IMPROVEMENT OPTIONS IN THE DISH STIRLING TECHNOLOGY

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Abstract

The dish-Stirling technology for electricity generation has been in development during more than 25 years. This technology using a Stirling engine fed with solar energy means a promising development regarding power generation. The value of efficiency of this technology, around 30% of normal direct solar radiation, is the highest when compared with other solar energy generation systems. However, the dish-Stirling technology has not achieved enough advancement to be really competitive with other renewable energy technologies. The competitiveness must take into account technical, economic and environmental issues. A state-of-the art review has been carried out in order to identify the developments needed to guarantee the feasibility of using the dish-Stirling technology for energy production, further than demonstration facilities that have been operated so far. The economic feasibility of dish-Stirling depends highly on equipment amortization, so the continuous operation of the system is a key factor. It would also improve the environmental impact since it means to decrease the environmental load of facility construction, due to the fact that this facility would be used for more time than exclusively operating from sun energy. The developments enabling this use are, on one hand the system hybridization, in such a way that guarantees the operation of the system with other energy sources when solar is lower than nominal operation value or is not available. On the other hand the thermal storage, providing system operation with stored energy during some periods such as transients. The stored energy would be obtained from excess of sun radiation in relation to nominal operation value. In this paper, a review of literature concerning state-of-the-art and developments of dish-Stirling technology has been performed, presenting the most outstanding issues considered for future implementation.

1. Introduction

In the last decades the demand of energy used by the human being has increased exponentially. With the main objective of supply this huge demand of energy, a lot of technologies have been developed. Until now, the most important percentage of the primary energy demand is covered by fossil fuels (Report International Energy Outlook, 2008). However, in the last years, the fossil fuel depletion, together with the environmental degradation caused by their use, has led to an increase in the use of clean technologies. In this way a variety of renewable energy technologies have been developed. One of the advantages of the renewable energies is that this kind of energy coming from the nature cannot be depleted. Thus, the scientific research and industry development in this field has been supported by local and global policies, in order to achieve sustainability of the Earth.

Regarding to the electricity generation the same problem appears. Now, the electricity can be produced from a variety of sources: thermal (from fossil fuels), hydraulic, nuclear and renewable. However, the biggest contribution is the one corresponding fossil fuels because nowadays the thermal sources are the most used for this electricity production in most of the countries (Varun et al, 2009).This intense use of fossil fuels has a clear consequence, an increase in the emission of pollutant gases.

In this context, the use of renewable energy must be promoted, and therefore research and development on them. Currently the use of renewable energy has meant the development of a variety of technologies, optimizing durability and cost issues, in such a way that some of them have achieved an acceptable level in comparison with conventional fossil fuel technologies. One of these technologies is the solar thermal technology.

The solar thermal technologies are: central receiver, parabolic trough and dish-Stirling. The two first technologies are suitable for high value production of electricity, whereas dish-Stirling technology enables distributed generation with units varying from 3 to 25 kW (Gener, 2008). Basically, a dish-Stirling unit consists of a dish receiver to collect and direct the sun rays in such a way that the concentrated sun energy is transferred to the fluid inside a Stirling engine. This engine is the responsible for producing the power that will be converted to electricity by means of a generator. The unit is supported by a metallic structure, placed on a concrete settlement to provide stability. The stability of the dish-Stirling unit is a significant issue, since the system has a tracking system to follow the sun rays guaranteeing the proper shape and position of the concentrated sun energy. The dish-Stirling technology presents the advantages of modularity, with possible applications varying from isolated facilities for distributed energy to big facilities with the aggregation of a high number of dish-Stirling units.

The dish-Stirling systemis the solar technology with a highest potential in the long term, due to the high efficiency and modularity, being especially attractive from the point of view of planning and funding (Romero, 2008). This technology could have a lot of importance in the distributed energy field (Pantoja, 2007). In spite of the high potential, the limitation of unit power (in any case lower than 25 kW) can avoid the use in applications for big scale production. Thus, the clearest application is the distributed generation for electricity production in isolated places where electric net is not available, where the dish-Stirling technology can be competitive with current commercial systems, such as photovoltaic or diesel generation.

