World Academy of Science, Engineering and Technology
International Journal of Humanities and Social Sciences
Vol:9, No:6, 2015

Contribution of the Cogeneration Systems to Environment and Sustainability

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***Abstract*—**A lower consumption of thermal energy will contribute not only to a reduction in the running costs, but also in the reduction of pollutant emissions that contribute to the greenhouse effect. Cogeneration or CHP (Combined Heat and Power) is the system that produces power and usable heat simultaneously by decreasing the pollutant emissions and increasing the efficiency. Combined production of mechanical or electrical and thermal energy using a simple energy source, such as oil, coal, natural or liquefied gas, biomass or the sun; affords remarkable energy savings and frequently makes it possible to operate with greater efficiency when compared to a system producing heat and power separately. This study aims to bring out the contributions of cogeneration systems to the environment and sustainability by saving the energy and reducing the emissions. In this way we made a comprehensive investigation in the literature by focusing on the environmental aspects of the cogeneration systems. In the light of these studies we reached that, cogeneration systems must be consider in sustainability and their benefits on protecting the ecology must be investigated.

***Keywords*—**Sustainability, cogeneration systems, energy economy, energy saving.

I. Introduction

THE reserve of energy resources in the world is tending to decrease; the amount of the energy needed by humanity is tending to increase. In addition, dependence of the humanity on using energy is increasing day by day due to the improving technology, rise in the life standards of people in the world. This situation is becoming the most important and essential issue of the world. In general, there are two ways to overcome this problem. One of them is to bring out and improve new and renewable energy sources such as solar or wind energy systems. The other way is to improve conventional energy converting systems for using existing energy source more efficiently and for longer time, such as cogeneration systems. In other words, people have to do their best to improve the sustainability of the energy resources [1]. Cogeneration can be explained as the simultaneous production of power and usable heat by using one type of energy source such as oil, coal, natural gas, liquefied gas, biomass, or the sun. That system affords remarkable energy savings and frequently makes it possible to operate with greater efficiency when compared to a system producing heat or power separately. In conventional power plants, a large amount of heat is produced but not used. These systems utilize the waste heat produced during electricity generation and allow more efficient fuel consumption. Along with the saving of fossil fuels, cogeneration also allows to reduce the emission of greenhouse gasses like CO_2 per unit useful energy output. By designing systems that can use the waste heat, the efficiency of energy production can be increased from current levels that range from %35 to %55 in the conventional plants to over %90 in cogeneration systems [2].

Using conventional energy conversion systems and fossil fuels to run them have very negative effect on the nature, environment and ecology. This is known for many years and this issue is on top of the energy politics of the countries. Air pollution and greenhouse problem are the issues that are studied by the scientists to overcome for many years. There is a general thought in the people especially they are not specialist in environmental issues that, one way is using renewable energy sources to overcome negative effects of fossil energy sources and conventional energy conversion systems. But we must analyze this situation together with that we live in the millennium age and energy is a necessity for us to continue our life just like water and air and it is impossible to live without energy. In addition to this in the current situation, all of the existing usable potential of the renewable energy sources is not sufficient to meet the energy demand for the humanity. In the light of these points, it is apparent we are obliged to use conventional energy sources and fossil fuels otherwise life will be very hard for us. That means air pollution and greenhouse effect will keep increasing day by day. Even though it seems impossible to finish the air pollution and greenhouse effect, they can be decreased by using more efficient energy conversion systems by the way using less fuel. One of the energy conversion systems which produce more energy by using less fuel is cogeneration systems. As mentioned before cogeneration systems produce two or more kind of energy by using one kind of fuel. Generally heat energy and electrical energy are produced in cogeneration systems. That means it is required only one type of fuel to produce two type of energy. In this wise less harmful gases and substances would be emit to the atmosphere. In this study, environmental benefits and necessity of cogeneration systems are put forward. To achieve this aim some scientific studies previously made on cogeneration systems are referred and analyzed.

