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Hybrid high solar share gas turbine systems with innovative gas turbine cycles

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Abstract

In this paper results from an ongoing research project (HYGATE) are presented, which is performed to reduce the levelized cost of electricity (LCOE) and to increase the CO_2 reduction potential of the solar-hybrid gas turbine plant concept (SHGT). Key improvements are the integration of thermal energy storage and the reduction of the operating temperature of the gas turbine to 950°C. As a result the solar receiver can provide the necessary temperature for solar-only operation of the plant at design point - without using the auxiliary burner. Annual performance calculations and an economic analysis of four different plant concepts were performed. Those concepts were analyzed using innovative power block processes. In general, such systems offer reliable and dispatchable power with low specific CO_2 emissions. A substantial decrease of CO_2 emissions has been achieved all along the four variants compared to results of a previous project [1]. Compared to the defined reference molten salt solar tower the solar-hybrid gas turbine plants as of now yield higher plant efficiencies, but have a slightly lower potential for CO_2 reduction. Among the SHGT plants the variants including a bottoming Organic Rankine Cycle (SHORCC and SHORCC-R) achieve the highest efficiencies but have significantly higher LCOE, caused by the high costs of the ORC components which are not yet commercially available in the required dimensions. The solar-hybrid combined cycle plant (SHCC) and solar-hybrid gas turbine plant with quasi isothermal compression and recuperation (SHGT-ICR) perform best among the SHGT plants in terms of LCOE, and can be considered an interesting alternative to molten salt tower plants. Taking into account other factors, such as plant complexity and water consumption, an isothermal solar gas turbine plant shows the most potential advantages. However, the SHCC has the highest technological maturity and is a likely candidate for a future demonstration plant.

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Keywords: solar thermal power plant; solar-hybrid power plant; solar tower plant

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1. Introduction

Nomenclature

DNI	Direct normal irradiance
HRSG	Heat recovery steam generator
HRVG	Heat recovery vapour generator
LCOE	Levelized cost of electricity
SHCC	Solar-hybrid combined cycle
SHGT	Solar-hybrid gas turbine plant
SHGT-ICR	Solar-hybrid gas turbine with quasi isothermal compression and recuperation
SHMST	Solar-hybrid molten salt tower
SHORCC	Solar-hybrid gas turbine with Organic Rankine Cycle
SHORCC-R	Solar-hybrid gas turbine with Organic Rankine Cycle and recuperation
TES	Thermal energy storage

Among all renewable energy technologies, only limited options exist to guarantee supply security, avoiding the need of back-up plants. Hybrid solar power plants can generate base load electricity despite the intermittent nature of solar radiation, by including a back-up burner system to the solar power plant. In the former research project SHCC a concept for a solar-hybrid combined cycle gas turbine system was elaborated [1]. The analysis showed that the concept provides feasible economical results compared to solar benchmark technologies, but with a significantly higher output of greenhouse gases (CO_2) [2]. Therefore, the current research project HYGATE puts the focus on decreasing the CO_2 emissions of solar-hybrid gas turbine systems (SHGT).

Besides including a thermal energy storage system (TES), the operating temperature of the gas turbine is decreased to 950°C, which is a realistic outlet temperature for solar receivers according to former and ongoing research [3], [4]. As a result the solar receiver can provide the necessary temperature for solar-only operation of the plant at design point without using the auxiliary burner. The lower gas turbine operating temperature generally results in lower gas turbine efficiency. However, the considered gas turbine can operate with a significantly lower cooling air mass flow at 950°C, which counteracts these efficiency losses. The lower gas turbine operating temperature also leads to different exhaust gas conditions. Therefore, it is of great interest to investigate which type of bottoming cycle fits best to the modified gas turbine operating conditions, and if the overall goal of reducing the CO_2 emissions can be achieved, while maintaining economic competitiveness with a current solar reference technology.

In this study four different power block concepts of a solar-hybrid gas turbine plant were defined considering the new boundary conditions. The plants were modelled with different sizes of solar fields and different storage capacities. The annual plant performance was analyzed and compared to each other and to a reference molten salt solar tower plant in terms of technical, economic and ecological figures. This study is part of the R&D project HYGATE (Hybrid High Solar Share Gas Turbine Systems), which is funded by the German Ministry for Environment, Nature and Nuclear Safety as well as the Ministry of Economics and Technology. The project consortium is led by MAN Diesel & Turbo with the partners German Aerospace Center (DLR), Technische Universität Dresden and VGB Powertech e.V.

2. System description and methodology

Generally, a hybrid solar tower plant consists of a heliostat field, a solar receiver installed on top of a solar tower, a back-up burner, possibly a TES system, and the power block for heat into electricity conversion. Four concepts of SHGT plants with different power blocks are investigated. Actual weather and solar irrigation data from a site in Northern Africa (Hassi R'Mel, Algeria, 2005) were chosen for the analysis.

All variants are based on a set of common boundary conditions of the solar-hybrid gas turbine system. A basic requirement of the gas turbine is the ability to extract the compressor outlet air for external heating, which is met only by few commercial gas turbines [5]. One of them is MAN's GT THM 1304-12 with 12.1 MW power output at ISO conditions. In this study a fictional upscale version of this gas turbine is used to achieve a gross electricity output of 50 MW for all systems. Parallel or serial arrangement of the solar receiver and the gas turbine combustion chamber are possible. To avoid high entry temperatures into the combustion chamber, a parallel arrangement has been chosen in the HYGATE project.

