widely used tools in software and hardware control-design applications (i.e. to simulate plant test and/or prototypes which require a great deal of control and measurement variables) [10, 11]. LabVIEW™ is a building-block interface with a wide range of possibilities for programing and has a user-friendly and very easy-to-use interface.

Once automating and monitoring the system, next step is to develop remote control tools. In fact, remote data visualization and on line data acquisition and control is a requirement for many systems [12].

This study introduces the integration of simulation, programing and monitoring of micro-CHP system. This solution is able to give information and to interact with the system behavior in real time. The user can acquire and control all influential variables (i.e. monitor data, create report files, evaluate model parameters, mobile application). Furthermore, the generated reports provide feedback, which may help develop new tools to improve system performance.

II. SENSORING AND DATA ACQUISITION

The micro-CCHP system developed in this paper produces heating, cooling and electric power, and it can work detached or attached to the grid. A fully functional ICE based prototype was built and tested. This prototype was divided into six different interactive subsystems: gas engine, heat pump, cooling system, exhaust gases heat exchanger, tap water circuit, and electric system.

Main aim of this work is to achieve a remote control of trigeneration unit so first stage of this research was to identify what parameters of the system should be monitored. Different subsystems instrumentation was performed. Local control of the system also required actuation on some devices. Sensors and actuators were installed and connected to a data acquisition system.

Figure 1 shows a scheme of the trigeneration system with different subsystems highlighted in different colors.

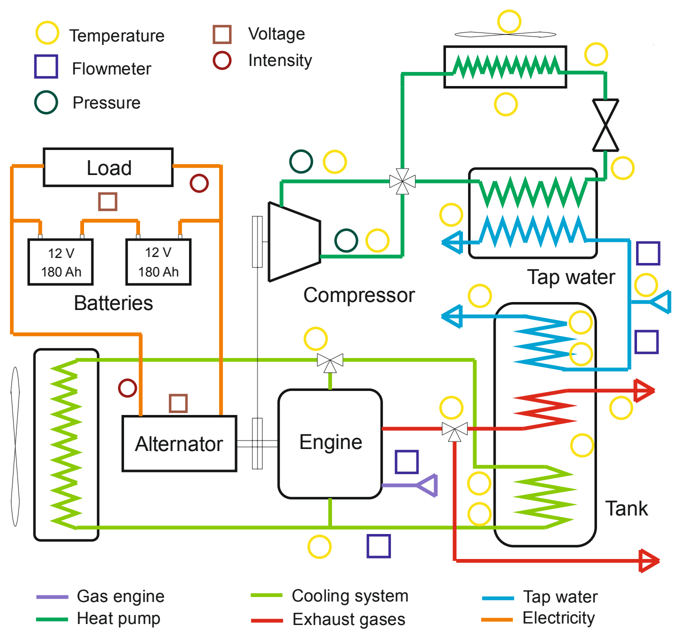

Figure 1. Trigeneration system scheme

Installed sensors location are represented in figure 1. Most of them are temperature sensors and flowmeters but pressure measurement is also necessary to control heat pump compressor status. Electric parameters of voltage, intensity and charge state of battery bank are also measured. All this sensors are part of monitoring system.

A data acquisition system is necessary in order to translate data read by sensors into information understandable by a computer using analog to digital converters. Sensors and actuators are controlled by data acquisition system using analog and digital inputs and outputs and it is finally connected to a PC. A LabVIEW™ program was developed to introduce monitoring and control to developed prototype.

A. *Monitoring and actuating system*

Different sensors and actuators were installed all over the prototype. Gas engine is powered by butane and it was necessary to install a gas flowmeter. It is also interesting to know engine butterfly valve position and engine speed. For these purposes a potentiometer and an optic sensor are installed respectively. Engine traditional start system is also replaced by relays in order to avoid access to the engine under any circumstance.

Heat pump is equipped with PT-100 temperature sensors to control refrigerant temperatures and condenser/evaporator external air flow temperatures. Pressure is also monitored in compressor inlet and output. A pressure transducer is used for this purpose. A pressure switch is also installed for safety reason.

Engine cooling system is equipped with temperature sensors and flowmeters. An important actuator in this system is a three-way motorized valve to choose between normal radiator circuit and heat recovery circuit. Exhaust gases recovery system is also equipped with temperature sensors. In this circuit the three-way valve employed is manually operated and an inductive sensor is used to know if exhaust gases pass through heat exchanger or not. Tap water circuit is also equipped with temperature sensors and flowmeters.

Finally electric system is also monitored. Hall Effect amperemeters are installed and CC voltage is directly read using a signal conditioning board.

B. *Data acquisition system*

A PC based data acquisition system was installed in this trigeneration unit. The core of the system is a National Instrument USB card. Unit chosen is a NI USB-6212 with 16 analog inputs, 0-10 V range, and 32 digital I/O, as main features. Although there are more than 16 sensors to be measured, the most of them are temperature ones, with very slow oscillations. So five multiplexer cards were designed and manufactured in order to permit all measures. Four multiplexer cards were used to measure temperature channels (4 channels each card) and the last one was used to measure pulse based sensors (flowmeters and optical sensor).

Two signal conditioning cards are also developed. A voltage measure card to adapt voltage signal to a 0-10 V range, and a butterfly valve position card to measure engine speed. For this last purpose, the potentiometer Wheatstone bridge output signal has also to be adapted to a voltage range of 0-10 V.

