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Development of an Innovative Microgrid: 2MSG–Micro Mobile Smart Grid

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Summary

Microgrids enable the deployment of clean energy technologies. Deployment of microgrid solutions is currently underway in many countries. This paper describes a stand alone modular and scalable energy power system, an innovative microgrid based on a mobile platform of 100~200kWe operating in cogenerating mode for the treatment of local waste and production of a high–quality fuel, the solid recovered fuel (SRF), having "standardized" chemical–physical properties and particle size, which is gasified to produce electricity and heat. Electricity generated by cogeneration unit of mobile platform and renewable sources like wind and solar photovoltaic installations is stored within an energy storage system. Intergration between energy generation, storage and management system meet the energy needs and load profile of microgrid users.

Keywords: Microgrid; Waste to Energy; Renewable Sources; Energy Storage; Distributed Energy; Resilience

1. Introduction

Today, the biggest challenge is reduction of greenhouse gas emission from the conventional thermal power plants is necessary. In order to achieve this fundamental objective, the power producers are marching towards usage of renewable energy sources (RES) [1].

A study on the US power system suggests that a conservative approach could reduce annual CO_2 emissions by 5% by 2030 [2]. Also, if the national electricity market were to function properly, the renewable energy technologies would offer the cheapest forms of power generation [3].

The major change in the electrical system is the demise of coal, which falls from 37% of global electricity today to just 11% in 2050. In China, coal capacity peaks in 2025 and generation in 2 030 as the new–build coal pipeline is exhausted and older plants retire or are pushed out by RES and batteries. In India, coal generation peaks in 2033 as cheap RES dominate capacity additions and soak up new demand. Coal loses the market for bulk electricity to cheaper RES, and the market for round–the–clock availability to more flexible gas, which better complements variable wind and solar. With a forecast horizon set at 2050 wind, solar and batteries are set to become far more deeply entrenched in the generation mix of almost every country than anyone has so far thought possible. Cheap renewables and batteries remake the world's power systems, with wind and solar producing nearly half of world electricity by 2050. The growing flexibility in demand will fundamentally change the gross load shape. No longer will supply have to dispatch and ramp to meet changes in demand but demand itself will shift to meet cheap RES generation, helping wind and solar to achieve higher shares of the electricity mix. By 2050 the outlook is electricity system utterly reshaped around wind, solar and batteries. These technologies provide bulk electricity and are supported by thermal plants that run at low overall capacity factors but can be dispatched when needed. We get very high penetration of RES (>60% wind and solar in Japan and India, >70% in France, Mexico and Germany, > 80% in the U.K. and Australia). And when we looked into the dynamics a simple truth emerged – in a high–renewables system, curtailment and back–up are a feature, not a bug [4].

In general, RES are small in capacity and mostly connected at distribution voltage level and are known as distributed generation (DG). This localized grouping of electricity generation, storage, and loads that normally operate connected to a centralized utility grid is called as a microgrid [5].

There are technical limits on the degree to which distributed generation can be connected, especially for some intermittent forms of renewable generation [6].

As both energy demand and environment concern increase dramatically in the past decade, centralized electricity supply through long transmission distance at a high voltage level may not be the optimal solution to fulfill the need of further development, particularly for remote areas without access to main grids. With RES such as wind power and solar energy integrated into power system (distributed generation system, DG) [7], the operation reliability of power grid has become an outstanding issue. DG relies on small scale of generation units to meet local demand. In order to ensure seamless integration of DG into power system and improve reliability and efficiency of power delivery, the concept of microgrids is proposed.

Microgrids are small scale of power grids operating at a low voltage level formed by local generations, storage device and controllable loads [8]. Energy transformation in microgrids relies on power electronic devices with essential control functions, providing electricity and thermal energy to local regions. Microgrids can operate in grid–connected or islanded modes [9]. Driven by the environmental problem and energy crisis, different kinds of renewable energies have gained development in power systems and provide great opportunities to the rapid expansion of microgrids. Although there exist many challenges, such as establishing standards for microgrids design and construction, great R&D efforts have been made in the US, EU and around world. Examples of the project are initiated by US department of energy [10].