The SBP company, working in the development of the dish-Stirling technology, establishes future costs around 0.08 €/kWh (Web SBP), that agree with objective values around 0.06 €/kWh of energy prices fixed by DOE (Department of Energy) of USA (WEB EIA) for 2011. It must be also taken into account that renewable sources mean an alternative in the long term for conventional fuels that could have an important cost increase due to resources depletion, together with politics issues for energetic independence. In particular, dish-Stirling energy could be compared with photovoltaic energy since it means the alternative facility for similar applications. The current value for photovoltaic energy is around 0.3 €/kWh (Solar Energy Tecnologies Program, 2009), though this value depends highly on facility size and type. Besides, the development of new technologies can further reduce this value in the short term, in such a way that the photovoltaic energy could be competitive without the need of government funds in 2015. The future comparison of photovoltaic with dish-Stirling is yet under uncertainty, and development issues will be determinant to favour one or other technology. Last but no least, the environmental evaluation of the dish-Stirling technology must be taken into account. It is necessary to provide a comparative environmental assessment of dish-Stirling technology with respect to a similar facility using the Life Cycle Assessment procedure. Comparing the dish-Stirling technology respect to the photovoltaic technology (Bravo, 2010) and analyzing the results in terms of CO2 emissions, it has been obtained that the level of environmental impact is similar for both technologies.

2. Review of dish Stirling technologies

The dish-Stirling technology has been studied in several research and development projects with a number of demonstration facilities supported by different companies and research bodies around the world (Reinalter et al, 2006) (Manzini et al, 2003).

The first dish Stirling systems had heater heads in which the solar flux was directly absorbed by the working fluid of the Stirling engine. This working fluid was circulating inside the tubes of the heater heads. Some examples of this kind of configuration are: the United Stirling of Sweden AB (USAB), the Vanguard system and the McDonnell system. These were some of the first developments in the dish Stirling field. Later, there was others like STM/Detroit Diesel 4-120 (STM4-120) and the Japanese Aisin Seiki Miyako Island NS30A (Stine et al, 1994). Each one of these systems had its own Stirling engine. The latest in this list is the system developed by the German company Schlaich, Bergermann und Partner (SBP) using the Stirling engine V-160 developed by SOLO kleinmotoren.SBP is a German company that has participated in the European project EURODISH (1998-2001) and ENVIRODISH (2002-2005), for the development and demonstration of dish-Stirling technology, together with other European companies and research institutions. These projects have worked on demonstration facilities in different European countries, such as Germany, Italy, France and Spain (Plataforma Solar de Almería – PSA- and Sevilla University) (Stine et al, 1994).

Development projects carried out by SBP and SES (Stirling Energy Systems) resulted in commercial equipment. As for the project leaded by SAIC (Science Applications International Corp.) and STM Power Inc., and the one coordinated inside the Cummins Dish-Stirling Joint Venture Program by associated members of the project WGA, both carried out in the United States, there is no information related to later commercialization.

Other companies such as Infinia (Web Infinia) in the USA are also leaders in the developments of dish-Stirling systems. Infinia is an organization that works on development of Stirling engines. The dish-Stirling technology units of 3 kW (PowerDishTM), is included in their technological offer both for distributed generation or big scale facilities. The first plant with Infinia technology is Casa delÁngelTermosolar, located at Casa de los Pinos (Web Renovalia Energy), Cuenca (Spain), with 0.99 MW power. The following project is 71 MW power and is located at Villarobledo, in Albacete (Spain) (Web EnergíasRenovables), currently in development phase. Innova is the latest company that has developed a mini-Dish Stirling (Web Innova).

3. Future of dish Stirling systems

The next years are going to be crucial in the development of the dish Stirling technology. One of the key issues for the commercial implementation of the dish Stirling systems is the cost of energy provided by this technology. In this sense, it is decisive to ensure the operation of the facility the longer time possible. As the operation of any solar technology depends on sun irradiation, the two main developments are focused on overcoming the limitation of this irradiation that depends on climatic conditions. On one hand, the use of other energy sources in combination with solar energy, so they can be used alternatively depending on climatic conditions. Thus, the system should be hybridized in order to enable the use of the equipment with different energy sources. It is especially interesting that the alternative energy sources are renewable, so the dish-Stirling unit works with less environmental impact. On the other hand, if sun energy could be stored so it could be used in times where it is not available or when the sun irradiation does not reach the nominal operation value of the system, it will mean also a great advantage. These two developments: hybridization and thermal storage would mean improvement regarding amortization of equipment, and also regarding transient operation

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3.1Thermal storage options.

The use of thermal storage enables to store energy when this is not necessary for operation, in such a way that it is available in the appropriate time, transient times, start-up or when the main source energy is not available (in the case of solar energy, in cloudy days or during night).

The thermal storage can be performed with Phase Change Materials (PCM). The thermal storage system associated to a dish-Stirling system could be installed as an isolated system, or integrated with a reflux receiver in case this technology is used in the system. For both cases, the management of the system is a key issue so it regulates the periods of energy storage and release.