The solar receiver system consists of a serial combination of a cavity receiver with metal tubes and a cluster of pressurized volumetric receivers. The cavity receiver with metal tubes is used for the lower temperature range, where compressed air is heated to a temperature of 700°C. The cluster of pressurized volumetric receivers is used for the higher temperature range (outlet temperature 950°C). A similar receiver has been tested successfully in Abengoa's Sanlucar Platform at a MW scale [6]. The outlet temperature is held constant by controlling the mass flow through the receiver. This combination is intended to combine the high efficiency and high operation temperatures of pressurized volumetric receivers with the assumed lower cost of the cavity tube receiver [1].

All variants use a dry cooling system suited for arid and semi-arid locations. The TES of the SHGT is a high-temperature regenerator-type TES system. While it is intended to reach a high solar share, current combustion chambers cannot safely be remotely ignited in the running power plant process under the given circumstances of chamber entrance temperature, pressure, flame temperature, and flame stability. Consequently, a maximum turndown rate of 7% of the design point gas turbine air mass flow was defined, resulting in a constant amount of fossil energy supplied to the system, effectively setting an upper boundary for the solar share. This rate was defined at the beginning of the project and is used for this study. Additionally, the turbine inlet temperature was set to 970°C for this study as a compromise to maintain stable combustion in all operating conditions [5]. The additional energy to heat the air mass flow from 950°C after the receiver to 970° is supplied by the fossil combustion, which reduces the maximum solar share. Ongoing work is showing that both issues can be improved.

Parameterization studies have been conducted earlier in the research project to identify optimal design parameters under the given boundary conditions [7]. In this study the analysis was made for three pre-defined combinations of TES capacity and solar field size for each SHGT variant. A plant with a solar field size with Solar Multiple 1 (SM1) has no TES. The solar field provides the exact heat input to operate the plant at design point conditions (minus the share of fuel energy needed to keep the combustion chamber operational). The plants with SM2 / SM3 have a TES capacity sufficient for 8 hours / 14 hours discharge operation, and a solar field twice / three times the solar heat input at design point conditions. In this study, the optimization of the TES size for a given solar field size is not considered. It is important to keep in mind that for each given Solar Multiple, a different TES size may lead to optimal results. Each variant of the SHGT plants is briefly introduced below and shown in Fig. 1. Further specifications as well as a description of the design point conditions are summarized in Appendix A.

2.1. Solar-hybrid combined cycle (SHCC)

Just as conventional combined cycle plants, solar-hybrid combined cycle plants use the exhaust heat from the gas turbine to operate a bottoming steam cycle. Various configurations are possible and have been discussed in previous work [1], [2]. This variant consists of one gas turbine, one dual-pressure heat recovery steam generator (HRSG) and one steam turbine. The gas turbine exhaust temperature is 402°C at design conditions. The steam parameters of the bottoming cycle are 375°C / 38 bar. The process results in a design point gross electric efficiency of 43.7%.

2.2. Solar-hybrid gas turbine with quasi isothermal compression and recuperation (SHGT-ICR)

This variant is based on a compressor with internal downstream cooling of all but the last compressor stage to provide a high efficiency due to low compression temperatures. This compressor concept is adapted from the commercially available MAN isothermal compressors [8]. The cooling medium is water, which is cooled by a dry cooling system. Instead of a bottoming cycle a recuperator is included to use the exhaust heat from the gas turbine, which is at a temperature of 420°C. The compressed air is heated in the recuperator from around 130°C to 400°C. The design point gross electric efficiency of the power block is 45.7%.

2.3. Solar-hybrid gas turbine with Organic Rankine Cycle (SHORCC)

Similar to the solar-hybrid combined cycle variant, a bottoming cycle is included to utilize the gas turbine exhaust heat. However, an Organic Rankine Cycle (ORC) with toluene as working fluid is investigated. The gas turbine exhaust temperature is 425°C. In the single pressure heat recovery vapor generator (HRVG) the working medium is heated to its working conditions of 90 bar and 380°C. This results in a gross power block electric efficiency of 47.5% at design point.

2.4. Solar-hybrid gas turbine with Organic Rankine Cycle and recuperator (SHORCC-R)

This variant also features an ORC process with toluene as working fluid and a single pressure HRVG. However, there is an additional recuperator, and lower ORC process parameters of 60 bar and 340°C. While in the other variants the receiver air inlet temperature is 400°C in design conditions, in this case the temperature is 460°C. The design point gross electric efficiency of the power block is 48.1%.

2.5. Reference plant: Solar-hybrid molten salt tower (SHMST)

A molten salt tower plant was used as a reference for solar-hybrid power plants. The model is based on a state of the art molten salt tower plant scaled to 50 MW_{el}. [1]. The working fluid is a mixture of 60% sodium nitrate and 40% potassium nitrate, which is also used as storage medium in a two-tank storage system. The working range of the salt mixture is from 290°C to 565°C. In the HRSG steam is generated at 126 bar / 552°C. The design point gross electric efficiency of the power block is 42.9%.