The development of RES and their integration within microgrids inevitably leads to the study of energy storage which guarantee the energy availability and enable a leveling of the absorption peak of the power grid (peak shaving), thus making it up for the drawbacks characterizing the DGs [10]. In the literature there are different energy storage systems each with different energy conversion process: electrochemical tanks, water – pH reservoir systems (pumped hydro), fuel cells, flywheels, SMES (superconducting magnetic energy storage), hydrogen storage and CAES (compressed air energy storage) [11].

Choosing the most appropriate system depends on different aspects. The main criteria are: charge/discharge time interval, storage capacity, overal efficiency and realization costs [11].

In more mature markets, the implementation of such microgrids could lead to benefits for the local community: increasing the amount of renewable energy generated, traded and distributed within their members; developing a connected network of distributed energy resources that will improve the overall resiliency and efficiency of the grid; and creating financial incentives and business models that encourage community investment in renewable sources and energy efficiency [12].

Microgrids are an effective solution in remote areas and it can also be used in universities and military bases to provide constant power in case of grid defects. Using the appropriate storage systems, they are used to reduce the cost of power by replacing electricity from the grid at peak times of the day.

2. Mobile platform for waste–to–energy

The DIMA, Department of Mechanical and Aerospace Engineering, University of Rome has developed an innovative microgrid based on a platform for waste treatment that enables solid waste transformation into a high–quality fuel, the solid recovered fuel (SRF) having “standardized” chemical–physical properties and particle size [13]. Table 1 shows the SRF quality classification in accordance with the European standards [14].

Table 1. SRF classification (UNI CEN/TS 15359).

Property	Statistical measure	Unit	Classes 1	2	3	4	5
NCV	Average	MJ/kg (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Cl	Average	% (d)	≤0.2	≤0.6	≤ 1.0	≤ 1.5	≤ 3.0
Hg	Median	mg/MJ (ar)	≤0.02	≤0.03	≤0.08	≤0.15	≤0.50
	80th perc.	mg/MJ (ar)	≤0.04	≤0.06	≤0.16	≤0.30	≤1.00

High–quality SRF product is suitable for energy recovery within the platform using the most advanced gasification process. The study aims at developing a mobile demonstration plant of 100~200kWe for energy recovery from waste in cogeneration by conversion of waste into SRF through a treatment system based on an innovative mechanochemical refining system. SRF is gasified within a gasification unit (syngas generation) and used to produce electricity and heat within a cogeneration module [13].

The first phase of the process concerns the development and design of the SRF production unit. The system will be able to produce SRF from waste. Through an innovative system the unsorted waste is transformed into standardized SRF with moisture reduction to 5% and its volumetric reduction by palletization. That SRF is therefore no waste but qualified as fuel. The purpose is to guarantee a fuel with high net calorific value (NCV) comparable with coal and constancy of physico–chemical characteristics. The second phase involves the energy production through an innovative plant of “robust gasification”: the innovation is in the adoption of gasification technology with standar modules from 100 to 200kWe in cogenerating mode. The technology of "robust gasification" is considered the cleanest way of waste–to–energy for many reasons: but gasification carried out in confined settings without waste incineration and fumes [13].

Waste transformation process essentially consists in a combination of low–cost physico–chemical treatments (micronization). Micronization is a refining process consisting of mechano–chemical treatments to be carried out in one continuous cycle plant able to produce a pelletized high–quality SRF. Micronization resulting from the application of an innovative technology of materials processing realized through friction and impact actions, putting variable pressures (from 8 000 to 15 000 atm) to destroy the bacterial flora (removing smells and fermentation), and make the product sterile, completely dehydrated (the water is vaporized) and always free from chlorine, sulphates and inert. With this technology you can obtain a reduction in volume by approximately 70%, a reduction in weight of around 50%, a reduction of the bacterial load and an increase in NCV of waste approximately up to 80%. From the environmental impact point of view, during processing do not use hot processes, do not use chemical additives (the only possible not channeled emission form is water vapour), does not produce smells or volatile microparticles or dioxin or any kind of pollutant in the air, water and soil, lack of water consumption, do not produce eluates, being treated waste daily. The study deals with the development and implementation of a characterization, treatment and recycling system through a waste mechanochemical refining system [13, 14].