C. *Operation and control*

Operating modes of the trigeneration system are configurable. A three stages switch was implemented to choose between three working modes:

- Manual mode. Actions are performed manually (electric switchboard panel). The system ignores signals from data acquisition card.
- PC mode. Actions are performed from LabVIEW™ programed touch screen or mobile application. The system ignores signals from electrical switchboard panel manual selectors.
- OFF mode. Actions are disabled. The system ignores all signals.

Three electronic boards are designed to achieve this goal. First card is necessary to switch between manual and PC modes and the other two boards are equipped with opto-isolators and relays, each card with eight actuation outputs.

In manual system it is possible to change the following trigeneration system parameters:

- Engine start switch
- Engine throttle
- Engine radiator activation switch
- Gas starter
- Heat pump fans switch
- Compressor start switch
- Heat pump inverter switch
- Cooling circuit three-way valve switch

They are all controlled on switchboard front panel. Figure 2 shows front panel with different switches and safety devices.

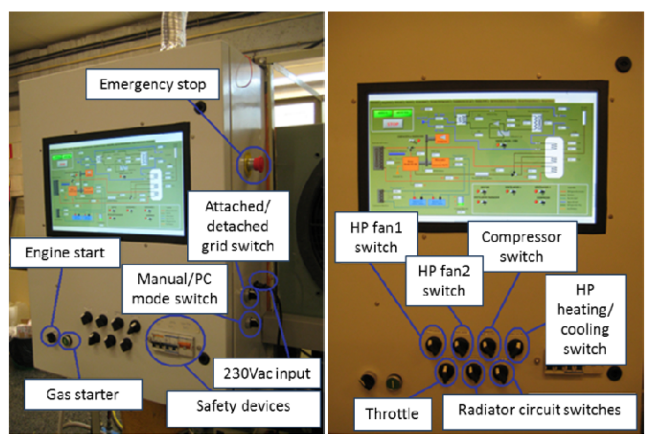

Figure 2. Front panel

For PC mode control a LabVIEW™ program was developed with two virtual instruments (VI), one for the whole control of the system and the other to save all variables and parameters used in the control system. Measured signals and parameters are saved to a SQL database in order to issue remote control communication. Twelve screens were designed in the main VI LabVIEW™ file to monitor and control every mentioned subsystem. Figure 2 also shows the touchscreen with main scheme of trigeneration system.

A. *LabVIEW™ programing*

LabVIEW™ programming is based in four while-blocks execution. Figure 3 shows program flowchart with an initialization block (that is only executed once) and four functional blocks.

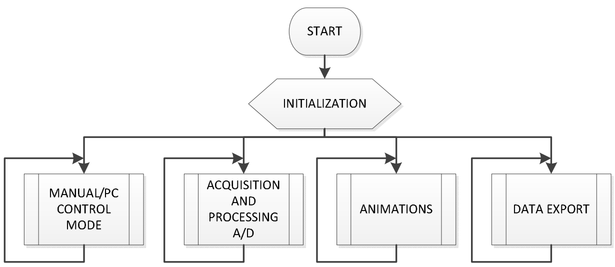

Figure 3. Program flowchart

Manual/PC control mode loop is also in charge of general switch control. Animations loop is used to display direction change of different flows in the charts (represented by arrows). Acquisition and processing of A/D signals loop is the core of the program. Four sequences of calculation are used in this loop: signals acquisition, mathematical operations, time analysis and array write. Last loop is dedicated to data export to SQL database. Database includes necessary information for remote monitoring and control of the system.

B. *Mobile phone remote control*

An App was developed in Android environment to provide remote control of the trigenertation system. Android App communicates with the database of the system using the local wi-fi connection or through the internet. A daemon should be listening in a configured port in the PC of the acquisition system for this purpose. State of the system information is included in the main screen, such as: engine speed, electric power, heating power, battery charge state or gas instant consumption. Indicators show status of every element of the system such as: heat pump, exhaust gases heat exchanger, cooling circuit, engine, communication, etc. App main screen is shown in figure 4a with labels in its programmed language (Spanish).

App also provides a control interface as shown in figure 4b. Due to safety reasons, local operator must indicate in the control program (communication screen) that remote connection is possible. Once it is done App user only has to change a switch status from OFF (NO) to ON (SI). There are five default status configured in the App: system off, just electricity, cogeneration, trigeneration with cooling and trigeneration with heating. Historical saved data can be also queried through mobile App, and data is displayed using charts.

Figure 4. App main screen (a). App control interface (b)

III. CONCLUSIONS

This work presents an integral LabVIEW™ program of monitoring, control and saving data of micro-CHP system. LabVIEW™ is one of the best solutions for control systems, because of integrating graphical tools facilitate building a wide range of applications using dramatically less time than other programming environments. Moreover, the fact that users have access by Android mobile phone application to control the main parameters, reduces human intervention dependency and simultaneously increases the system efficiency. Growing efficiency is heavily determined by reduction possible human errors and real-time system control. Future applicability works could focus on analysis historical database in order to improve micro-CHP system and to offer researchers more opportunities to design broader applications.

Summarizing, this proposal offers a reliable, efficient and low cost solution for data acquisition and control, during long periods of time without being physically present in the working zone.

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