

Integrated Solar Gas Turbine Cogeneration Power Plant

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Abstract

Concentrating solar power technologies and desalination plants in the Mediterranean area are one promising option. They deliver two key products for economic development, which is power and water, both at a reasonable and also sustainable cost. From this standpoint the present study was under taken to include proposed design of Integrated Solar Gas turbine Cogeneration power Plant (ISGCP). The ISGCP is specified for electrical power generation and seawater desalination by using Thermo-Compressor Multi Effect Distillation unit (TC-MED). To establish the ranges for which solar energy for power generation and seawater desalination would competitive to fossil energy and investigate the potential effect of the proposed design of ISGCP mathematical model has been developed and implemented on simulation program. The economical effectiveness in optimizing model was characterized by the condition of attaining maximum fuel saving in the EPG. The study result shows for the case study (ISGCP with annual shear of solar distilled water production 18.4%) the annual specific rate of fossil fuel saving in EPG due to solar thermal power contribution amount 281.5 ton.fuel/MW.year and the corresponding decrease in exhaust gases emission (nitrogen oxides (NO_x) 358.7 kg/MW.year, carbon dioxides (CO₂) 856.9 ton/MW.year). Furthermore implementation of ISGCP design for modification of grid connected gas turbine cogeneration plant integrated with six effects TC-MED unit will increase the annual distilled water production by 6631 ton/year.MW besides boosting 1421.6 MW.hr/year.MW of surplus high voltage electricity in EPG. Finally the ISGCP design is promising technology for climate compatible power with such enormous potential that TC-MED unit would allow 24 hr economical dispatch of distilled water with reliable, high maneuver of electrical power, specifically for daytime-demand peaks.

Keywords: Concentrating Solar Power; Multi Effect Distillation; Parabolic Solar Collector; Thermo-Compressor.

Introduction

The Middle East and North Africa (MENA) region has the poorest water resources in the world. In the future, the water situation is expected to worsen in

the region due to rapid growth of population, urbanization and industrial development. With a population expected to be doubling until 2050, the MENA region would be facing a serious water crisis, if it would remain relying only on the available natural renewable freshwater resources. Since all of the natural supplies of potable water are fully exploited in this region, desalination of sea and brackish water has been used to supply the major portion of potable water in some countries or to augment it in others. Therefore, more than fifty percent of the total desalinated water is produced in the MENA region [1]. Currently cogeneration plants are one of the most commercial technologies for the water and electrical power generation [2,3]. The main advantages of such plants are energy savings and reduced operational costs. But unfortunately the majority of the energy currently used for cogeneration plants is obtained from oil or natural gas [1,3]. These fossil fuels are rapidly being depleted because of their finite supply, but also their prices have fluctuated widely over the last two years. Furthermore, large scale seawater desalination plants have the potential to add significantly to the greenhouse gas emissions held largely responsible for climate change.

Recent advances in research of low temperature processes have resulted in an increase of the desalting capacity and a reduction in the energy consumption of Multi Effect Distillation (MED) plants [4], providing long-term operation under remarkable steady conditions. However, the Thermo-Compressor MED (TC-MED) plants have recently acquired a potential interest [1,3]. There is considerable interest presently in the possibility of constructing grid connected Gas Turbine Cogeneration Plants (GTCP) where a power generation cycle provides waste heat to TC-MED unit and surplus power to the Electrical Power Grid (EPG) Therefore, a more sustainable operation of developed cogeneration plants or existing GTCP must be oriented to the improvement of the plant economical effectiveness and minimization of environmental impact.

