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Small scale power generation Unit using Biomass gasification: The SUBe Project

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***Abstract*—This paper presents a research and development project aiming to demonstrate the technical feasibility of using forest biomass for power generation using small scale systems. For this purpose, an experimental setup, suitable to be used as a distributed generation unit, has been developed. Then, key developments of this project rely on the design and development of the biomass gasifier prototype as well as on the syngas cleanup system to fuel a conventional internal combustion engine for running the synchronous generator. Also, a suitable monitoring and control system will be developed to assure the safe operation of the whole system and to control the coordinated operation of the integrated subsystems. High level control functionalities will be implemented for performing load following when the power unit is operated in stand-alone or to adjust the output power following requests of the distribution system operator.**

***Keywords*—Biomass gasification, internal combustion engine, electricity, forest waste valorization, coordinated control**

I. Introduction

Using of solid biomass fuels has been considered a promising pathway to reduce the fossil fuels usage in the energy sector and, therefore, to reduce the greenhouse gas emissions in Europe [1]. Also, according to the energy policy framework established under the "Clean Energy for all Europeans Package", the change for a clean energy will bring considerable benefits for consumers and economy. The EU leadership is underlined in what concerns tackling the global warming and to provide an important contribution to the EU long-term strategy of achieving the carbon neutrality in 2050.

Following the ongoing efforts at the EU level, the Portuguese government reinforce the commitment to achieve the neutrality of the carbon emissions by the end of 2050, drawing a clear vision of the deep decarburisation of the national economy. For this purpose, a demographic model of territorial cohesion is planned to be followed, aiming to contribute for wealthy creation and efficient use of the endogenous resources.

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Thus, using biomass as an energy resource plays an important role within this endeavour. Considering the importance of the forests in the Portuguese economy and, also, the impacts of rural fires in both economic and social dimensions, it is essential to develop solutions for using the biomass as energy resource, aiming to help the management of rural areas by removing the fuel load in them and, therefore, reducing the spread of rural fires and to add value to the biomass available in rural areas. For this purpose, the logistic issues are expected to be improved, through the promotion and government support for the dissemination and of both collection and storage centres, following a local and distributed logic, to make the biomass available in a municipal and intermunicipal scale. These issues are included in the action line aiming to promote a better use of biomass for energy applications of the Portuguese energy policies advocated by the National Plan for Energy and Climate 2030.

Moreover, using the biomass available in rural areas will contribute to face the concerns related with security of supply, which are in line with the national economy decarburization, considering the specific characteristics of the Portuguese power system and, additionally, to seek for increasing its resilience. Within this framework, using biomass as Renewable Energy Source (RES) will also contribute to increase the diversification of energy resources and to manage the power supply by exploiting the complementarity of RES.

Both small and micro scale energy production units, although easier to deploy due to size, biomass availability and legislation advantages, present lower electrical efficiencies in comparison to bigger facilities, mainly due to the drop of the steam turbines isentropic efficiency [2]. Therefore, the concept of gasification is becoming more interesting due to the utilization of the Internal Combustion Engine (ICE) or gas microturbines in combination with the valorisation of heat in Combined Heat and Power (CHP) applications, resulting to higher efficiencies that can make investments of biomass gasification more appealing and economically viable. Because the biomass is spread widely around the country, a small scale biomass conversion system would be more competitive than a larger plant due to the portability and feedstock transportation costs [3] Nonetheless, the market penetration of small and micro scale biomass gasification systems was not significant. This could be due to the lack of commercial solutions to deliver stable, reliable and cost-effective technologies [4], [5].

Thus, the project SUBe – Small scale power generation Unit using Biomass gasification (PCIF/GVB/0197/2017), aims to contribute for overcoming some of the technology barriers of using biomass gasification for power generation in small and micro scale applications. For this purpose, an experimental set up has been developed with flexibility enough to address the following main tasks: Collection and pre-treatment of rural biomass; Biomass gasification; Gas cleaning; Feeding the syngas to the Internal Combustion Engine (ICE); Running the synchronous generator to produce electricity. This system, rated around 5 kW, is suitable to be used in distributed energy applications in rural areas. Therefore, the solution to be implemented should be modular, operated with a significant automation level and based on specific designs reported on the available literature and on commercially available technologies. Also, they will support two system operation modes: Grid connected, when the system is delivering electricity to the distribution network; Stand-alone, when the system is feeding local variable loads.