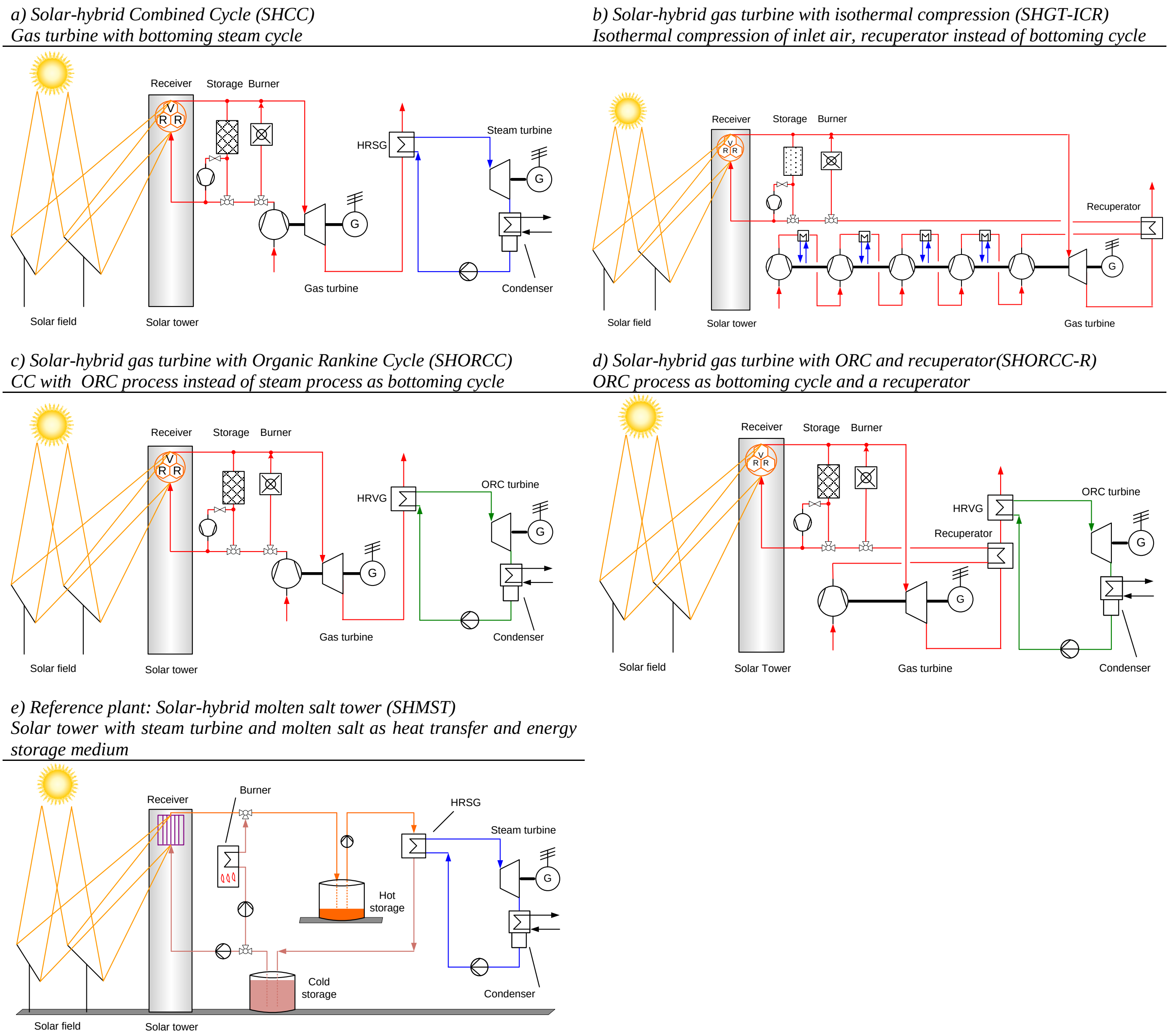

Fig. 1. Overview of solar-hybrid gas turbine processes in this study.

2.6. Methodology

Different software tools were used for the design optimization and annual performance calculation of the SHGT plants. The commercial software Ebsilon Professional was applied for the plant layout and performance simulation. The software HFLCAL [9] was used for the layout of the cost optimized solar fields, solar tower height, receiver aperture areas and positioning. To calculate the annual energy yields an interface in Excel was used, which utilizes the results from the field layout calculation and controls the thermodynamic plant simulation model. For each hour the performance of the plant was calculated based on the hourly values of the solar irradiation (DNI), the actual weather conditions (temperature, pressure, humidity) and the solar position angles according to the geographic location of the site and time [2] (Fig. 2a: Workflow). Two operation strategies were defined, taking into account the several operation states during solar mode, storage charging, storage discharging, hybrid, mixed and fossil mode (Fig. 2b: Overview of operation states). The full-load operation strategy ("0…24") requires the plant to constantly provide maximum power during all hours of the year. The solar-only ("solar only") operation strategy puts the focus on maximal solar energy output. The plant is operational only if solar energy input is provided either from solar irradiation or the storage.