Among the energy sources suitable to drive cogeneration plants, solar energy is one of the most promising options [5,6], due to the coupling of the disperse nature and availability of solar radiation with water demand supply requirements in many world locations and especially in the MENA region. Solar power generation and desalination are an inexhaustible energy system and they considerably reduce greenhouse gas emissions and local pollution. The results of recent studies [5,7] in the field of solar power generation shows that Parabolic Solar Collectors Arrays (PSCA) for solar thermal power generation will play an important role in a well balanced mix of traditional and renewable energy sources, efficient power technologies and rational use of energy. From this standpoint Integrated Solar Gas turbine Cogeneration Plants (ISGCP) in the MENA region are one of the promising options. They deliver two key products for economic development, which is power and water, both at a reasonable and also sustainable cost. To establish the ranges for which solar energy for power generation and seawater desalination would compete to fossil energy model of ISGCP was proposed. The ISGCP is specified for hybrid solar / fossil fuel electrical power generation and seawater desalination by using TC-MED unit.

Basic Design of Gas Turbine

Cogeneration Plant (GTCP):

The main components of the GTCP are the Gas Turbine Unit (GTU), a single pressure Waste Heat Boiler (WHB) and a TC-MED. A process flow diagram for a GTCP is shown in figure 1. The GTU consists of an Air Compressor (AC), Combustion Chamber (CC), Gas

Turbine (GT), and electrical Generator (G). The GTU exhaust heat is recovered in a WHB, raising superheated motive steam for the plant (i.e. steam needs to work the Thermo-Compressor (TC) and the thermal Deaerator (D)). Additional steam can be raised by adding Supplementary Firing (SF) to the system, burning more fossil fuel in the turbine exhaust before the gas enters the WHB. The WHB (figure 1) is composed of three separate heat exchangers: a superheater, an evaporator, and an economizer. Also in order to improve the efficiency of the WHB and reduce the amount of deaeration steam, the returned condensate preheater is included in the WHB.

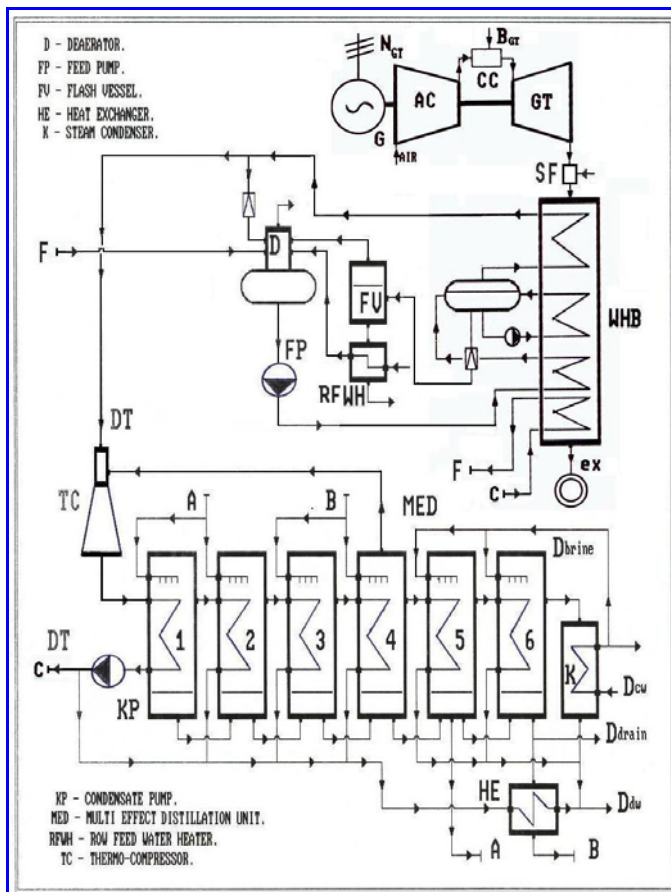


Figure 1: Schematic diagram of the basic design for GTCP integrated with TC-MED unit.

The six effects MED unit (figure 1) comprises a train of evaporative-condensers with a heat rejection condenser (K) at the end. The vapor from the last evaporator (effect) is condensed by seawater coolant in the heat rejection condenser. By leaving the condenser, a part of this seawater is rejected. The

remainder share used as raw water (brine) and sprayed over the heating tube bundles of the fifth and sixth effects, after a simple injection of anti-scaling agent. Part of this raw water becomes the feed brine for the first four-evaporator effects. The brine is thus cascaded and flash-cooled in effects.