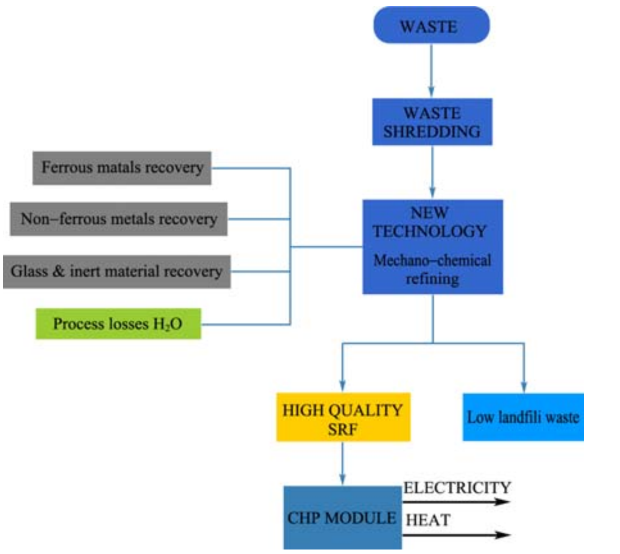

Figure 1. Mechano–chemical refining system.

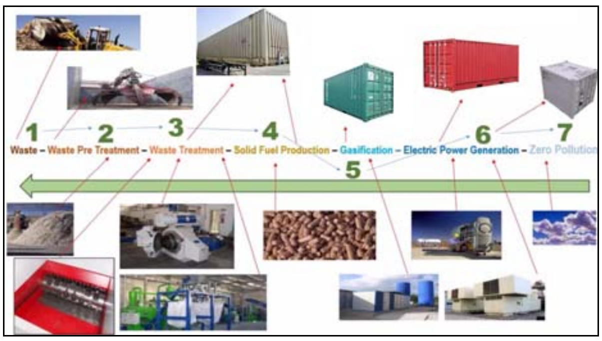

Figure 2. Mobile platform for waste–to–energy.

Production and gasification of SRF and the combustion of syngas take place in modular units arranged in appropriate mobile units (containers) appropriately config.d. Unit 1 (waste treater – SRF producer) performs a pre–treatment and micronization of waste to produce SRF. SRF is reduced into pellets (within auxiliary unit 4, pelletizer) introduced in unit 2 (Gasifier) to produce syngas and then in CHP unit 3 to produce electricity and heat (Fig. 2). Unit 1 (waste treater–solid fuel producer, WtE machinery) is shown in Fig. 3.

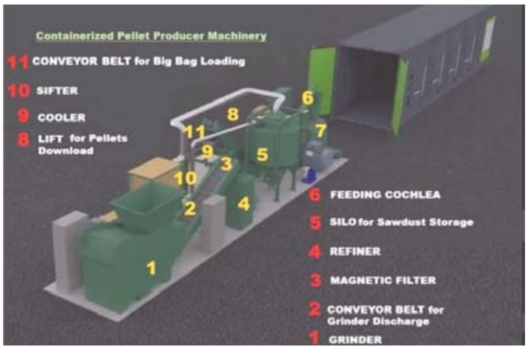

Figure 3. Design of unit 1 (waste treater – SRF production).

Table 1 shows main features of the modular units of the waste treatment and energy recovery system [13].

Table 1. Productivity of waste treatment platform.