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II. Environmental Impact Evaluation of Cogeneration

Although cogeneration is an old and proven energy conversion system, in recent years a resurgence of interest has come into world of energetic issue because of the energy crisis that has taken part in dockets of the countries in the world. Cogeneration systems and district heating/cooling applications offer us some proven, reliable, applicable and cost effective solutions which make very important contributions to meet global heat and electricity demand. Because of energy supply efficiency, use of waste heat and low carbon renewable energy resources of those systems, they are an important part of greenhouse gas emission reduction strategies of the countries in the world. Cogeneration is the simultaneous production of power and usable heat by using one type of energy source such as oil, coal, natural gas, liquefied gas, biomass or the Sun. In most of the cogeneration applications, the energy types produced simultaneously are electric and heat energy. Generally, those systems utilize the waste heat energy produced during electricity generation [1]-[3].

A. Emissions Balances for Cogeneration and Separate Heat and Electricity

Computing the air quality effects of any technological change is always made difficult by the complexity, expense, and inaccuracy of air quality modeling. In the case of cogeneration, this computation is further complicated by difficulties in determining the emissions changes occurring in the central utility system and by substantial variability in the emissions factors to be applied to the cogeneration systems. The response of the utility system to an increase in cogenerated power, a critical parameter in determining not only emissions impact but also oil savings (or Ioss) is difficult to predict. The addition of significant levels of cogenerated power to a utility's service area will affect both its current operations and future expansion. If the cogenerated power represents a displacement of current electricity demand in the service area (i.e., with retrofit of an existing facility for cogeneration), the utility will either reduce its own electricity production or reduce power imports, with its decision based on costs, contractual obligations or, perhaps, politics. It may also move up the retirement date for an older power plant or cancel planned capacity additions in response to cogeneration systems' displacement of either current or anticipated future demand. Because most utility grids draw on a mix of nuclear, coal, and oil fired steam electric generators for base and intermediate loads. These plants may be scattered over a wide area; and because control systems for the fossil plants may vary drastically in effectiveness, the pollution implications of the response of the utility system to cogeneration are highly variable [4].

III. Cogeneration Systems' Benefits

Generally, environment friendly energy sources are thought as a kind of energy which is renewable, meaning that the use of such energy never damages the environmental stability and not harms the nature. Some types of energy can be thought of as renewable anf fully friend to the environment, and many governments promote the use of such energy and the development of new types of energy generating technology which fit with this explanation. Parallel with the rising of energy demand of people there is an increase in concerns about that at which ratio on greenhouse gas emissions will be realized and damages of them. There are a lot of factors effective on decreasing the harmful emissions and parallel with this some choices are exist. In the concept of this point, energy efficiency is another important consideration. Increasing the energy efficiency is a vital way to make sustainable energy stretch further [5]. From this point, cogeneration systems may make positive effect to protect the nature in two ways. One of them is to use cogeneration systems together with some renewable energy conversion systems like solar systems or heat pumps. This way can be thought as a first-hand application for saving nature. Second one is fuel saving aspect of cogeneration. Less fuel using has same meaning with less harmful gas emissions.

There are many studies on using cogeneration systems with renewable systems in the open literature. One of them was made by Martin Pehnt with the name of environmental impacts of distributed energy systems –the case of cogeneration. This study investigates environmental impacts of micro cogeneration by carrying out a detailed life cycle assessment and an analysis of local air quality impacts of micro cogeneration systems. Most micro cogeneration systems are superior, as far as the reduction of GHG emissions is concerned, not only to average electricity and heat supply, but also to state-of-the art separate production of electricity in gas power plants and heat in condensing boilers. The GHG advantages of micro cogeneration plants are comparable to district heating with CHP. Under the assumption that gas condensing boilers are the competing heat-supply technology, all technologies are within a very narrow range. Looking at the GHG reduction potential on the level of a supply object (e.g. a single-family house) by modeling the operation with a CHP optimization tool, the achievable mitigation potential is somewhat lower, because the micro cogeneration systems do not supply the whole energy demand. Here, fuel cells offer the advantage of a higher power-to-heat ratio. Environmental impacts other than those related to climate and resource protection relate more specifically to technology. In addition to investigating the emissions side, analysis of the air quality situation of a residential area supplied by reciprocating engines was carried out. The analysis shows that for the selected conditions, the additional emission of NO_x due to the engines does not create severe additional environmental impacts. Another study was made by Thilak Raj et al. as a review study on renewable energy based on cogeneration technologies. That paper reviews the present day cogeneration technologies based on renewable sources of energy. In addition, study of novel methods, existing designs, theoretical and experimental analyses, modeling and simulation, environmental issues and economic and related energy policies have been discussed in this study. One of the energy conversion applications which are suitable for being used together or as a cogeneration system is solar energy system.