Part of the vapor produced in the fourth effect of distillation unit is drawn up by the TC, which compresses it with motive steam from WHB to feed the first effect. The condensate from the first effect is collected, and part of this distillate is returned to the deaerator (D) after preheating in the WHB, the excess above the original quantity of motive steam flows together with condensate from the second, third, and fourth effects into the Heat Exchanger (HE). Hereafter the subcooled condensate from the HE, mixed with remainder condensate of the unit formalizes the distilled water productivity (DDW) of the plant.

Integrated Solar Gas Turbine

Cogeneration Plant (ISGCP)

Overview:

The primary focus of this study was directed toward determining the technical viability and effectiveness of a modern approach to grid connected ISGCP. This approach includes the combining of the following technologies: grid connected gas turbine cogeneration system, modified TC-MED unit for seawater desalination, PSCA for solar thermal power generation, and backpressure Steam Turbine (ST)/Generator (G) to cogenerate steam for MED unit and electricity for EPG. A process flow diagram for an ISGCP is shown in figure 2. The PSCA consists of a large field of single-axis tracking solar collectors. The solar field is composed of many parallel rows of solar collectors aligned on a north-south horizontal axis. The collectors track the sun from east to west during the day to ensure that the sun is continuously focused on the linear receiver. Solar steam with dryness fraction less than 0.75 is generated directly as the feed water circulates through the receiver and returns to the flash Steam Separator Vessel (SSV) in the power block. Fossil steam from WHB is then piped to the powerhouse and mixed with solar steam where it is used to drive the ST to produce high voltage electricity (option a). While in case of option b, solar steam is then fed to a high pressure cylinder of ST. After the share of useful steam energy has been spent in the ST, the exhaust steam following through the Moisture Separator (MS). At the MS outlet the solar steam is mixed (at the TC inlet design pressure of motive steam 5 bar) with the fossil steam fraction coming from the WHB and then routed to the low pressure cylinder of ST. After the majority of useful steam energy has been spent in the ST (option a) or high- and low-pressure cylinders of ST (option b), the exhaust steam (at the TC outlet design pressure of steam 0.32 bar) is routed to the first effect of TC-MED. At this operation mode of plant (Integrated solar mode of operation) all vapor produced in the fourth effect will be fed to the fifth effect. Therefore at Integrated solar mode of operation the distillation unit designed to produce additional quantity of distilled water.