As for potential fluids working as PCM, there are experiences for Stirling engine in lithium fluoride (Asselman, 1976) (London et al, 1990) and magnesium hydrates (Wiersea et al, 2007). As for known systems, in the 2009 Clean Technology congress (Weaver, 2009) a low-temperature Stirling engine – SolarHeartTM Engine- was presented for conversion of hot sources around 100-300ºC, including thermal solar, geothermal and industrial waste flow. The facility integrated sun roof collectors (SolarFlowTM System) with a tank for thermal storage, including also an advanced control system to optimize the generated or stored energy for power supply.

For PCM selection, the key factors are nominal temperature, that in the case of dish-Stirling engine is high (around 500-900ºC), and thermal capacity (Gil et al, 2009). There are also other factors: cost-benefit balance, and technical and environmental criteria. The cost depends on the PCM itself and also on the heat exchanger needed for charge and release of the system. As for technical aspects: high energetic density, good heat transfer coefficient (efficiency), mechanical and chemical stability (to withstand cycles of charge and discharge), compatibility with other materials, reversibility of cycles of charge and discharge (hysteresis), low thermal losses and easy control management.

Regarding dish-Stirling technology, it is known that Stirling Energy Systems (SES) and Infinia are working on the integration of thermal storage systems. In particular, Infinia started a project supported by DOE, where 40-50 systems will be used for demonstration in Sandia facilities. As a result of the research, Infinia presented a patent in 2010 (reference WO2010006319) (Qiu et al, 2010).

The device for thermal storage presented in this patent consists of a container with the PCM, having an input and output for heat flow. This device is reflux receiver type, in such a way that the input receives energy from an external source through thermal energy transport members. The energy is transferred either to the output and / or the PCM. Other thermal energy transport members will be in charge of transferring energy from PCM to output when this energy is required. The output is connected to the Stirling engine. The control system is significantly important to manage heat transfer flows through elements operation. In this patent, extensive information is presented regarding material selection that must take into account a high phase change temperature together with a high latent heat of fusion. This is the case for eutectic salts, such as LiF/NaF/MgF2, LiF/NaF y NaF/NaCl, or other material such as Li, LiOH, LiH, LiF/CaF2, LiF, NaF, CaF2 y MgF2. In this patent, the lithium hidrade (LiH) is presented as one of the most suitable PCM for use in the dish-Stirling technology. LiH has a high specific energy, available in the range of working temperature from 500 to 1000ºC.

The lithium fluoride (LiF) has also suitable values, with the highest energy density in this range. There are eutectic salts, such as LiF/NaF/MgF2, with similar values for operation in the dish-Stirling systems. However, LiH and LiF have advantages regarding production and use of the PCM, due to weight and security reasons.

The thermal storage system presented in this patent can operate in combination with hybridization in such a way that there are two different input energy sources.

3.2Hybridization options.

The hybridization is the use of several energy sources in a facility. The advantages are: adaptation of production to electricity demand (flexibility), stability of production in transient period, management improvement, increase of use of equipment (amortization) and start-up support. Hybridization is significantly interesting when it is applied with two (or more) renewable energies, both for resources consumption and pollutant emissions. The environmental impact of hybridization has been evaluated for different combination of energy sources: wind energy with biomass (Perez et al, 2010) and wind energy with photovoltaic energy (Nema et al, 2009). If the environmental impact of the isolated energy sources is considered, it results specially interesting to apply hybridization of solar energy with biomass, since they are the ones that present low values regarding this indicator.

As for the dish-Stirling technology, a number of developments have been carried out by different companies and research institutions. The hybridization means an important potential for cost reduction (Eyer and Iannucci, 1999) of the technology with the highest efficiency for solar energy power generation. The design of the hybrid receiver, that provides the heat transfer to the Stirling engine from solar or the alternative source, is the key point of the developments, since is a complex technical issue.

The hybridization projects for dish-Stirling technology were initiated in 1981. In the present article only the most recent (since 1995) and important developments are mentioned and briefly introduced. These are: SAIC/STMSundish System (1999-2000) (Mayette et al, 2001),Biodish (2000-2003) (Ramos et al, 2010), HYPHIRE (1997-2000) (Laing and Reusch, 2001) (Laing and Palsson, 2002) and Sandia project (1995-2002) (Moreno et al, 1999):

- SAIC/STM Sundish System (DIR): installation of a dish-Stirling unit in a landfill for exploitation of biogas, with a time of operation of 600 hours. The main problem found was the fouling due to composition of biogas and the lack of continuity of this composition. A filter a continuous monitoring of the composition was necessary to adapt combustion characteristics. The receiver consists of a bundle of thin parallel tubes, located in a truncated cone.