Solar energy can be importantly utilized for cogeneration systems and various such technologies have been proposed. Using focusing collectors, solar energy can be converted in a central power plant to electrical energy which can then be utilized to operate a vapor compression refrigerator to produce cooling. At the same time, the waste heat rejected by the heat engine can be used to drive an absorption refrigerator. This system is simply called a solar powered cogeneration system for air conditioning and refrigeration and can play a dual role by saving energy and reducing the environmental pollution [6]. Y. June Wu and Marc A. Rosen made a study on Assessing and optimizing the economic and environmental impacts of cogeneration/district energy systems using an energy equilibrium model. In this study energy equilibrium models which can be valuable aids in energy planning and decision-making. In such models, supply is represented by a cost-minimizing linear sub model and demand by a smooth vector-valued function of prices. In this paper, we use the energy equilibrium model to study conventional systems and cogeneration-based district energy (DE) systems for providing heating, cooling and electrical services, not only to assess the potential economic and environmental benefits of cogeneration-based DE systems, but also to develop optimal configurations while accounting for such factors as economics and environmental impact. The energy equilibrium model is formulated and solved with software called WATEMS, which uses sequential non-linear programming to calculate inter temporal equilibrium of energy supplies and demands. The methods of analysis and evaluation for the economic and environmental impacts are carefully explored. An illustrative energy equilibrium model of conventional and cogeneration-based DE systems is developed within WATEMS to compare quantitatively the economic and environmental impacts of those systems for various scenarios [7]. Goktun studied the solar power cogeneration system for air conditioning and refrigeration. By employing the energetic optimization technique, the optimal performance of a focusing collector-driven, an irreversible Carnot cogeneration system for air conditioning and refrigeration is investigated. A minimum value for the total solar insolation needed to overcome internal irreversibilities for start-up of the system is defined and the effect of the collector design parameters on this value is investigated [8]. Photovoltaic cogeneration in the built environment was investigated and studied by Morgan D Bazilian at al. In this study it is said that building integrated photovoltaic (BiPV) systems can form a cohesive design, construction, and energy solution for the built environment. The benefits of building integration are well documented and are gaining significant public recognition and government support. PV cells, however, convert only a small portion of the incoming insolation into electricity. The rest is either reflected or lost in the form of sensible heat and light. Various research projects have been conducted on the forms these by-products can take as cogeneration. The term cogeneration is usually associated with utility-scale fossil-fuel electrical generation using combined heat and power production. It is used here in the same spirit in the evaluation of waste heat and by-products in the production of PV electricity. It is important to have a proper synthesis between BiPV cogeneration products, building design, and other HVAC systems in order to avoid overheating or redundancy. Thus, this paper looks at the state-of-the-art in PV cogeneration from a whole building perspective. Both built examples and research will be reviewed. By taking a holistic approach to the research and products already available, the tools for a more effective building integrated system can be devised. This should increase net system efficiency and lower installed cost per unit area. An evaluation method is also presented that examines the energy and economic performances of PV/T systems. The performed evaluation shows that applications that most efficiently use the low quality thermal energy produced will be the most suitable niche markets in the short- and mid-term [9]. Experimental activity on two tubular solid oxide fuel cell cogeneration plants in a real industrial environment was investigated by M. Gariglio at al. The aim of the mentioned study is the comparison of two similar experimental campaigns performed on the two prototypes with different nominal power, in order to investigate the performance of the two generator designs. The factorial analysis has been applied considering two factors: setup temperature of the generator and fuel utilization factor. First, the obtained data have been analyzed by using the ANOVA of the experimental data of some dependent variables. Then, the regression models have been obtained for every dependent variable considered, and an optimization analysis has been performed. The analysis shows that the stack voltage sensitivity to the fuel utilization of the two systems has nearly the same value; and the stack voltage sensitivity to the generator setup temperature is different for the two systems [10]. In a study on solar cogeneration panels, which investigated the method of combining photovoltaic cells with the transpired solar air heater, constructed prototypes, measured the combined electrical and thermal energies produced and compared the results with single function reference panels. The results showed that combining the PV cells with the transpired solar wall panels can produce higher total combined solar efficiencies than either of the PV or thermal panels on their own [11]. Lindenberger et al. presented an article on optimization of solar district heating systems; seasonal storage, heat pumps, and cogeneration which focused onto demonstrate the working of deco in a pilot housing project of the Bayerische Forschungsstiftung (Bavarian Research Foundation). The quantitative results, i.e. the percentages of fossil fuels saved and emissions reduced with the help of different technology combinations at different costs, are specific to the pilot project. On the other hand, the qualitative interdependencies between energy conservation, emission mitigation and cost increases revealed by deco are likely to be the same in all regional energy systems in moderate climates at the present level of energy prices. The use of heat pumps (especially electric driven) has formed a new area of research. Heat pumps can be used together with cogeneration systems in some ways [12]. Marc A. Rosen made a study which's name is allocating carbon dioxide emissions from cogeneration systems: descriptions of selected output-based methods. In this article, selected methods for allocating emissions for cogeneration systems are described and compared. In addition, exergy values for typical commodities encountered in cogeneration are presented. The reasoning behind this author's view is that the exergy based method is the most meaningful and accurate of the methods [13]. Mancarella proposed a novel approach to energy and CO2 emission modeling of cogeneration systems coupled to electric heat pumps. The specific objectives were to identify the relevant parameters and variables involved in the analysis of such composite systems, and to provide a synthetic and indicative assessment of the energy and environmental benefits potentially brought with respect to conventional energy systems. The conditions at which energy and emission benefits occur, and their extent with respect to classical generation means, are illustrated through various numerical examples, highlighting the generality and effectiveness of the models introduced [14]. A comparative parametric analysis was carried out in a small-scale combined heat and power plant incorporating a heat pump and the conventional system in which heat is produced in a hot water boiler and electrical energy is drawn from the power grid [15].