Unit	Product	Hourly capacity	Hourly thermal availability
Unit 1	SRF	0.5t/h	3.25×10^6 kCal/h
Unit 2	Syngas	1 334m^3/h	11.4×10^6 kCal/h
Unit 3	Syngas	1 250~1 450m^3/h	333kWh (GCV) 120kWh(NCV)

3. 2MSG–Mobile Mobile Smart Grid

Micrograds are an effective solution such as in remote areas: decentralised generation and storage may also be a highly attractive method for bringing energy access to those areas of the world currently without sufficient energy services, for example a small rural village as shown in Fig. 4.

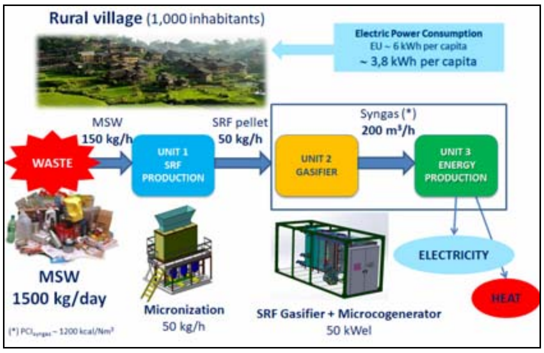

Figure 4. application of modile platform for waste–to–energy tailored for a small rural village.

As shown in Fig. 5, waste treatment platform can be integrated within a Micro Mobile Smart Grid Infrastructure (2MSG), an innovative microgrid solution which includes RES, energy storage systems (ESS) – which include battery energy storage systems (BESS) and other devices (micro–CAES, fuel cells, etc) – and monitoring and control systems (EMS) to exactly meet electricity demand during all hours of the day.

The innovative approach and special characteristics of the microgrid make it adaptable in a flexible way to different operating contexts both in civil and defense sector.

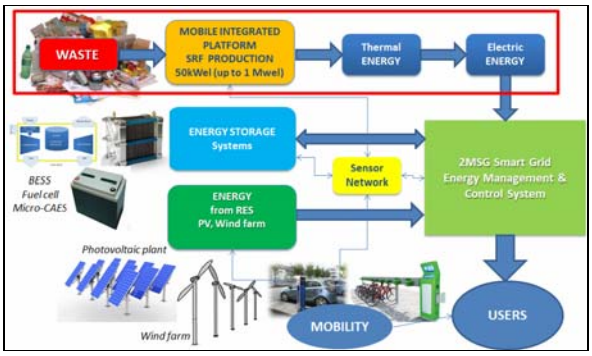

Figure 5. Concept of 2MSG.

The main challenge is to manage BESS and schedule of the energy exchanges with the utility in order to satisfy the stability of the microgrid and to minimize the overall costs [15].

Energy storage is the key to realizing the full potential of microgrids and reducing dependence on fossil fuel systems for power supply and power quality and it plays an increasing role within microgrid systems.

BESS and other energy storage systems (fuel cells, micro–CAES, etc.) must properly managed to enable peak shaving and load leveling by storing energy during low demand hours and using the stored energy during high demand hours and therefore achieve energy efficiency. By storing electricity using a system as a battery, fuel cell or different energy storage systems is possible to reduce electrical power consumption during periods of maximum energy demand (Fig. 6).

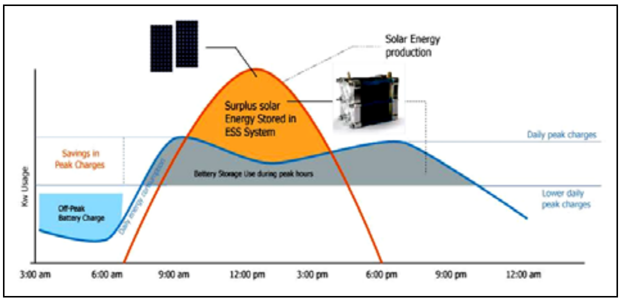

Figure 6. Peak shaving and load leveling by using RES and ESS.