The intent of the economic assessment was primarily to compare the variants within each other. The Levelized Cost of Electricity (LCOE) was calculated for all variants in analogy to the method from the former SHCC project [1]. The LCOE is the price at which the electricity must be sold to break even within the lifetime of the project. It includes the capital cost of the initial investment, lifetime, discount rate, fuel and O&M costs. The approach includes the following simplifications: 40/60%

private/debt finance with equal interest rate, plant operation time equals depreciation period, neglect of taxes and government incentives, neglect of increase in prices and inflation during construction and neglect of increase of prices and inflation of O&M cost. The data used for the cost calculation and the financial boundary conditions can be found in Appendix A.

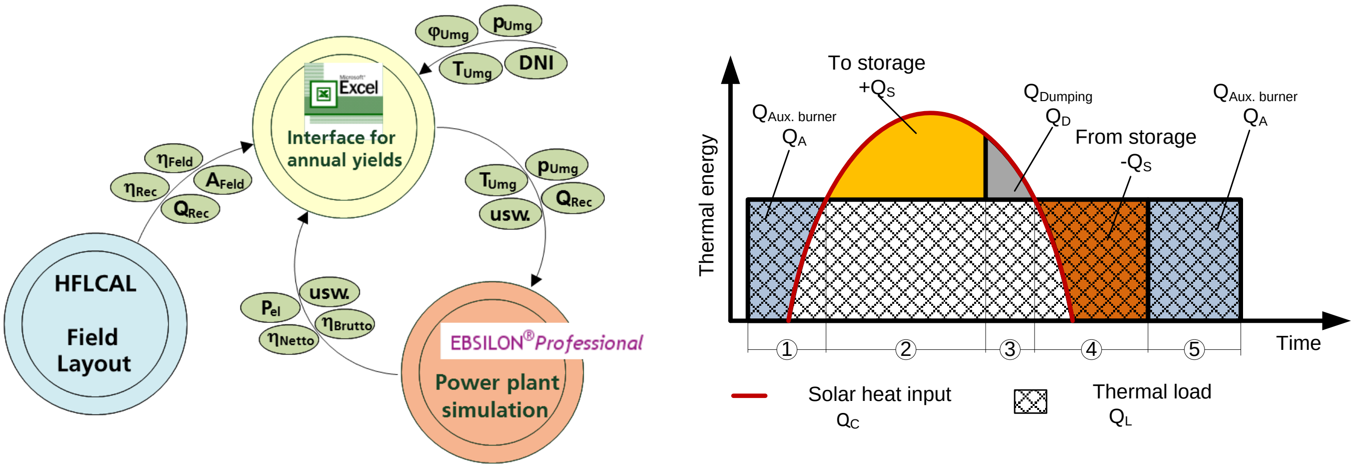

Fig. 2. (a) Workflow and simulation software; (b) Operation states of a SHGT plant during an idealized day.

3. Results

The annual performance calculations show that the power block efficiencies of all SHGT variants are considerably higher than the reference SHMST plant (Fig. 3a). The ORC variants show the highest annual net electrical efficiencies of 46.1% (SHORCC) and 45.3% (SHORCC-R) for SM1 and baseload operation. There is a decline of efficiency from the SM1 variants to SM3, which is mainly caused by the parasitic electric consumption of the fan circulating air from the receiver exit through the storage back to the receiver during storage charging. The total plant efficiency is considerably higher in baseload operation for all SHGT plants and the SHMST plant (Fig. 3b). When in solar operation the input energy in the efficiency equation is the solar energy provided to the heliostat field, which has to be collected, concentrated and converted to heat in the receiver before it is fed into the power block. In fossil operation the input energy is the fossil fuel energy, which can be fed into the power block more directly.

The solar share is defined as the ratio of receiver solar thermal energy input to the total thermal energy input. As seen in Fig. 4a, the results show a strong increase of the solar share across all variants with higher solar multiples, and most of all, the inclusion of storage. The highest annual solar share of the SHGT variants is above 80% for SM3 and solar only operation, and approximately 58% at full load operation. The SHGT-ICR variant shows the best performance among the SHGT variants. However, all SHGT variants achieve a significantly lower solar share than the MST reference plant. As mentioned earlier, this is mainly caused by the need of constant operation of the combustion chamber (7% air mass flow turndown rate) and the increased gas turbine inlet temperature of 970°C, which causes a maximum for the solar share at design point conditions around 85% - 87%. The MST plant achieves 100% solar share at design point conditions.