Moreover, a suitable monitoring and control system will be developed to assure the safe operation of the biomass gasification-based power plant and to control the coordinated operation of the integrated subsystems. Also, high level control functionalities will be implemented allowing the biomass gasification based power unit to perform load following when operated in stand-alone, providing voltage and frequency control, or to adjust the output powers following requests of the distribution system operator when interconnected to the distribution system and to improve the whole system performance in both modes of operation.

II. Biomass Gasification for Power Generation

Biomass gasification has been considered as one of the most promising technology of renewable energy conversion applications. However, the choice of the gasification system depends on many factors, such as biomass characterization, gasifier capacity and end use applications. According to the literature review presented in [6], [7], the downdraft gasifiers with throat are found prominent for both ICE and thermal applications as the tar and particulates content in producer gas is accepted for these technologies. Thus, the following sections provide a critical review of the literature considering the gasifier integration with the engine/generator set to produce electricity for direct usage.

A. *The Gasification System*

Biomass gasification is the process of partial combustion of biomass feedstock, under controlled air supply, producing a mixture of gases, commonly known as syngas or producer gas, containing Hydrogen (H_2), Carbon Monoxide (CO), Methane (CH_4) and some other inert gases. This process comprises four main steps [8]-[11]: Drying to remove the moisture from biomass fuel and its conversion into steam; Pyrolysis undergoing after biomass is heated for thermal decomposition of biomass fuels in the absence of Oxygen (O_2); Oxidation or combustion taking place at high temperatures range in the presence of O_2 (air); Reduction where the reactions of reduction take place, resulting the formation of CO, H_2 and CH_4.

The quality of the syngas generated in the gasification process is strongly influenced by both the design of the gasifier and the flow patterns of air and biomass particles within a gasifier. However, for a specific gasifier design, there are two major variable parameters commonly used to achieve an acceptable level of the syngas quality: The Equivalent Ratio (ER) and the Superficial Velocity (SV) [10], [11].

The ER is defined as the ratio of the air volume supplied per kg of biomass fuel and the volume of air which is necessary for stoichiometric combustion of the above volume of biomass fuel. The ER is considered as one of the most important variables in the gasification process, which affect the quality of the syngas, since the amount of air fed into downdraft gasifiers control the biomass consumption rate [12]-[15]. The stoichiometric air/fuel ratio in cubic meters per kg of biomass can be expressed in terms of chemical composition of the fuel. Typical values of ER for biomass gasification vary between 0.2 and 0.4 [10].

In turn, the SV is defined as the ratio of the syngas production rate at normal operating conditions and the narrowest cross-sectional area of the gasifier. SV influences the gas production rate, the gas energy content, the fuel consumption rate, the power output and both char and tar production rates [16]-[18]. The SV is independent of the reactor size, allowing a direct comparison of gasifiers with different power outputs. Low values of SV result in a slow pyrolysis process with high yields of char and significant quantities of unburned tars. In contrast, high values of SV result in a very fast pyrolysis process, formation of a reduced amount of char and very hot gases in the flaming zone. A good performance of the gasifier, in terms of syngas low tar contents, was achieved for SV values of about 0,4 Nm/s [16].

According to [10] the main output parameters of the biomass gasification process in downdraft gasifiers are the syngas composition, the calorific value of syngas, the thermal power of the gasifier, the gas yield and the efficiency of the thermochemical process.

The composition of the syngas is strongly dependent of the temperature of the reactor, which is influenced by the ER value. Also, the concentrations of H_2, CO and CH_4 are controlled by the kinetics of the chemical reactions occurring in the gasification process. Therefore, the oxidizing agent has a considerable influence on the calorific value of the syngas. Using air as oxidant agent produces syngas with high concentrations of Nitrogen (N_2) and, hence, with a lower calorific value. On the other hand, the concentration of H_2, CO and CH_4 increase significantly if O_2, water steam or a mixture of both is used [19]. A typical gas composition from biomass gasification in downdraft gasifiers, using air as the oxidizing agent is: 15-20% of H_2, 15-20% of CO, 0,5-2% of CH_4, 10-15% of CO_2, being the remaining parts N_2, O_2 and C_xH_y [10]. The syngas calorific value does not exceed 6 MJ/Nm^3 [17].

The yield is used to measure the specific production of the syngas, in cubic meters, per mass of the feedstock supplied to the gasification system. This parameter is directly proportional to the ER variation [17], [20] and to the residence time of the gases in the reduction zone of the gasifier [3]. The ash content in biomass contributes to limit significantly the yield of the syngas. Typical values for wood gasification in a downdraft gasifier range between 2 and 3 Nm^3/kg [10].