A study was made on multi-objective optimization of a solar-hybrid cogeneration cycle Application to CGAM problem. In their study an exergo-economic multi-objective optimization is reported here of a solar-hybrid cogeneration cycle. Modifications are applied to the well-known CGAM problem through hybridization by appropriate heliostat field design around the power tower to meet the plant's annual demand. The new cycle is optimized via a multi-objective genetic algorithm in Matlab optimization toolbox. Considering exergy efficiency and product cost as objective functions, and principal variables as decision variables, the optimum point is determined according to Pareto frontier graphs. The corresponding optimum decision variables are set as inputs of the system and the technical results are a 48% reduction in fuel consumption which leads to a corresponding decrease in CO2 emissions and a considerable decrease in chemical exergy destruction as the main source of irreversibility. In the analyses, the net power generated is fixed at 30MW with a marginal deviation in order to compare the results with the conventional cycle. Despite the technical advantages of this scheme, the total product cost rises significantly (by about 87%), which is an expected economic outcome [16]. The researchers made a study with the name of Cogeneration solar system using thermoelectric module and fresnel lens. The main purpose of their paper is the experimental investigation of an electricity and preheated water cogeneration system by thermoelectric. In the presented design, Fresnel lens and thermoelectric module (TE module) were utilized in order to concentrate solar beam and generate electrical power, respectively. The energy of concentrated sunlight on the heat absorber of TE module is transferred to cold water reservoir. Heat transfer in TE module leads to temperature difference in its both sides and finally electrical power is generated. The main components of this system consist of a mono-axial adjustable structure, a thermoelectric generator (TEG) and a Fresnel lens with an area of 0.09 m^2. Results revealed that matched load output power is 1.08W with 51.33% efficiency under radiation intensity of 705.9 W/m2. In order to apply TE module capacity optimally for electrical generation, it is recommended to employ an array of Fresnel lenses which transfer heat to TE module by an intermediate fluid [17].