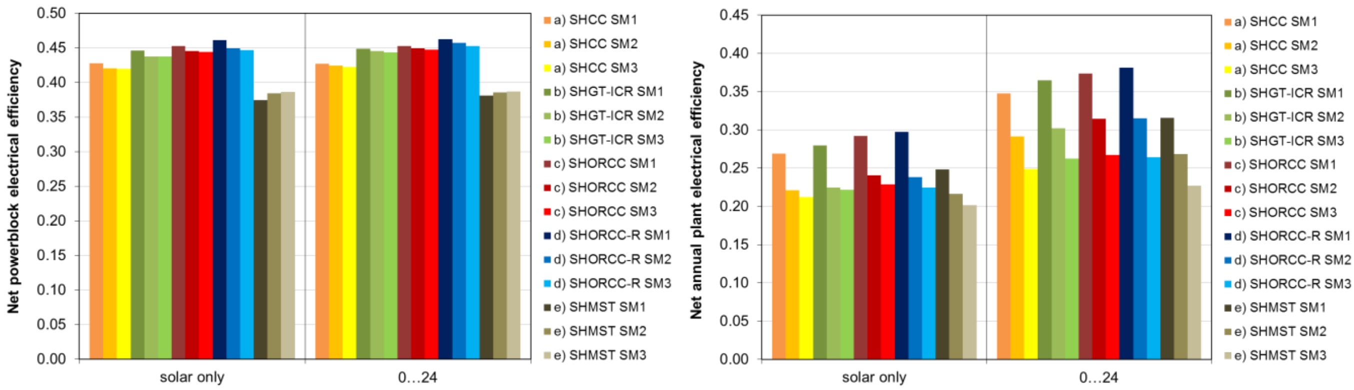

Fig. 3. Annual results of: (a) Net power block electrical efficiency; (b) Net plant electrical efficiency.

The specific CO_2-emission metric in Fig. 4b displays largely the same tendencies and allows to compare the ecological impact with other types of power plants. As a reference, modern combined cycle power plants fired with natural gas achieve annual specific CO_2 emissions of about 0.4 kg CO_2 per kWh. In base-load operation solar-hybrid plants produce only up to 10 % less specific CO_2 emissions per unit of electricity if there is no storage included (SM1). For larger solar field sizes and storage capacities specific CO_2 emissions down to 0.085 kg CO_2 per kWh for the SHGT-ICR can be reached in solar-only operation, while the SHMST have 0.034 kg CO_2 per kWh.

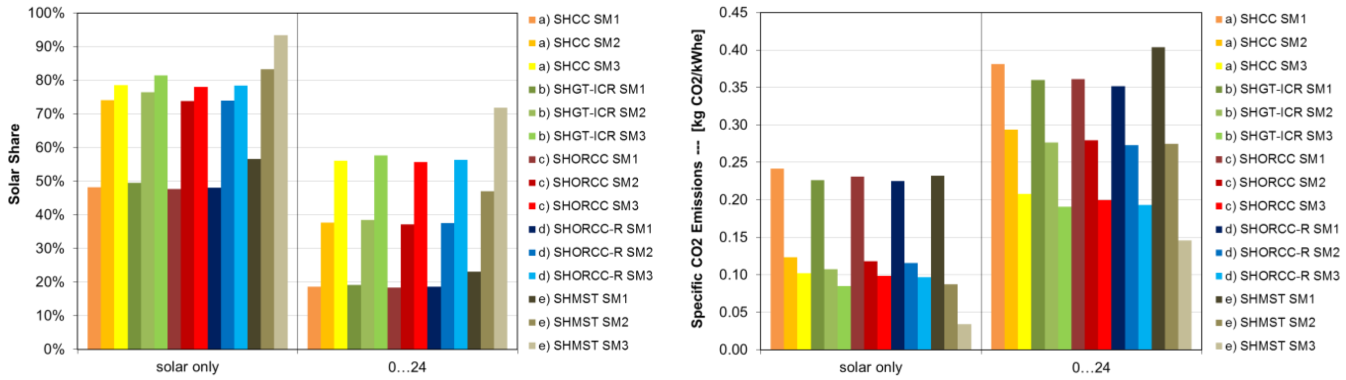

Fig. 4. Annual results of: (a) Solar share; (b) Specific CO_2 emissions.

The LCOE were calculated with common cost assumptions for all variants, as seen in Appendix A. As already stated the main purpose of the cost calculations is to compare the variants with each other. The sensitivity of certain input parameters like the potential variance of component costs of the solar part, the variance in future gas prices, or the cost of yet to be developed components etc, were not considered in this study. The results of the LCOE calculations are shown in Fig. 5, with the SHMST SM3 variant in baseload operation as reference point (100%) for all variants. The lowest LCOE in solar only operation are achieved by the SHGT-ICR and the SHMST variants without storage (SM1, 100% each). In baseload operation the lowest LCOE are achieved by the SHGT-ICR variant without storage (SM1) with 78% of the reference. The SHCC and SHGT-ICR variants show similar performance as the SHMST plant. The ORC variants (SHORCC, SHORCC-R) show considerably higher LCOE due to high specific costs of the ORC components. ORC cycles with an electrical power output in the range of 15 MW are not yet commercially available, therefore the higher specific costs of smaller units had to be assumed in the calculations, further increasing their specific investment costs. A sensitivity analysis has shown that the ORC variants could be brought on a level with the other SHGT variants if the specific ORC power block investments costs were lowered by roughly one third.