3.1 New generation energy storage: micro–CAES

Electrical energy storage systems are playing a fundamental role in the development of microgrids, due to the high penetration of the energy produced by RES, the possibility of leveling the absorption peak of the electric network (peak shaving) and the advantage of separating the production phase from the exertion phase (time shift) [11, 16]. Compressed air energy storage systems (CAES) are one of the most promising technologies of this field, because they are characterized by a high reliability, low environmental impact and a remarkable energy density. The main disadvantage of big systems is that they depend on geological formations which are necessary to the storage. On the contrary, micro–CAES system with a rigid storage vessel guarantees a high portability of the system and a higher adaptability even with distributed or stand–alone energy productions. Compressed air energy storage systems (CAES) represent one of the most developed technologies for powerful systems (10~100MW) because they guarantee a remarkable charging capacity and a long–time intervals for the discharge phase, but at the same time they present some disadvantages, as: the compression heat dissipation and their dependence on the geological formation for the storage [11].

At DIMA Department we carried out thermodynamical and energy analyses of a micro–CAES system, a small storage system (3kW) with a storage capacity of $1m^3$ and pressure storage of 50bar. The quasi–isothermal micro–CAES (Fig. 7), which in a trigeneration system, enables the production of electric, thermal and refrigeration energies.

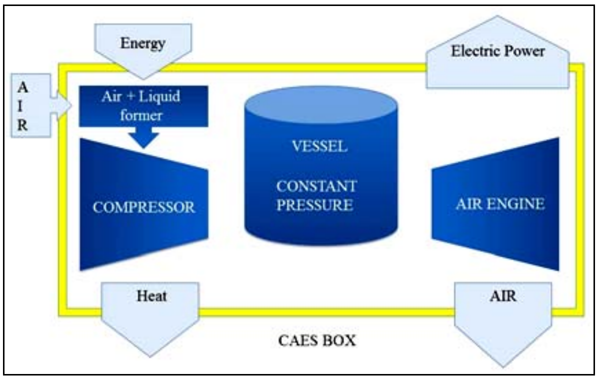

Figure 7. Scheme of a quasi–isotheral micro–CAES.

The system examined perform a charge/discharge cycle in 1.88h for the storage phase and 1.08h to perform the full discharge of the system absorbing 5.34kWh for charge phase provided almost entirely by RES. During the discharge phase there was a release of 2.81kWh for a round–trip efficiency of 52%. The thermal storage determined by the heat subtracted during the compression phase was of 1.89kWh, whereas the refrigeration energy stored during the expansion phase was of 1.39kWh. However, compression air systems can offer some advantages respect to conventional electrochemical tanks which require precious and expensive materials (characterized by a short service life), efficiency affected by the operating conditions and high dissipation costs [11].

4. Conclusion

The development of microgrid of a new design as in the case of the micro mobile smart grid (2MSG) provides a range of energy and environmental benefits: reaching sustainability, efficiency in energy suppy, readiness for use, availability, resilience, effective integration of renewable energy sources and storage systems, optimizing of energy use (energy efficiency), monitoring and control (energy management system), reducing dependence on fossil fuels, maximum efficiency of transformation and the minimum environmental impact, saving on energy losses, implementation of circular economy techniques (waste–to–energy).

The mobile platform for waste–to–energy can be successfully integrated into a 2MSG which includes RES, energy storage and monitoring and control systems to exactly meet in real time energy demand. The mobile platfom is designed as a basic module on the size of 100~200kWe (scalable up to 1MWe) for energy recovery form waste operating in cogenerating mode and the units arranged in conteiners can be easily displaced. The platfom provide economical production of electricity avoiding high–cost peak hours electricity, to meet basic energy needs with RES and SRF from waste.

Environmental benefits related to reduction of impact of the waste by reducing landfilling, reduction of GHG emissions by maximizing the energy recovery from waste and cutting down air pollutants, reducing transmission and distribution losses.

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