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Date: 4 November 2019 - PM	**HALL: UI2**
MAIN TRACK: Control Techniques for RESs,	**SESSION CHAIRS: Naci Genc, Massimo Caruso**
14:20-14:40	**ID:7 Prediction of higher heating value HHV of date palm biomass fuel using artificial intelligence method** Bousdira Khalida (Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Énergies Renouvelables, CDER, 47133, Ghardaïa, Algeria)*;Ziani Mohamed (I Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Énergies Renouvelables, CDER, 47133, Ghardaïa, Algeria)*; Sabrina Belaid (I Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Énergies Renouvelables, CDER, 47133, Ghardaïa, Algeria)*; Hamid Oudjana Samir (I Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Énergies Renouvelables, CDER, 47133, Ghardaïa, Algeria)*; Khadidja Sobhi (I Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Énergies Renouvelables, CDER, 47133, Ghardaïa, Algeria)*; Said Midane (I Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Énergies Renouvelables, CDER, 47133, Ghardaïa, Algeria)*
14:40-15:00	**ID:116 Using Biomass Gasification for Small Scale Power Generation Systems: Specifications of the Conceptual Framework** Fernanda O. Resende (University of Aveiro, Escola Superior de Tecnolgia e Gestão de Águeda)*; Valter Silva (University of Aveiro, Escola Superior de Tecnolgia e Gestão de Águeda); Miguel Mendonça (University of Aveiro, Escola Superior de Tecnolgia e Gestão de Águeda);A.C. Barbosa (University of Aveiro, Escola Superior de Tecnolgia e Gestão de Águeda); P. Brito (Polytechnic Institute of Bragança & CIMO); J.C. Azevedo (Polytechnic Institute of Bragança & CIMO); A. Almeida (Polytechnic Institute of Bragança & CIMO);H.T. Gomes (Polytechnic Institute of Bragança & CIMO)
15:00-15:20	**ID:49 A novel design of solid oxide fuel cell-based combined cooling, heat and power residential system in the UK** Xinjie Yuan (University College London)*; Yuanchang Liu (University College London); Richard Bucknall (University College London)
15:20-15:40	**ID:106 Evaluating heat current through concrete crush for heat storing application** J. Birgitta Martinkauppi (University of Vaasa)*; Erkki Hiltunen (University of Vaasa)
15:40-16:00	**ID:124 Real-Time Qualitative Model for Estimate Water Content in PEM Fuel Cell** Gomer Abel Rubio (ESPOL)*; Wilton Edixon Agila (ESPOL); Livington Miranda (ESPOL); Byron Lima (UPS)
16:00-16:20	**COFFEE BREAK**
MAIN TRACK: Control Techniques for RESs	**SESSION CHAIRS: V. Fernao Pires, Luz Cárdenas Herrera**
16:20-16:40	**ID:10 Optimized Decentralized Control Strategy of Grid-Connected Residential Photovoltaic Inverters Based on Voltage Sensitivity Matrix** Jinrui Tang (Wuhan University of Technology)*; Yuanchao Qiu (Wuhan University of Technology); Binyu Xiong (Wuhan University of Technology); Yang Li (Wuhan University of Technology); Chengqing YUAN (Wuhan University of Technology); Yuwei SUN (Wuhan University of Technology)
16:40-17:00	**ID:14 Optimization Design and Feature Research on VSG Control Strategy of Marine Photovoltaic Grid-connected Inverter** Xujing Tang (Wuhan University of Technology); Huang Yaling (Wuhan University of Technology); Yuwei SUN (Wuhan University of Technology)*; Chengqing YUAN (Wuhan University of Technology); Hang Yu (Wuhan University of Technology)
17:00-17:20	**ID:51 Output Characteristics of Energy Harvesting Using Multiple Energy Sources** Toshihiko Ishiyama (Hachinohe Institute of Technology)*
17:20-17:40	**ID:196 The Closed Loop Controller Gain Characterization for Enhanced Current Quality in Solar Inverters coupled with Weak Grid** Ramachandra K Sekhar (Indian Institute of Technology, Ropar)*; Baibhav Kumar Gupta (Indian Institute of Technology, Ropar); Amol Ishwarrao Gedam (Indian Institute of Technology, Ropar)
17:40-18:00	**ID:228 PV Power Based Duty Cycle Control of Quasi-Resonant Inverter for Induction Cooking** Adem Sular (Van Yuzuncu Yil University); Ali Mamizadeh (Van Yuzuncu Yil University); Naci Genc (Van Yuzuncu Yil University)*; Muhammed Karaca (Van Yuzuncu Yil University)