The gasification efficiency is strongly dependent of the type of biomass used, its particle size, the ER value and the design of the gasifier. The cold efficiency is commonly used to compare efficiencies, corresponding to the ratio of the heating value in the syngas and in the feedstock. Typical values of the cold efficiency in a downdraft gasifier are between 50 and 80% [10].

The literature overview allows concluding that the performance parameters of the biomass gasification in a downdraft reactor are strictly dependent on the physical-chemical properties of the feedstock, such as the moisture content and the particle size. They are influenced by the process parameters, which determines the temperature levels. The system efficiency depends on the design features of the gasifier, such as the location of air inlets and the volume of the gasification zone.

B. *The ICE fuelled with syngas*

ICE have been commonly used with downdraft gasifiers and several researches has been performed on studying and improving the operation of ICE, since the syngas quality as a fuel is considerably poorer than the quality of the conventional fossil fuels. Using the syngas from biomass gasification for electricity generation exploiting the ICE, requires assuring that the syngas quality is sufficiently high in terms of the content of both particulates and tar in order to keep the ICE reliable operation and to provide an adequate durability of the several components of the ICE, such as the valves, the combustion chamber, the pistons, etc. According to [21] the allowing particulates and tar concentration of syngas should be less than 50 mg/Nm^3 and 100 g/Nm^3, respectively, for assuring the satisfactory operation of the ICE.

The parameters which mainly affect the performance of the ICE are the energy density of the heating value of the syngas/air mixture, the displacement volume of the engine, the methane or octane number of the fuel, the flame speed of the fuel/air mixture, the auto-ignition delay period, the compression ratio of the engine and the spark timing [10].

The energy density of a fuel/air stoichiometric mixture is commonly determined in terms of the volumetric heating value, which is lower in syngas than in conventional fossil fuels. Therefore, a considerable power de-rating is verified when the ICE switches to syngas. However, a lesser value of power de-rating could be achieved if the syngas is used in engines with a higher compression ratio. Thus, the current engine technology trend to exploit advantages of lean combustion operation. For syngas/air mixtures the lean combustion condition is achieved when the air/fuel ratio is greater than 2 and, in such condition, the relative density of energy of the syngas/air mixture may be significantly increased [22]. Syngas is adequate for a lean burn and combustion of a corresponding fuel/air mixture results in low NOx emissions due to the lower combustion temperature and in the low specific fuel consumption [10].

The amount of a combustion mixture which can be delivered for a combustion chamber in a cylinder is determined by the displaced volume of the engine and the initial pressure and temperature. When the ICE is switched for syngas, the fuel amount should be increased significantly and could exceed its capacity. Therefore, a turbocharger is required for increasing the pressure of the air/syngas mixture in the beginning of the compression process in a cylinder.

Regarding the flame speed, it depends on the chemical composition of fuel, the amount of air used in the combustion process (characterized by the parameter ER) and both pressure and temperature of the fuel/air mixture, having a significant effect on the ICE performance and on the level of pollutant emissions [23]. At typical engine operating conditions, characterized by high pressures and temperatures, the syngas laminar flame velocity values should be calculated to be lower than that of isooctane but higher than methane [10].

Due to the considerable H_2 concentration in syngas, a smaller spark advancement is required in the spark timing to achieve a better ICE performance. In this case the spark is fired when the piston is very close to its top dead centre. The spark timings in engines fuelled by syngas are retarded, when compared to the conventional ones, aiming to achieve a higher efficiency. According to [24], the ignition timing must be retarded with an increase in a compression ratio in order to achieve the maximum brake torque point.

For gaseous fuels, the methane number is used to compare knock properties. ICE with high compression ratio requires fuels with high octane/methane number in order to avoid an uncontrolled self-ignition of the fuel and the formation of sharp pressure peaks in the cylinders after the start of such a combustion process. It should be noted that the syngas has a higher methane number than natural gas and therefore it is not prone to detonation during the compression stroke [25]. The high concentration of inert gases in syngas acts as a knock compressor explaining the high methane number with respect to natural gas [26], [27]. Gaseous fuels with high H_2 concentrations usually are less resistant to detonation. However, the high flame speed of the fuel/air mixture significantly reduces the probability of knocking [28].

The auto-ignition delay period of a fuel/air mixture is an important parameter to be considered in the ICE operation. This parameter is defined as the time required for the mixture to spontaneously ignite at certain temperature and pressure conditions. The ignition delay depends on the syngas composition and on the syngas/air ratio in the engine [29]. The expected lower combustion temperatures, together with the longer auto-ignition delay period would make it possible to increase the compression ratio of the engine without increasing the knock tendency [22].