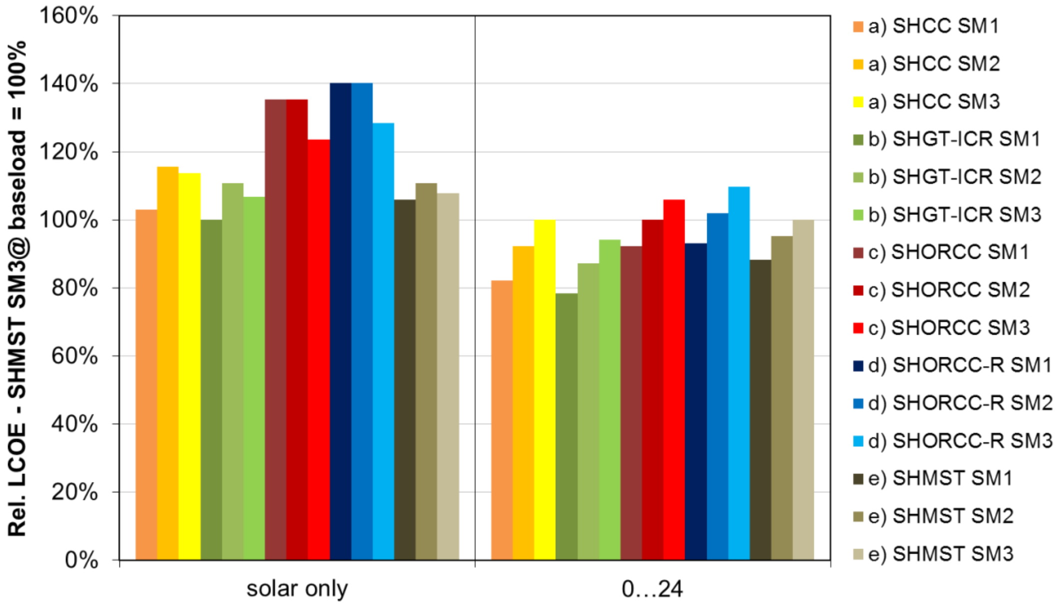

Fig. 5. Relative Levelized Cost of Electricity (LCOE), 100% = SHMST SM3 @ baseload operation.

In Fig. 6 the relation between specific CO_2 emissions and the cost of electricity generation is displayed for baseload operation. Generally higher solar multiples, and thus lower, CO_2 emissions lead to increased LCOEs for all variants. While the SHGT-ICR variant achieves the lowest LCOE of the SM3 variants, significantly less CO_2 emissions are generated by a comparable MST plant at the cost of 5% higher LCOE.

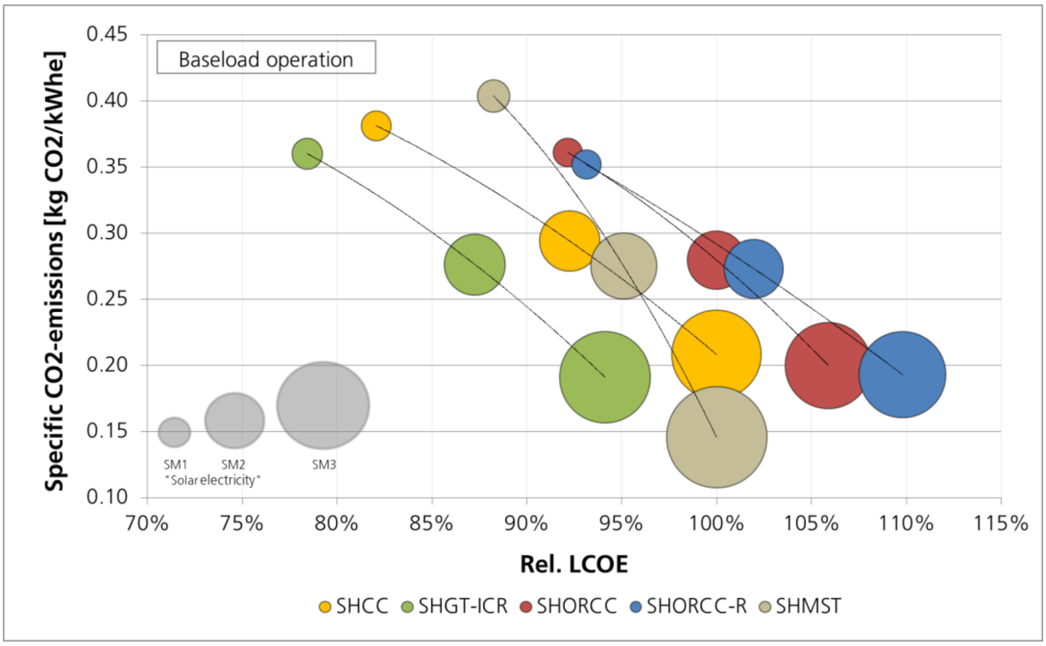

Fig. 6. Relation between specific CO_2 emissions and the cost of electricity generation. The circle area is proportional to the annual “solar electricity” (solar share per total electricity output). 100% LCOE equals MST SM3 variant in baseload operation.

An expert rating was performed using the quality function deployment method (QFD), in order to include other influences in the analysis, such as the overall plant complexity, the technological maturity and the water consumption. The results of the individual assessment and the total result is shown in Fig. 7. The SHGT-ICR plant achieves the highest total rating, but the gas turbine requires a high amount of development to reach commercial availability. The SHCC process is the closest to being available, and achieves the second best rating considering all factors.