Using Biomass Gasification for Small Scale Power Generation Systems:

Specifications of the Conceptual Framework

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***Abstract*—The development of small-scale power generation units based on biomass gasification is an effective mean to meet the growth interest of deployment of local power generation exploiting endogenous renewable energy sources. However, significant research and development activities are required towards the deployment of cost-effective solutions suitable to be used in several applications and with different biomass feedstock. For this purpose, a flexible experimental setup is required to be developed. This paper proposes a critical review of the current state of the art of the available technologies suitable for small-scale power generation using biomass gasification. The main guidelines to develop cost-effective solutions are identified and the conceptual framework of the experimental setup is proposed. Also, the operational specifications are presented.**

Keywords—Biomass gasification; syngas; distributed generation; renewable energy systems; grid integration

I. INTRODUCTION

The interest growth of local power generation by means of technologies exploiting Renewable Energy Sources (RES) is providing real opportunities for the development of small-scale systems based on biomass gasification to produce electricity. In fact, gasification systems for on-site power generation are becoming of increasing interest, since they promote the forest biomass use, giving economic value to materials of high potential availability in rural areas that are currently not fully exploited [1]. An efficient wood production in the multitude of small-scale forests could provide an important contribution to rural employment generation, enabling the energy systems to be partially supported by RES of rural neighborhoods. Forest management strategies could be increasingly improved to minimize the wildfire risks while increase biomass productivity. Also, on-site consumption on residual biomass avoids the need of transportation and gives the possibility to use it to provide electricity.

Biomass gasification using downdraft gasifiers over the micro and small-scale of power supply is considered as a established technology. However, due to the numerous variables, such as the typologies of biomass (forest harvesting and, sawmill by-products and farm litter or agricultural waste), their size and shape, etc., gasifiers characterized by high flexibility of operation and durability need to be developed [1], [2]. Therefore, additional research is required to develop cost-effective solutions aiming a possible regulation of gasifiers as a function of the processed biomass, by accounting several typologies. This will contribute to widespread micro-scale systems using biomass gasification for power generation and Combined Heat and Power (CHP) applications.

The biomass gasification process produces syngas, which is an important feedstock for the chemical and energy industries, since it has been used to feed Internal Combustion Engines (ICE) and gas turbines. However, ICE requires syngas with low tar and low quantity of particles contamination [3]. Therefore, gas cleaning systems and combustion chamber modifications have been recommended for ICE based applications [4]. In the case of small-scale power generation units based on biomass gasification, downdraft gasifiers are generally used, since they produce low tar concentration syngas, allowing the use of simpler syngas cleaning systems.

Small-scale power plants based on biomass gasification are expected to be competitive to convert highly dispersed and low value waste biomass to syngas. It is also necessary that the tasks of collecting and pretreatment of the raw material must be done locally and with low cost. Then, this research is focused on the development of a gasifier to work with locally collected and pretreated biomass. For this purpose, it is necessary to analyze the interaction between gasifier characteristics, operating parameters and both physical and chemical characteristics within the framework of biomass gasification. Regarding the raw material, it will be required identifying and characterizing the biomass, as well as defining a pretreatment procedure that will provide the biomass physical properties required to the effective operation of the gasifier. Simultaneously, a coordinated control system is intended to be developed to supervise and control the operation of the integrated subsystems. Also, advanced control functionalities will be implemented aiming the grid integration of RES using biomass gasification. These developments are proposed to be achieved within the framework of the SUBe Project, reference PCIF/GVB/0197/2017.

This work is found by the Portuguese Foundation of Science and Technology (FCT) within the framework of the SUBe Project, ref.: PCIF/GVB/0197/2017

To validate the proposed developments, an experimental set up will be developed with flexibility enough to test the main components individually and the entire system operation. For this purpose, the conceptual operational framework of the small-scale power generation system based on biomass gasification was defined and both the operation and control main requirements are specified.