The literature overview highlights that the switching of ICE to syngas is followed by the engine power de-rating, due to the low energy density of syngas/air mixture and the volumetric efficiency of the engine. Also, due to the relatively high flame speed of the syngas/air mixture, the spark ignition time should be retarded to increase the efficiency of the engine operation. Finally, the possibility of using ICE with higher compression rated without increase the knock tendency is an important advantage when engines with high compression ratio are employed. In fact, the use of air as an oxidiser agent in the biomass gasification process leads to high concentration of N_2 in the fuel/air mixture, acting as a knock suppressor.

C. *The syngas conditioning*

As already mentioned previously, the gas produced during the biomass gasification cannot be used in the end use applications. It must be cooled and cleaned properly for both smooth and efficient operation of the ICE. There are multiple options to clean-up the syngas, such as physical processes, thermal process and catalytic process [6]. Physical gas cleaning is one of the simplest cleaning methods comprised of either filtration or wet scrubbing of the syngas in order to remove the tar and particulate matter from the gas steam through gas/solid or gas/liquid interactions. The filtration may be conducted either in high temperature or ambient temperature, while the scrubbing is usually conducted at ambient temperature. However, the fouling of particulate matter and sticky tar has been considered a crucial problem.

In the thermal process of gas cleaning the heavy tar species are cracked down to lighter and less problematic smaller molecules, such as CH_4, CO and H_2. However, the efficiency for tar cracking is usually achieved at very high temperatures. Moreover, the physical filtration and even high temperature cracking is inefficient to meet the ICE fuel requirements [5]. Therefore, using effective catalysts is often considered as an attractive method without the need of cooling the syngas. However, in [3] the syngas is cleaned following three major stages: cyclone separator, cooling towers and filters.

III. THE PROJECT PROPOSAL

The SUBe project proposal aims to develop an experimental set-up of a small system with capability to generate electricity using the biomass available in Portuguese rural areas. This small power plant should be suitable to be used as a distributed power generation unit. Therefore, the intended technical solution involves addressing the following main tasks: Collection and pretreatment of biomass; Biomass gasification; Syngas clean-up; Switching the ICE to syngas; Running the synchronous generator for power generation. According to the literature review presented in section II, the biomass gasification, the syngas clean-up and switching the ICE from conventional fossil fuels to syngas are expected to be challenging tasks for the implementation of the small power generation system using biomass gasification. Key developments of the SUBe project rely on designing and development of the biomass gasifier and the syngas cleaning system. It must be stressed that the conventional ICE has been highlighted in the available literature as a cost-effective solution and the most efficient technology for small-scale power generation exploiting biomass gasification. However, there are several stringent requirements concerning the syngas composition, to be used as a fuel in the ICE. Therefore, the biomass gasifier prototype that has been developed follows the conceptual solution of the downdraft type gasifier, as recommended in the available literature, since they provide syngas with low tar oils and fast response times, being suitable for powering ICE feeding either fixed or variable loads. Also, the clean up system will be designed and implemented to remove particulates and tars before feeding the syngas to the ICE. Another issue to be carefully addressed relies on the ICE fueled by syngas to produce the mechanical power required to run the synchronous generator. The general overview of the small biomass gasification power plant is provided in Fig.1.

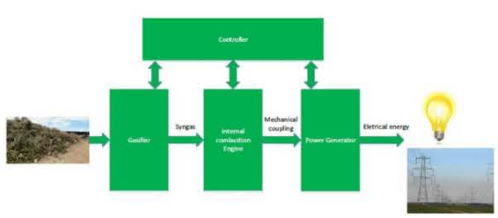

Fig. 1. General overview of the SUBe concept

Besides the assembling of the whole system, a suitable monitoring and control system will be developed to assure the safe operation of biomass gasification-based power plant and to control the coordinated operation of the integrated subsystems. It is required to have automatic controls and safety monitoring systems, focusing specially the biomass gasifier to keep the stability of the system operation, which will be achieved by controlling the ER to maintain the gasifier temperatures to desired values. In addition, high level control functionalities will be implemented allowing the power unit performing load following when operated in stand-alone or to adjust the output powers following the distribution system operator requests when interconnected to the distribution network. The implementation of these control functionalities are also innovative developments with the framework of the SUBe project. The following sections provide a general overview about the main subsystems.