Rafael Galvao et al. presented the development of an energy model based on a mixed system of renewable energy, with primary energy sources as solar and biomass. It was a hybrid and autonomous system with solar PV panels and gasification cogeneration technology. Also it was an environment friendly process aiming to reduce the energy demand, costs and emissions. This energy model is a new sustainable standard about energy consumption efficiency (electrical and thermal demands) of a small hotel building and a relevant contribution to certify the building in compliance with the laws of the country on the thermal performance of buildings [18]. Some other researchers investigated the socio-economic drivers of large urban biomass cogeneration sustainable energy supply for Austria's capital Vienna. They provided a detailed case study on Austria's by far largest biomass cogeneration plant. They described and analyzed the history of the project, putting particular emphasis on the main driving forces and actors behind the entire project development process. There are some other works in the literature on using cogeneration with different systems together to save more energy [19].

In the study made by Burer et al. and named as Multi-criteria optimization of a district cogeneration plant integrating a solid oxide fuel cell–gas turbine combined cycle, heat pumps and chillers; a simultaneous optimization of the design and operation of a district heating, cooling and power generation plant supplying a small stock of residential buildings has been undertaken with regards to cost and O2 emissions. The simulation of the plant considers a super structure including a solid oxide fuel cell–gas turbine combined cycle, a compression heat pump, a compression chiller and/or an absorption chiller and an additional gas boiler. The Pareto-frontier obtained as the global solution of the optimization problem delivers the minimal CO2 emission rates, achievable with the technology considered for a given accepted investment, or respectively the minimal cost associated with a given emission abatement commitment [20]. A review study was made by Jeff Smithers on Review of sugarcane trash recovery systems for energy cogeneration in South Africa. He says that biomass is a potential sustainable source of energy. Approximately one third of the energy available from sugar cane is contained in the top sand leaves trash), which are generally either burnt prior to harvesting or are not recovered from the field. Based on results reported in the literature and assuming 50% trash recovery efficiency, it is estimated that 1.353 million ton soft rash is available annually for cogeneration in South Africa, which could potentially produce 180.1MW over a 200 day milling season. Studies in Brazil and Australia have shown that the most efficient way of recovering the top sand leaves for cogeneration of power at sugar mills is to use a chopper harvester with the separation of canes talk sand trash on the harvester either fully or partially turned off.

In South Africa more than 90% of the sugarcane crop is burnt and manually harvested and hence new systems are proposed to recover the trash and to transport the material to the mill [21]. Dario Buoro and his friends made a study on Optimization of a Distributed Cogeneration System with solar district heating. The aim of the related study is to identify the optimal energy production system and its optimal operation strategy required to satisfy the energy demand of a set of users in an industrial area. A distributed energy supply system is made up of a district heating network, a solar thermal plant with long term heat storage, a set of Combined Heat and Power units and conventional components also, such as boilers and compression chillers. In this way the required heat can be produced by solar thermal modules, by natural gas cogenerators, or by conventional boilers. The decision variable set of the optimization procedure includes the sizes of various components, the solar field extension and the thermal energy recovered in the heat storage, while additional binary decision variables describe the existence/absence of each considered component and its on/off operation status. The optimization algorithm is based on a Mixed Integer Linear Programming (MILP) model that minimizes the total annual cost for owning, maintaining and operating the whole energy supply system. It allows calculating both the economic and the environmental benefits of the solar thermal plant, cooperating with the cogeneration units, as well as the share of the thermal demand covered by renewable energy, in the optimal solutions. The results obtained analyzing different system configurations show that the minimum value of the average useful heat costs is achieved when cogenerators, district heating network, solar field and heat storage are all included in the energy supply system and optimized consistently. Thus, the integrated solution turns out to be the best from both the economic and environmental points of view [22]. The aim of the study which is made by Marta Serrano Delgado and his friend is to model and to simulate the thermal and electrical efficiencies of the cogeneration plant of a paper mill. The final purpose is the benefits optimization by adjusting production to the amount of energy to be sold. It is necessary to know it because the sale price goes down when the actual production of electrical energy does not match the scheduled power [23].

IV. Conclusion

Importance of cogeneration systems is well known for many years by the people who interests with energy. But environmental and ecological aspects of the cogeneration are very important too. Those systems' less fuel using specification and efficiency level make them very important for environment. Due to they provide with the primary energy savings and have high efficiency levels and decrease the greenhouse gas emissions, these systems make important contributions to the environment and nature. This efficiency also reduces air pollution and greenhouse gas emissions, increases power reliability and quality, reduces grid congestion and avoids distribution losses. All in all, cogeneration systems make very important contributions to the nature in different ways.

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