II. Biomass Gasification for Small-Scale Power Generation: Critical overview of literature

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 [4]-[8], the downdraft gasifiers with throat are found prominent for ICE applications as the tar and particulates content in syngas is accepted for these technologies. Thus, the following sections provide a critical overview of the literature considering the gasifier integration with the engine/generator set to produce electricity on micro-scale units.

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 [9]-[14]: 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 reduction reactions take place, resulting the formation of CO, H_2 and CH_4. According to the literature review [7]-[20], the quality of the syngas generated in the gasification process is strongly influenced by the design of the gasifier, including the throat diameter and the reduction zone length, as well as by the flow patterns of air and biomass particles within a gasifier. However, for a specific gasifier design, there are two major variable operation parameters commonly used to achieve an acceptable level of the syngas quality: The Equivalent Ratio (ER) and the Superficial Velocity (SV).

The ER is the ratio of actual air-biomass fuel ratio to the stoichiometric air-biomass fuel ratio. 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 [14]-[15]. Typical values of ER for biomass gasification vary between 0.2 and 0.4 [11]. The theoretical optimum point for gasification is near 0.25 ER, since all the char is converted into producer gas providing its maximum energy. Below 0.25, char is remaining and some energy losses through char. At higher ER, some gas is burned and the temperature inside the gasifier increases. 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 [13]-[15]. 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 [13].

The performance parameters of the biomass gasification process in downdraft gasifiers with throat are the syngas composition, the syngas calorific value, the gasifier thermal power, the gas yield and the efficiency of the thermochemical process [11]. The composition of the syngas is strongly dependent of the temperature of the reactor [21], 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, which does not exceed 6 MJ/Nm^3 [14].

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 [16] 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 [11]. The cold efficiency corresponds to the ratio of the heating value in the syngas and in the feedstock. Typical values in a downdraft gasifier are between 50 and 80% [11]. Using preheat air as the gasifier agent contributes to improve the syngas quality, increasing the cold gas efficiency. Simultaneously, using preheated air, also contributes to reduce the ash and char contents, as well as the time required to obtain a stable gasification process [17], [18].

The throat diameter of a downdraft gasifier is a very sensitive design feature, which strongly affects the performance parameters of the biomass gasification process. This is related with the bed pressure drop that must be contained in a narrow range, and relies in the shape and size of the feedstock [19], [20].

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 combustion properties of syngas, such as the calorific value, are lower than those of the conventional hydrocarbon fuels, such as gasoline and natural gas, but are still satisfactory for use as fuel in ICE after appropriate cleaning processes [1]. According to [22] 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 heating value of the syngas/air mixture, the displacement volume of the engine, the flame speed of the fuel/air mixture, the auto-ignition delay period, the compression ratio of the engine and the spark timing [11].

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 fuelling the ICE with syngas. However, syngas as a higher methane number than natural gas and therefore it is not prone to detonation during the compression stroke. The high concentration of inert gases in syngas acts as a knock suppressor, explaining the high methane number with respect to natural gas [25], despite the presence of H_2 contributes to a lower resistance to detonation.

The auto-ignition delay period of a fuel/air mixture is also an important parameter to be considered in the ICE operation. It defines the time required spontaneous ignition, which depends on temperature and pressure conditions, the syngas composition and on the syngas/air ratio in the engine. Regarding these parameters, the syngas allows a longer auto-ignition delay period. The lower knock tendency and longer auto-ignition delay enables using engines with a higher compression ratio allowing to reduce the power de-rating [25].

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. Since syngas contains N_2, when the ICE is fuelled to syngas, the amount of it supplied to the engine should be increased to compensate the lower concentration of fuel compounds. For that, a compressor can be used to increase the pressure of the inlet air/syngas mixture. 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]. 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. 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.

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], [26]. 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 [2]. Therefore, using effective catalysts is often considered as an attractive method without the need of cooling the syngas. However, in [5], the syngas is cleaned following three major stages: cyclone separator, cooling systems and filters.

D. Main remarks and recommendations

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 biomass typology, moisture content, size and shape. They are influenced by the operation parameters, focusing mainly the ER and the SV, which determine the gasifier temperature levels. The system efficiency depends, also, on the design features of the gasifier focusing the location of air inlets, the throat diameter and the length of the reduction zone.