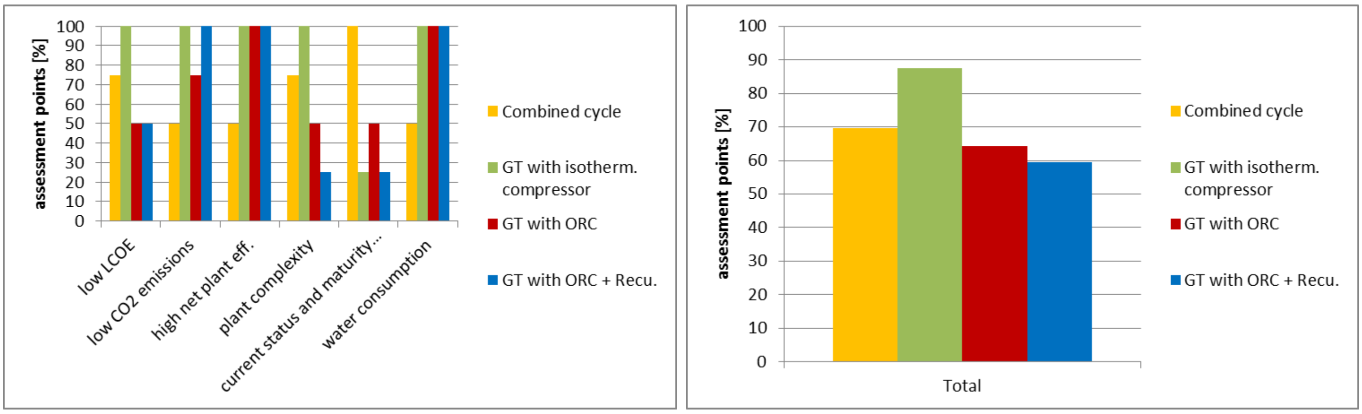

Fig. 7. (a) Individual assessment of criteria; (b) Total result of the expert rating.

4. Conclusions

Four types of innovative solar-hybrid gas turbine plants were analyzed in terms of annual performance and electricity generation costs. They were compared to a more established technology which can fulfill a similar role in the power market, the molten salt tower plant. Various configurations of solar multiple, thermal energy storage size and operational strategy were investigated, in order to gain a broad understanding of each technologies performance characteristics.

Given that a main intent of building solar power plants is to reduce greenhouse gas emissions (“CO_2 emissions”), the need for an inclusion of storage in SHGT plants is pointed out by the results, otherwise there is only a marginal emission reduction potential compared to modern highly efficient combined cycle power plant. High Solar Multiples are recommended as well, as they greatly increase the emission reduction potential. The reference technology molten salt tower performs better than the SHGT variants in terms of CO_2-emission reduction, as long as a significant storage capacity is included. Even though all of the SHGT variants operate at a significantly higher annual net electric efficiency than the SHMST plant, the solar share and CO_2-reduction potential of SHGT plants is limited by its inability to completely shut down the combustion chamber during solar operation. However, current work indicates that in the near future the maximum turndown rate of the combustion chamber can be reduced to a lower value than in this study, or even completely put down to zero, which could provide a significant decrease of CO_2 emissions.

Among the SHGT plants the variants including an Organic Rankine Cycle (ORC) achieve the highest efficiencies but also significantly higher LCOE, which is caused by the high cost of the ORC components which are not commercially available in the needed power range. The SHCC and SHGT-ICR perform best among the SHGT plants in term of cost, and can be considered an interesting alternative to molten salt tower plants. Taking into account other factors, such as plant complexity and water consumption, an isothermal solar gas turbine plant shows the most potential advantages. Nevertheless, a combined cycle solar-hybrid power plant is the most advanced option considering the technological maturity. It also offers an interesting overall performance rating, and is a likely candidate for a future demonstration plant.