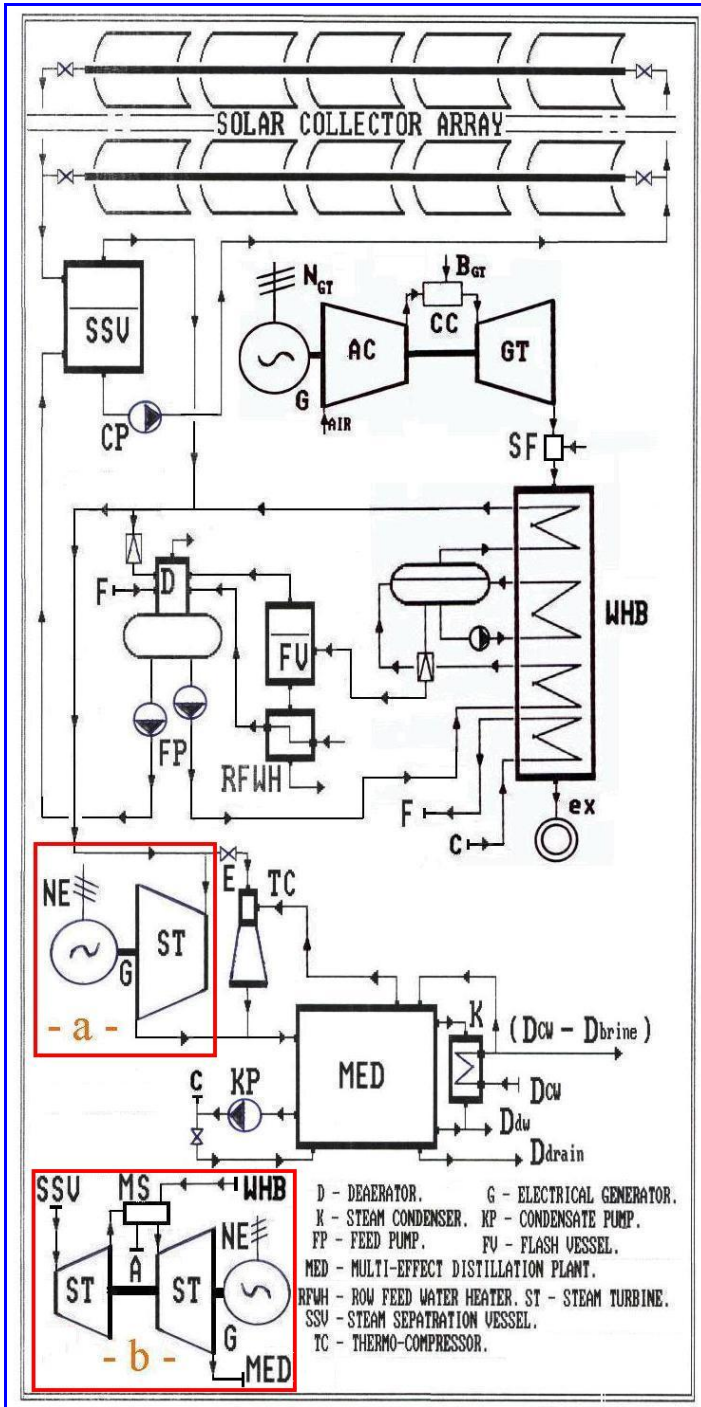


Figure 2: Schematic diagram of ISGCP.

It is important here to note that for the proposed model of ISGCP the PSCA and WHR will provide the rate of heat consumption for cogeneration plant. Thereupon the boundary conditions for increasing the solar field are the design characteristics and performance of ST, and the rate of heat consumption for the first effect of TC-MED unit.

Operation Strategy of ISGCP:

The initially proposed operation strategy of ISGCP is very simple: the plant operates during sunny periods at integrated solar mode of operation with an increasing in distilled water production and feeding the surplus high voltage electricity into EPG. Whereas, solar and fossil steam generation in ISGCP is delivered to backpressure steam turbine for electrical power generation and utilizing the exhaust steam in the first effect of TC-MED. While during cloudy periods and at night the ISGCP operates as a conventional GTCP integrated with EPG (i.e. gas turbine power generation cycle provides waste heat to TC-MED and electrical power to EPG).

It is also interesting to note that the ISGCP has generated much interest because it offers an innovative way to reduce fossil fuel consumption and improve the maneuver characteristic of cogeneration plant integrated with EPG and provides operational advantages over conventional single purpose desalination plants. The modular arrangement of ISGCP also facilitates power generation dispatching because the plant can be operated independently (with or without the solar field) if part of the solar field is down for maintenance or if at night less than the GTCP total capacity is required. This may give a higher efficiency for small loading than if the total capacity was operated.

Investigation Method and

Computational Model of ISGCP:

The primary objective of the present study was to identify and investigate the effectiveness and thermodynamic performance of the proposed model for ISGCP. Evidently ISGCP analysis and design is a complex procedure requiring comparatively elaborate calculations and it is virtually impossible to perform even the simplest design-point optimization without the help of a plant analysis computer code. Also the code enables off-design and part-load performance predictions. It was, therefore, necessary to develop detailed computational models for key components in the plant, which could be used to predict the performance of those components under different boundary conditions in a realistic way. To satisfy this objective, the program is divided into two major sections (design point and off design) to allow the rapid analysis of ISGCP and to perform the required investigations. The developed computational model of ISGCP provides the opportunity to do a detailed analysis of the effects of the design characteristics for the PSCA and TC-MED, the live steam pressure at the inlet of the ST, the annual share of solar thermal power on the thermal effectiveness of ISGCP. The thermal effectiveness in the optimizing model was characterized by the condition of attaining a maximum fuel saving in the EPG and may be carried out by using the following criterion:

$$\Delta BST = \frac{(QSB)_O}{Q_{cv} * (ESB)_O} * \frac{(DDW)_N}{(DDW)_O} + \frac{3600 * (NST + NGT)}{Q_{cv} * EST} - BGT - BSF \Rightarrow \max \quad (1)$$

where:

$(QSB)_O$ – the output thermal energy of steam boiler in conventional design of TC-MED plant (MJ/hr).

$(DDW)_O$, $(DDW)_N$ – the distilled water production in conventional design of TC-MED plant and proposed design of ISGCP (ton/hr).

$(ESB)_O$ – the efficiency of steam boiler in conventional design of TC-MED plant.

NST, NGT – the electrical power generation of the ST and GTU in proposed design of ISGCP (MW).

EST – the efficiency of the power generation in EPG.

BGT, BSF – the rate of fossil fuel consumption for GTU and SF in proposed design of ISGCP (ton/hr).

Q_{cv} – the heat value of fossil fuel (kJ/kg).

In addition to direct fossil fuel savings, ISGCP yields significant environmental benefits through using traditional and renewable energy sources more efficiently. In particular, it is a highly effective means of reducing carbon dioxide (CO₂) and Oxides of nitrogen (NO_x) emissions. To calculate NO_x and CO₂ savings it is necessary to look at what is being displaced. Thereby, the principle applied in present study, it is assumed that ISGCP displaces electricity from a mix of fuels and thermal power from a conventional low pressure steam boiler with a mixed type of fuels

Finally the equations applied in the computational model of ISGCP are described in the following standard methods:

- * Clear sky method for estimation the solar radiation [8].
- * The solution method of thermal design for PSCA [9, 10].
- * Off-Design performance evaluation of single pressure combined cycle power plants [11].
- * The solution method of thermal design for WHB [12].
- * The solution method of thermal design and off- design performance for high temperature gas turbine units [13].
- * The solution method of thermal design for thermo-compressors [14].
- * The solution method of thermal design for multi-effects distillation plants [15].

It is important here to notes that, the meteorological data introduced in the computational model is for the 32.78 deg. Also to make the results of the study as realistic as possible the GTU was selected from units available on the

markets (H-25 [16]) and choosing appropriate parameters for motive steam of TC-MED [3].

Analysis and Results

The effectiveness of the proposed design for ISGCP is a strong function of the design thermal power of PSCA as well as the design characteristics and operation mode of cogeneration plant. As shown in figure 3 the rate of fossil fuel saving DBST2 in EPG increased with the Local Apparent Time (LAT < 12 hr) at the plant site and reaches its maximum value at the solar noon (LAT=12 hr). As a result of the rising in the solar radiation intensity on a surface of, and the efficiency increasing (ESCA) for, the PSCA. Consequently there is an increase in the output (QSCA, figure 4) of the PSCA.