A. *Pretreatment of Biomass*

The collection/harvesting and processing of biomass feedstock is intended to be integrated in the process of energy conversion using biomass gasification. Thus, it is necessary to produce a protocol for forest biomass provision for the gasification process and to evaluate the biomass available locally in the centre and northeaster regions of Portugal from forests and rural areas. These protocols will present the specific best practices to be followed in sustainable harvesting and procession of forest biomass for energy. The protocols will be made based on a thorough literature review of both scientific and technical publications, addressing the following aspects of biomass: Characterization (density, heating values, ash composition, moisture, ash, volatile and fixed carbon content); Methods, tools and processes for harvesting and collection; Pre-processing (chopping, chipping, bundling); Transportation; Storage; Upgrading (drying, torrefaction).

The assessment of biomass will provide detailed information per study area on the forest area, forest area per species, forest volume (total, per species), forest volume available from harvesting and from thinning. This information will make possible to estimate the potential use of biomass as feedstock for bioenergy in the two regions. A protocol will be elaborated for the supply of forest biomass for gasification in the northeast and centre of Portugal and the guidelines for collection/harvesting and pre-treatment of the biomass feedstock for gasification.

B. *Biomass Conversion to Mechanical Energy*

The prototypes to be developed involve the biomass gasifier and the cleanup syngas system. Thus, the main principles of the gasification-based combustion science should be carefully evaluated aiming to expand the range of usable fuels obtained from rural biomass gasification and to produce a cleaner syngas, minimizing the tar levels at acceptable costs. Thus, the first step comprises the selection of the desired power capacity of the small-scale power unit and the downstream ICE to generate mechanical power. Also, designing the gasifier involves the definition of its geometry, sizing (that affects the production of particles) and materials to be used. The literature review presented in section II recommends using the downdraft gasifier, which produces low tar levels to fuel the ICE. Therefore, these technological solutions have been adopted within the framework of the SUBe project. It must be stressed that the gasifier will be constructed using commercially available materials such as steel pipe, sheet and plate and, also, corrosion resistant materials. These materials will be selected according to their availability and conventional fabrication techniques that will contribute to reduce costs. The syngas cleanup system will be developed aiming to remove particulates, tars and water. Also, the design of the cleanup system requires determining the magnitude, size and nature of the contaminants and then to couple this information with the methods available for their removal. For this purpose, the most promising solutions will be identified from the available literature and evaluated to adopt a cost-effective solution that allows obtaining syngas with the tar levels accepted by the ICE.

The biomass gasifier is sized according to the fuel consumption of the ICE [24], [28]. The effect of design and operating parameters on the gasification process of biomass, analysed in several works developed more recently, were also considered for the definition of the gasifier design [9], [10]. The gasifier operation will be monitored and controlled based on the temperature measurement in the heated air inlet, pyrolysis, combustion and reduction zones, and in the gas producer outlet, and flow rate measurements of air inlet. The control of the gasifier operation will be performed by adjusting the inlet air flow to obtain the combustion temperature that corresponds to the ER of the combustion to which the maximum cold gas efficiency is obtained. This temperature depends on the gasifier and on the feedstock physical and chemical properties, so it will have to be determined experimentally, based on the measure of the composition and flow rate of the syngas produced. The composition will be determined using a gas analyser, placed after the producer gas clean-up system.

The gas produced in downdraft gasifiers carries dust, containing of tars and particulates. These contaminants must be removed, otherwise they will deteriorate the engine. In the first steps of the project a clean-up system will be developed regarding, mainly, the remove of particles, since we expect to have low tar concentration in the produced gas. It will be composed by a cyclone separator, that removes larger dust particles from the hot gases leaving the gasifier, followed by a gas cooler, where tar condensates, and filter that removes the smaller particles and tar droplets. If too high levels of tar in the producer gas are observed, a scrubber will be included in the clean-up system.

A system to prepare the mixture of producer gas and air, in the correct ratio, and supply it to the engine will be developed. This fuel supply system consists on a tube where converges, and are mixed, the producer gas coming from the cleaning system and the atmospheric air. The control of the desired composition of the fuel/air mixture is accomplished by metering the admitted air flow rate using a motorized valve. The mixture flow rate supplied to the engine is controlled by a motorized valve, located after the mixing zone of the tube. The positions of the valves that provides the required combustible gas mixture load to supply to the engine and the desired air/syngas mixture composition, are determined based on the measurement of the air and fuel gas flows. For this purpose, the air and fuel inlet ducts are equipped with air mass probes.