- Biodish (DIR): ceramic cylinder-shape receiver that absorbs sun radiation in the inner face and combustion energy in the outer surface, alternatively or at the same time. The combustion burner is swirl type. The ceramic material is silicon carbide (SiC) reinforced with carbon fibre to withstand the high internal pressure (up to 150 bar). The main drawback of this receiver is the complex production and the high cost. This project performed also an economic analysis for feasibility of a plant with 50 to 100 dish-Stirling units hybridized with gasified biomass.

- HYPHIRE (reflux receiver): heat pipe receiver of sodium, with a working temperature between 700 and 850ºC. It consists of three heat exchange surfaces: inner surface for receiving sun energy, outer finned surface for gas combustion and heat output for Stirling engine. The system can operate isolated or simultaneously with both energy sources. It has been tested during 117 hours in sun mode, 92 hours in combustion mode and 56 hours in simultaneous mode in PSA (Plataforma Solar de Almería).

- Sandia (reflux receiver): heat pipe receiver of sodium, with a working temperature around 750ºC. The combustion system is provided with a metallic matrix burner, operating in radiant mode. The exchange surface with combustion gases is provided with fins to enhance the heat transfer.

An important issue for the design of the hybrid system is the burner selection. It can be determinant for the design of other components, such as the receiver, since it collects the energy released by this burner. The burners are classified according to different criteria (Baukal, 2004). The pressure supply determines if the burner is atmospheric or supercharged. The time where the mixture between oxidant and fuel is done, determines if it is a premix burner. If the combustion takes place very nearly to burner surface without diffusion flame, the burner is called radiant. Thus, the combustion energy is released by radiation caused by the high temperature of the material.

The fuel type must be also taken into account. It determines if the burner is considered as gas, liquid or solid burner. The gaseous state of the fuel improves the mixture with the oxidant, thus improving the combustion both for energy release and emissions level. In the case of liquid state, the fuel must be vaporized before combustion, thus adding complexity to the system. As for solid fuels, the complete combustion depends highly on the aggregation level and the status of the solid. The fouling is also more critical for solid fuels, followed by liquids.

As for burner geometry, it can be basically rectangular or round-shaped. The latter is preferred due to production considerations and elimination of corners that can represent failure points of the burner. In another geometrical position, the burner can be located concentrically to combustion source. The burner shape determines also the fluid movement. Thus, a turbulent flow can be imposed (swirl flow) in comparison to laminar flow. The level of turbulence has an influence also on combustion conditions. There are low turbulent burners with specific flame characteristics specially designed to operate with poor mixture with high efficiency and low emissions (Cheng et al, 2000).

Regarding material, the burner can be metallic or ceramic. Depending on the material selection, the burner can withstand the high combustion temperature with both type of material. The ceramic burner has a better mechanical stability, though its drawback is fragility.

CONCLUSIONS

In this paper, the state-of-the art of dish-Stirling technology has been reviewed, emphasizing the two technical developments that could assure its future implementation: hybridization and thermal storage. Nowadays, the dish-Stirling technology is presented as a promising technology, but yet in development phase. This technology can play a key role regarding distributed generation systems due to unit modularity with power range from 3 to 25 kW. As for big scale grid-connected applications consisting of a large number of dish-Stirling units, the commercial facilities that are being constructed at present in the USA could be related to energetic independence more than to real competitiveness of the technology. In fact, in the USA, the dish-Stirling suppliers receive important support from government for research projects, mainly SES (Stirling Energy Systems) and Infinia.

Hybridization is one of the developments that linked to dish-Stirling technology could guarantee a comparative level with other power generation technologies. It improves reliability and flexibility of system operation, and increases time operation for the facility. Besides, if the secondary energy source is a renewable source, such as biogas, the environmental impact could be further optimized. Future works on hybridization should take into account previous works that are presented in this paper, together with considerations regarding burner definition. Also the use of thermal storage can provide to dish-Stirling technology of competitiveness. The use of stored energy accumulated in the system itself when the energy level exceed the nominal operation value, improves also reliability and flexibility. In this case, a recent patent of one of the company leaders of dish-Stirling technology, Infinia, has been analyzed.

The current review has enabled to identify developments needed for future implementations of dish-Stirling technology. Thus, there are technical challenges to face to assure real feasibility of this promising technology. Further efforts are required to result in profitable and reliable systems that can generate power both for distributed generation and grid-connected applications, guaranteeing a continuous operation based on combination of solar and other renewable sources.

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