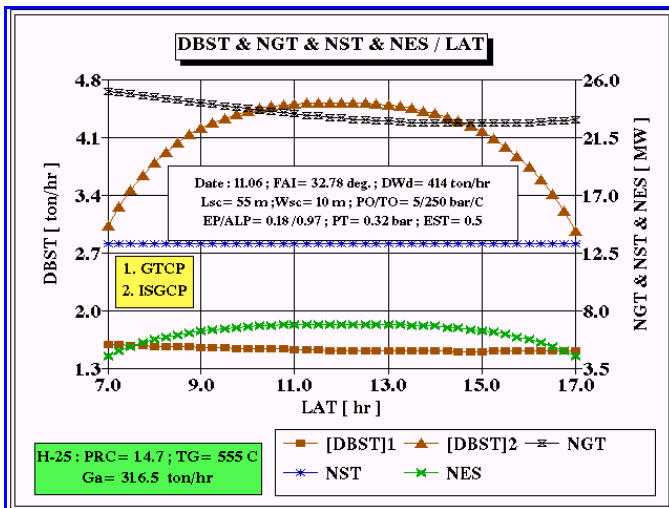


Figure 3: Variation of the rate of fossil fuel saving (DBST), gas turbine unit output power (NGT), steam turbine output power (NST), and solar electrical power generation (NES) with Local Apparent Time (LAT) at the plant site.

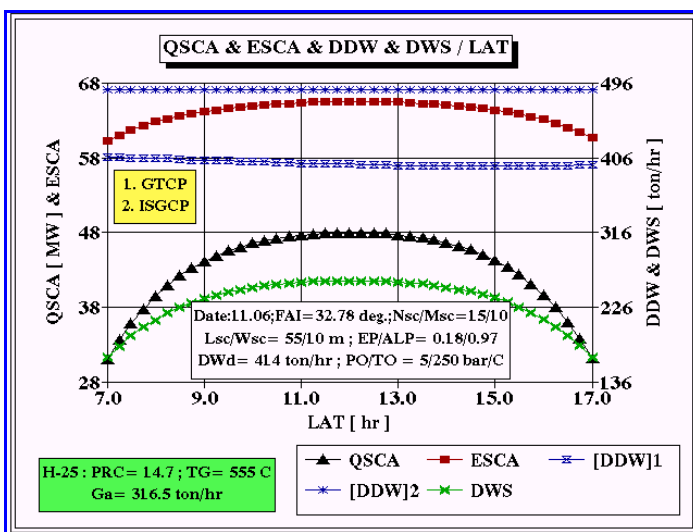


Figure 4: Variation of the output (QSCA) of, efficiency (ESCA), for the PSCA, the plant distilled water production (DDW), and solar distilled water production (DWS) with Local Apparent Time (LAT) at plant site.

Therefore as displayed in figure 3 the solar electrical power generation (NES) and solar distilled water production (DWS, figure 4) of the plant will be increased, besides the slight drops in ST electrical power (NST) due to an increase in the rate of solar steam generation and consequently a decrease in live steam temperature at the inlet of ST. Hereafter the rate of fossil fuel saving in EPG decreased with the LAT increasing (LAT > 12 hr). Because of the solar radiation intensity on the surface of the PSCA decrease with corresponding drop in the efficiency (ESCA, figure 4). Hence as illustrated in figure 3 the solar electrical power generation (NES) and solar distilled water production (DWS) of the plant will be decreased.

Figure 3 also displayed the variation of the rate of fossil fuel saving DBST1 in EPG for GTCP with LAT. The minimum value of DBST1 was coincident with the maximum ambient air temperature at the plant site as a consequence of maximum drops in the GTU power generation (NGT) and TC-MED distilled water production ((DDW)1, figure 4) due to the GTCP off-design performance.

The effect of solar radiation intensity on the efficiency (ESCA) of PSCA is plotted in figure 4 versus the LAT at the plant site. The efficiency of the PSCA increase in the forenoon (LAT < 12 hr) and decrease in the afternoon (LAT > 12 hr) periods of operation. The efficiency (ESCA) rises due to the increasing in absorbed solar radiation by the outside surface of the absorber tubes in the PSCA. Consequently the output (QSCA) of the PSCA, Which increases at a greater rate than the heat losses from the absorber tubes due to the increase in the heat transfer coefficient of the two-phase flow inside the absorber tubes and in the ambient air temperature. While opposing effects of solar radiation intensity decreases, the efficiency of PSCA in the afternoon period decreases, too.