Appendix A. Design point specifications and results

Table 1. Design point specifications and results

Site Specification																	
	Site	[-]	Hassi R'Mel, Algeria														
	Latitude / Longitude / Altitude	[°N] / [°S] / [m]	32.9 / 3.2 / 746														
	Ambient Temperature (mean)	[°C]	19.2														
	Annual Solar Resource (DNI)	[kWh/m²a]	2,258														
Design Point Definition																	
	Design point definition	[-]	21.03. , solar noon, 921 W/m²														
	Design point conditions	[-]	25°C, 60% r.h., 1013 mbar														
Design Point System Layout			**SHCC**			**SHGT-ICR**			**SHORCC**			**SHORCC-R**			**SHMST**		
			SM1	**SM2**	**SM3**	**SM1**	**SM2**	**SM3**	**SM1**	**SM2**	**SM3**	**SM1**	**SM2**	**SM3**	**SM1**	**SM2**	**SM3**
	Net Power (Plant@DP)	[MWe]	48.8	47.1	45.3	48.1	46.4	44.6	47.4	45.8	44.2	47.8	45.0	42.3	45.7	44.5	43.4
	Gross Power (Plant @DP)	[MWe]	50.00	50.00	50.00	50.0	50.0	50.00	50.0	50.0	50.00	50.0	50.0	50.00	50.0	50.0	50.00
	Net Power Plant Efficiency (@DP)	[%]															
	Net Power Block Efficiency (@DP)	[%]	42.7%	41.2%	39.6%	44.0%	42.4%	40.8%	45.1%	43.5%	42.0%	46.0%	43.3%	40.6%	39.2%	38.2%	37.2%
	Solar Receiver/ Solar field Design Power	[MWth]	98.1	196.2	294.3	95.2	190.3	285.5	89.5	179.1	268.6	89.0	178.1	267.1	116.0	231.9	347.8
	Tower Height	[m]	152.50	215	263.1	154	205.7	259.2	160.8	212.5	246.2	163.2	215	256.3	155	208.2	222.4
	Total Solar Field Reflective Area	[m²]	195052	392645	589996	187308	381634	562045	171094	346544	530101	170489	352957	540991	202312	412005	643478
	Total Plant Ground Area	[km²]	0.780	1.571	2.360	0.749	1.527	2.248	0.684	1.386	2.120	0.682	1.412	2.164	0.809	1.648	2.574
	Thermal Storage Capacity	[MWh]	0	785	1374	0	765	1339	0	716	1254	0	712	1247	0	933	1632
	Solar Field Energy Input	[GWh/a]	440.5	886.7	1332.3	423.0	861.8	1269.2	386.4	782.6	1197.1	385.0	797.0	1221.6	456.9	930.5	1453.3
Annual Yields																	
solar only	Net Electric Energy	[GWhe/a]	175.6	227.3	316.9	173.1	220.3	310.5	170.5	219.4	308.4	172.1	219.9	307.4	159.5	222.4	302.8
0…24	Net Electric Energy	[GWhe/a]	454.8	451.2	447.7	448.8	446.6	444.1	442.9	439.5	436.1	446.7	440.6	433.1	397.0	395.6	394.5
solar only	Fuel Energy	[GWht/a]	212.3	140.2	161.7	196.0	118.4	131.9	197.2	129.3	152.3	193.5	127.4	148.6	184.9	97.1	51.4
0…24	Fuel Energy	[GWht/a]	866.9	663.3	465.9	808.1	617.1	424.2	799.6	614.3	436.1	786.0	601.6	418.0	801.5	544.2	287.4
solar only	Annual net efficiency powerblock	[%]	42.8%	42.1%	42.0%	44.6%	43.8%	43.7%	45.3%	44.5%	44.4%	46.1%	45.0%	44.7%	37.5%	38.4%	38.6%
0…24	Annual net efficiency powerblock	[%]	42.7%	42.4%	42.3%	44.9%	44.6%	44.3%	45.2%	44.9%	44.7%	46.3%	45.7%	45.2%	38.1%	38.5%	38.7%
solar only	Solar Share	[%]	48.3%	74.0%	78.6%	49.5%	76.5%	81.5%	47.7%	73.8%	78.1%	48.1%	74.0%	78.4%	56.5%	83.2%	93.5%
0…24	Solar Share	[%]	18.6%	37.6%	56.0%	19.2%	38.4%	57.7%	18.3%	37.2%	55.6%	18.6%	37.6%	56.4%	23.1%	47.0%	71.8%
solar only	Operating Hours	[h]	3489	4585	6354	3489	4505	6288	3484	4550	6351	3488	4580	6408	3640	5036	6788
0…24	Operating Hours	[h]	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760
solar only	Specific CO2 Emissions	[kg CO2/kWhe]	0.242	0.123	0.102	0.226	0.107	0.085	0.231	0.118	0.099	0.225	0.116	0.097	0.232	0.087	0.034
0…24	Specific CO2 Emissions	[kg CO2/kWhe]	0.381	0.294	0.208	0.360	0.276	0.191	0.361	0.280	0.200	0.352	0.273	0.193	0.404	0.275	0.146
solar only	Annual net efficiency plant	[%]	26.9%	22.1%	21.2%	28.0%	22.5%	22.2%	29.2%	24.1%	22.9%	29.8%	23.8%	22.4%	24.8%	21.6%	20.1%
0…24	Annual net efficiency plant	[%]	34.8%	29.1%	24.9%	36.5%	30.2%	26.2%	37.3%	31.5%	26.7%	38.2%	31.5%	26.4%	31.5%	26.8%	22.7%
Investment cost input																	
	Spec. Installed Heliostat Cost	[€/m²]	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
	Spec. Cost Cavity Tube Receiver	[T€/MWt]	150	150	150	150	150	150	150	150	150	150	150	150	115	115	115
	Spec. Cost Volumetric Receiver	[T€/MWt]	175	175	175	175	175	175	175	175	175	175	175	175			
	Spec. Cost Thermal Storage	[T€/MWh]	40	40	40	40	40	40	40	40	40	40	40	40	35	35	35
	Spec. Cost Power Block	[T€/MWe]	706	732	760	713	740	769	1695	1754	1818	1866	1981	2111	744	764	784
	Spec. Cost Fuel (natural gas)	[€/MWhth]	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Project Lifetime	[a]	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Interest Rate	[-]	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Levelized Cost of Electricity																	
solar only	**Rel. LCOE**	[%]	**95.5%**	**107.3%**	**105.5%**	**92.7%**	**102.7%**	**99.1%**	**125.5%**	**125.5%**	**114.5%**	**130.0%**	**130.0%**	**119.1%**	**98.2%**	**102.7%**	**100.0%**
0…24	**Rel. LCOE**	[%]	**76.1%**	**85.5%**	**92.7%**	**72.7%**	**80.9%**	**87.3%**	**85.5%**	**92.7%**	**98.2%**	**86.4%**	**94.5%**	**101.8%**	**81.8%**	**88.2%**	**92.7%**

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