Fuelling the ICE with 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. That results from the fact that air is used as an oxidiser agent in the biomass gasification process, leading to a high concentration of N_2 in the fuel/air mixture. However, this high concentration of N_2 acts as a knock suppressor, allowing to increase de compression rate of the engine, and thus mitigate the engine power de-rating. Moreover, the spark ignition time should be retarded to increase the efficiency of the engine operation.

Regarding the syngas conditioning system, the syngas is cleaned following three major stages: cyclone separator, cooling system and filters. If too high levels of tar in the producer gas are observed, exceeding the acceptable levels of the ICE, a scrubber should be included in the clean-up system.

III. The Conceptual Framework of RES Based on Biomass Gasification

As already mentioned previously, the SUBe project aims to develop an experimental set-up of a micro-scale biomass-based power generation system, suitable to be used as a distributed RES in Portuguese rural areas. Therefore, the intended technical solution involves addressing the following main tasks: Collection and pre-treatment of biomass; Biomass gasification; Syngas clean-up; Fuelling the ICE with syngas; Running the synchronous generator for power generation.

Following the recommendations provided by the literature review presented in section II, the biomass gasifier prototype to develop follows the conceptual solutions of the downdraft type gasifier with throat, since they provide syngas with low tars and fast response times, being suitable for powering ICE feeding either fixed or variable loads. Also, the gas condition system will be developed for cooling and removing particulates and tars before feeding the syngas to the ICE. Another issue to be carefully addressed relies on the adjustments of the ICE fuelled by syngas to run a conventional synchronous generator. However, key features of the biomass gasifier prototype rely on increasing its flexibility of operation. For this purpose, several design parameters are required to be adapted following the gasification of a large range of biomass feedstock. In addition, 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. Moreover, high level control functionalities will be implemented allowing the power unit to perform 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 [27]. The implementation of these control functions are also innovative advances within the framework of the SUBe project. The following sections provide the technical specifications of the operational framework of the main subsystems.

A. Biomass Conversion to Mechanical Energy

As already mentioned previously, the prototypes to be developed involve the biomass gasifier, the syngas condition system and the improvements of the ICE to be fueled with syngas. Thus, the main principles of the gasification were carefully evaluated aiming to expand the range of usable biomass fuels to produce a cleaner syngas. For this purpose, the main guidelines reported on the literature of biomass gasification in a micro and small scale [4], [28], [29], have been considered in a first stage. In a second stage, these parameters are intended to be adjusted experimentally, considering both the type and the shape of the biomass to be used. Therefore, the development of the gasifier prototype follows a modular approach with flexibility enough to easily change their main geometric parameters, including the throat diameter.

The first step comprises the selection of the power rating of both the synchronous generator and the ICE. Also, designing the downdraft gasifier involves the definition of its geometry parameters and the materials to be used. The biomass gasifier is sized according to the estimated fuel consumption of the ICE [24]. The throat diameter will be defined to obtain the intended SV, which allows the production of good quality syngas. Larger throat diameters should also be considered to lower SV and, hence, preventing charcoal dusting [30].

The combustion and reduction zones will be thermally isolated, as it can be observed from Fig. 1, to ensure stable and high temperature levels in these zones, contributing for lower tar concentration in syngas. Also, it must be stressed that the gasifier will be built using commercially available materials, which will be selected according to their availability and manufacturing techniques aiming to reduce costs.

The grade is located at the end of the reduction zone (Fig. 1), to prevent undesirable biomass loss. Holes are frequent into both the combustion and pyrolysis zones, being influenced by the biomass moisture and size. They are pockets of air that made reactions following preferential directions lowering the gasification process efficiency [10]. In order to reduce the holes formation, a brake bed-bridges is required to be included. For this purpose, a grade vibration system is intended to be used. The gasification air will be preheated, by heat exchange with the hot syngas that exits the gasifier, as presented in Fig. 1, aiming to produce higher quality syngas.

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 on the 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 be determined experimentally, based on the measure of the composition and flow rate of the produced syngas. For this purpose, the Mamos gas analyzer 230V-Syngas, Madur will be used. Gas mass probes will be used in the syngas outlet of the gasifier to measure the produced gas flow rate.