C. *The electrical generator*

The conversion of mechanical power to electrical power is intended to be performed by using a conventional cost-effective synchronous generator rated around 5 kW. Control functionalities will be developed to properly assure the interface with the distribution network and to perform load following when the small-scale power generation unit based on biomass gasification is intended to be used in stand-alone mode of operation. Conventional synchronous generators are usually equipped with Automatic Voltage Regulator (AVR) to perform voltage regulation and to control the reactive power injected to or absorbed from the electrical network. So, the AVR will be exploited to provide voltage control, focusing mainly the operation of the small-scale power unit based on biomass gasification in standalone. When the system is operated in grid connected mode, several improvements will be required to allow the AVR contributing to adjust the reactive power to operate the system according to the required power factor.

Additional developments are required to implement and integrate the power frequency control system, which will be responsible for performing frequency control by adjusting the active power generation and, therefore, the outputs of the downstream systems, such as the speed of the Internal Combustion Engine (ICE) and, therefore, the ICE intake. Also, this controller will allow the power generation system performing load following functionalities. To support this development a suitable mathematical model able to represent the dynamic behavior of the small-scale power generation unit based on biomass gasification will be derived and validated using experimental data. In addition, some improvements will be performed regarding the AVR and the power frequency controller aiming to allow these controllers accepting requests (set points of active and reactive power and voltage) sent by the distribution system operator when the system is intended to be operated in grid interconnected mode. These control functionalities are key developments regarding the small-scale power unit based on biomass gasification, assuring its effective operation in grid connected mode and in standalone mode. Also, these control functionalities should be exploited within the framework of further developments to integrate this system within the smart grids operation framework.

D. *Monitoring and Control System*

The monitoring and control system aims to supervise several key variables that provide information about the safe operation of the system, control the coordinated operation of the system involving the operational interaction between them and implement high level control and management functionalities to increase the system operation flexibility. It must be stressed that the automatic and unattended operation is a key issue for small scale power generation units based on biomass gasification. These requires automatic fuel feed and char-ash removal equipment which should also be controlled. Also, the mechanical system needs to be controlled to obtain better performance and to have a superior gas production to be used in the internal combustion engine, thus, optimizing the production of electrical energy on the entire system.

The control system of the gasifier will be done using a PIC32MX795 Microchip microcontrollers, a 32 bits microcontroller without floating point capabilities. The various parameters that have been monitored during the experiment are: bed temperature, exit gas temperature, biomass consumption rate, ash/char extraction rate, gas flow rate, gas composition and pressure drops across the reactor, cyclone and scrubbers. Temperature measurements were carried out using K type thermocouples. Five thermocouples were inserted along the length of the reactor and, with the help of the microcontroller display the temperature in a vertical plan. The ventilator is used to inject air inside the gasifier. The air flow in controlled by the microcontroller. Gas flow rate was measured using a calibrated venturimeter, and biomass consumption using a strain gauge-based weighing balance with least count: 1 kg. An online gas analyzer with measurement range for CO/CH4/H2: 0–100% by volume was used for measuring gas composition, and data were acquired at an interval of 0.5 min. Pressure differences at various locations were measured using U tube water manometers.

At the ignition phase there is not enough syngas to be burned into the internal combustion engine, so that the residual syngas must be burned in a torch. A valve will be used to control the flow of the syngas in two different paths: the torch (at ignition phase) and the ICE in steady state operation. Note that, the ignition phase tends to be a durable phase. This is because the ignition is slow, and after the ignition there is a time to the burning enters in a steady state to produce the syngas in a consistent way for running the ICE.

At a high control level, there is a control based on an embedded power computer to control in a coordinated way all the subsystems. This power computer can be connected to the internet for monitoring and controlling the energy production system.

IV. Conclusions

The development of small-scale power generation units based on biomass gasification have been supported by a few research and development activities carried out around the world. In Portugal these developments are still in a very early stage. However, biomass gasification is recognised as an effective process to meet the growing interest of disseminating local power generation exploiting renewable energy resources. Furthermore, these systems present an increasing potential for use in rural areas, either to feed isolated loads or to generate electricity to be injected into local distribution networks. In Portugal, real opportunities exist for the deployment of these systems, using biomass gasification, since it is expected that these systems will provide important contributions to support the management and valorisation of the biomass available in rural areas, which will play a key role in the prevention and fighting of forest fires. For this purpose, significant research and development activities are required, involving several areas of knowledge, to find cost-effective solutions suitable for rural applications to be attained in a commercial environment in a short-term.

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