It is also interesting to note that the efficiency (ESCA) of, and output (QSCA) for, the PSCA are strong functions of a climate type, and ambient air temperature at the plant site. In addition, the rate of fossil fuel saving of, the solar power generation and distilled water production for, the ISGCP are strong functions of the thermal input from the PSCA. Thus, the effectiveness of the proposed design of ISGCP was best determined by calculating the outputs of PSCA, GTU and ST power generation, distilled water production of MED unit, and SF fossil fuel consumption on a short interval basis (15 min), and summing the results over the course of a year. Figure 5 is a typical example of the annual specific rate of fossil fuel saving (DBY) and due to solar thermal power contribution (DBSY), solar electrical power generation (NESY), and the solar distilled water production (DWSY) for the proposed design of ISGCP. For the case study (*ISGCP with design thermal power consumption of TC-MED (QT=39.4 MW) and annual shear of distilled water production 17.4 %*) the annual specific rate of fossil fuel saving in EPG due to solar thermal power contribution amount 193 ton.fuel/year for each MW design thermal energy of TC-MED. The corresponding decrease in exhaust gases emission (nitrogen oxides (NOx) 254.9 kg/MW.year, carbon dioxides (CO2) 587.5 ton/MW.year).

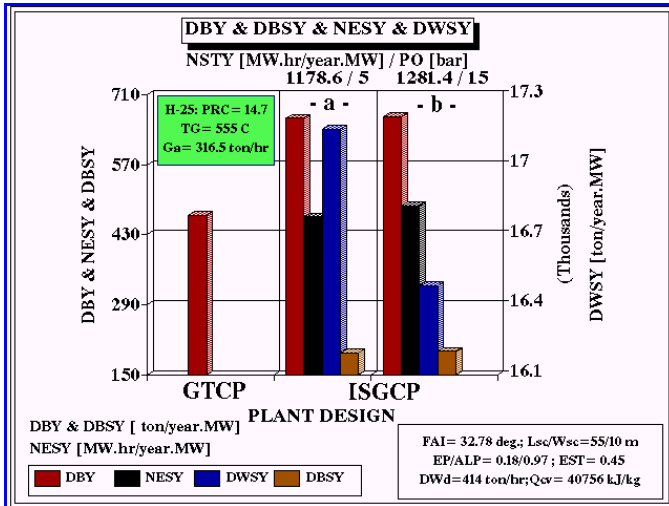


Figure 5: The annual specific, fossil fuel saving (DBY) and fossil fuel saving due to solar thermal power contribution (DBSY), solar power generation (NESY), and solar distilled water production (DWSY).

Figure 5 also illustrates there is 41.2 % increase in the DBY for ISGCP design in comparison with GTCP design as a result of two reasons. First the increase in plant electrical power generation (NSTY) and distilled water production. Second, the plant solar electrical power generation (NESY) and distilled water production (DWSY), caused by significant contribution of the PSCA solar thermal power output. Two options of steam cycle configurations are applied for the ISGCP. As can be seen from figure 5, compared to option 'a', option 'b' offers the possibility to have a higher annual specific rate of fossil fuel saving for a given size of the PSCA and the difference in DBSY is about 1.4 %. There is a rather moderate increase in power output (NSTY) of ST when applying option 'b', caused by a higher specific work done of ST. There is also a significant difference in solar power generation (NESY) between the two options, which is about 4.9 %. As a consequence of this option 'a' give a higher DWSY than the option 'b'.

The effect of live steam pressure (PO) at the inlet of ST on the thermal effectiveness of option 'b' for ISGCP is plotted in figure 6. The DBSY in EPG continuously increases with the rise of PO at the inlet of backpressure ST. As a result of the increase in ISGCP solar electrical power generation (NESY) caused by a higher specific work done and efficiency of steam turbine as a live steam pressure rises with constant augmentation in distilled water production (DDWY) of the plant. However, the higher PO, the lower thermal power output of PSCA. This is a normal behavior for PSCA, because higher PO rise the saturation temperature of two-phase flow in the absorber tubes of, and subsequently the heat losses from, PSCA. It is also interesting to note that, where the live steam pressure is high (PO = 35 bar), the maximum possible size of PSCA (from the technical boundary conditions given in section 3) can oversize due to the increase in the rate of heat consumption for ISGCP. Thereby as shown in figure 6 a significant rise in the annual specific rate of fossil fuel saving in EPG due to solar thermal power contribution. As a result, the higher increase in the thermal power output of PSCA is followed by an increase in the solar power generation (NESY) and solar distilled water