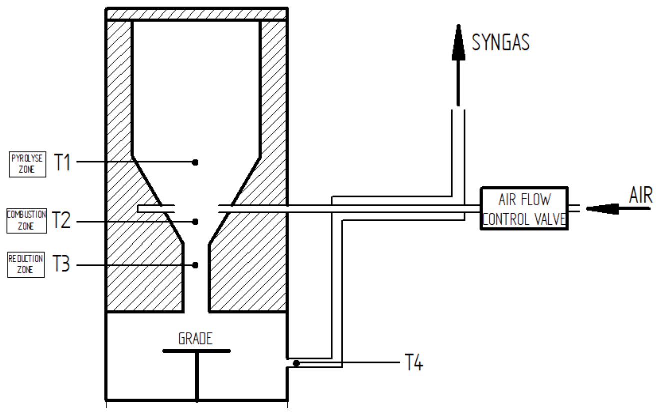

Fig. 1. The downdraft gasifier conceptual design

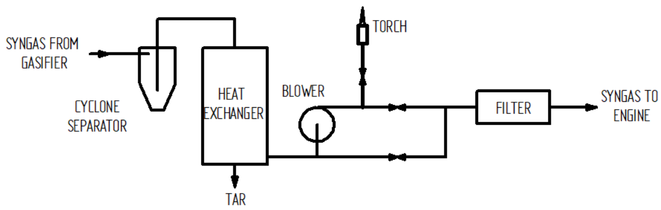

Fig. 2. Scheme of the syngas conditioning system

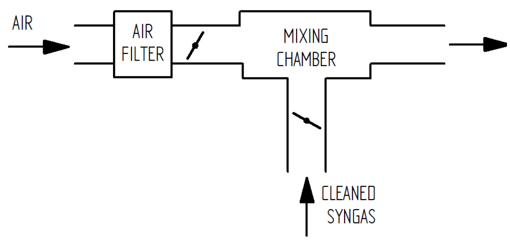

Fig. 3. Modified air/syngas regulator to the ICE

The gas produced in downdraft gasifiers carries dust, containing tars and particulates. These contaminants must be removed using a cyclone separator, that removes larger dust particles from the hot gases leaving the gasifier, followed by a heat exchange for gas cooler, where tar condensates, and filter that removes the smaller particles and tar droplets. The scheme of the syngas conditioning system is presented in Fig. 2.

A system to prepare the mixture of producer gas and air, in the correct ratio, and supply it to the engine will be developed according to Fig. 3. The fuel supply system consists on a mixing chamber where converges, and are mixed, the producer gas coming from the cleaning system and atmospheric air. The control of the desired composition of the fuel/air composition and the mixture flow rate supplied to the engine is accomplished by metering and controlling the admitted air and syngas flows, using air motorized valves. 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.

B. The electrical generator

The conversion of mechanical to electrical power will be performed through a three-phase, 50 Hz, conventional Synchronous Generator (SG) rated around 5 kW, with capability to provide voltage and frequency control. For this purpose, the SG will be equipped with both the excitation and governor systems. The Automatic Voltage Regulator (AVR) allows performing voltage regulation by supplying and automatically adjusting the field current of the SG, ensuring simultaneously that the operation limits are not exceeded, considering the SG, the excitation system and other auxiliary devices. The Fig. 4 presents the functional scheme a typical excitation system.

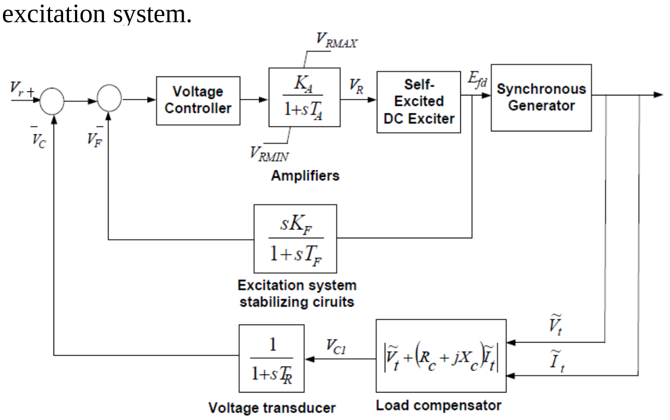

Fig. 4. Scheme of the typical SG excitation system [31]

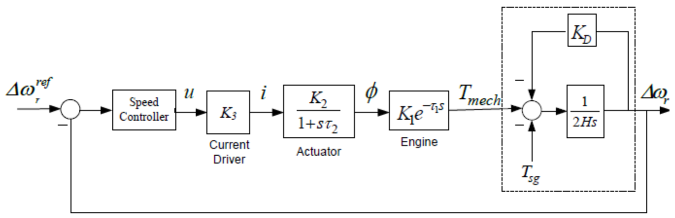

Fig. 5. Scheme of the typical ICE governor [31]

The AVR can be exploited to control the reactive power injected to or absorbed from the electrical network. So, the AVR will be used to provide voltage control, focusing mainly the biomass gasification-based power unit in standalone operation. When the system is operated in grid connected mode, the AVR will be used to adjust the reactive power to operate the system according to the required power factor. Thus, a digital controller with embedded microprocessors will be used to perform the various control function of the SG excitation system, including AVR, Var/power factor control and a host of excitation limiters to regulate and maintain the SG safe operation. Also, the power frequency control system will be included aiming to keep constant the ICE speed, by changing the amount of syngas feed to the ICE, in order to perform frequency control, following the control scheme of a typical ICE governor presented in Fig. 5. This controller will allow the biomass gasification-based power system performing load following when operated in standalone. Conventional PID controllers are also employed in the digital controller [31]. In addition, both the AVR and the power frequency controller should be able for 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.

C. Monitoring and Control System

The monitoring system aims to make accurate measurements of the temperature, pressure and mass flow throughout the entire gasifier and main system components, in order to safe operate the biomass-based generation power plant. Also, it aims improving knowledge about gasification performance and enhance control of the coordinated operation of the system, involving the operational interaction between the several systems, as well as to implement high level control and management functionalities to increase the whole system operation flexibility.

The control system of the gasifier will be supported by PIC32MX795 Microchip microcontrollers. The various parameters that should be monitored are: Temperature inside the gasifier, exit gas temperature, biomass consumption rate, ash/char extraction rate, gas flow rate, gas composition and pressure drop across the reactor, cyclone and filters. Temperature measurements were carried out using K type thermocouples inserted along the gasifier and at the syngas outlet, as it can be observed from Fig. 1, and before the ICE.

The microcontroller controls the ER aiming to keep gasifier temperatures to desirable levels to assure the stability of its operation. For this purpose, the air flow mass is measured and used to actuate the air flow control valve (Fig. 1). Also, the control system controls the process of the syngas feeding to the ICE. During the gasifier system start-up, the poor-quality syngas will be burned in a flare. Following the gasifier steady state operation, the ICE will start-up and the acceptable quality syngas will be supplied to the ICE. Several valves are used to switch the flow of syngas in different paths, as it can be observed in Fig. 2. Their operation should be fully automated and properly coordinated together with the air blower speed to suit the ICE requirements. During the ICE steady state operation, the air/syngas ratio is controlled to achieve high performance levels. For this purpose, the valve located downstream the air filter of Fig. 3 will be actuated based on the measurements of both the air and syngas mass flows. During load following operation, both the valves should be actuated in a coordinated way aiming to keep the proper ratio of air/syngas mixture and, simultaneously, control the ICE speed to be kept on its set value. The interactions between the several subsystems and their coordinated operation will be supported by advanced control and managements functionalities to be implemented in the higher-level control system [32], [33], which will be supported by software running on an embedded power computer. This computer will also support the control panel of the small biomass gasification power unit.

IV. CONCLUSIONS

Downdraft gasifiers with throat are identified to be practical for production syngas with acceptable calorific values and less tar contents to be used in ICE applications at micro and small-scale power generation using biomass gasification. However, the amount of tar in the syngas is reported to be strongly dependent of the gasifier operating temperature conditions, feedstock typologies and reactor design parameters. Therefore, additional research is required aiming to expand the range of biomass feedstock to the used in downdraft gasifiers, which requires increasing the gasifier operation flexibility attempting to adapt key design parameters and automatic controls following different typologies of biomass feedstock. The SUBe project is expected to provide key developments within this framework.

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