production (DWSY) of ISGCP. For the case study (ISGCP with annual shear of distilled water production 18.4% and power generation efficiency (EST= 0.4) in EPG) the annual specific rate of fossil fuel saving in EPG due to solar thermal power contribution amount 281.5 ton.fuel/MW.year and the corresponding decrease in exhaust gases emission (nitrogen oxides (NOx) 358.7 kg/MW.year, carbon dioxides (CO2) 856.9 ton/MW.year).

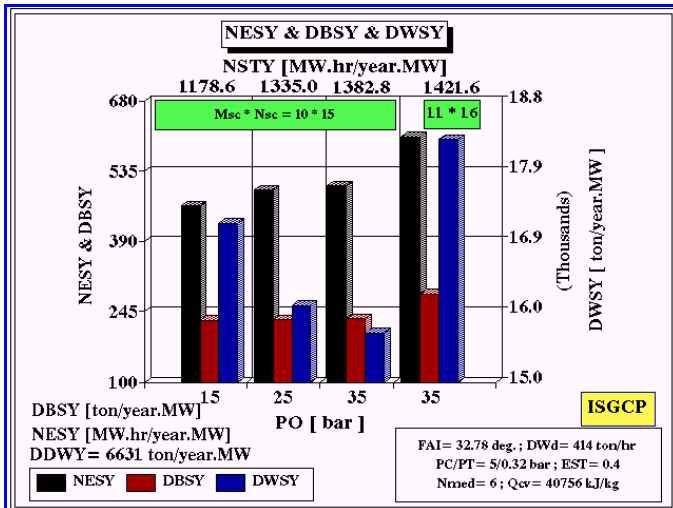


Figure 6: The annual specific, fossil fuel saving due to solar thermal power contribution (DBSY), solar power generation (NESY), and solar distilled water production (DWSY) versus the live steam pressure (PO) at the inlet of steam turbine.

Figure 7 shows the monthly variation of the rate of fossil fuel saving per month due to solar thermal power contribution (DBSM), solar electrical power generation (NESM), solar distilled water production (DWSM), and the augmentation in distilled water production (DDWM) for the proposed ISGCP design. The increase in the DBSM during the summer season (April 1: August 31) in comparison with winter season (November 1: January 31) is due to the two reasons. First the increase solar radiation intensity on the surface of PSCA, the ambient air temperature at the plant site rise, and subsequently an increase in the output of PSCA, during the summer season. Second, the increase in daily period of the ISGCP operation at cogeneration mode due to the rise in the sun shine hours during the summer season causes an increase in the solar electrical power generation (NESM) and distilled water production (DWSM). Figure 7 also illustrates the reverse relation between the electrical power generation efficiency (EST) in the EPG and the effectiveness of ISGCP. The DBSM reduce due to the low rate of fossil fuel consumption in EPG for electrical power generation It is important to predict the effect of external parameters such as the climate type and visibility in the sky at the plant site on the performance of ISGCP. Figure 8 illustrates there is obvious connection between visibility in the sky at the plant site and the effectiveness of proposed ISGCP design. As the visibility in the sky at the plant site decreases from 25 km to 15 km, there is a 37.5 % reduction in the specific rate of annual fossil fuel saving due to the solar thermal power contribution. As a result of the decrease in the plant solar power generation (NESY) and distilled water production (DWSY) caused by a lower solar radiation intensity on the surface of PSCA and,

subsequently, the output thermal power of PSCA. For the same reason the annual share of the solar distilled water production (SDR) varies from the maximum value at 25 km visibility to its minimum value at 5 km visibility.

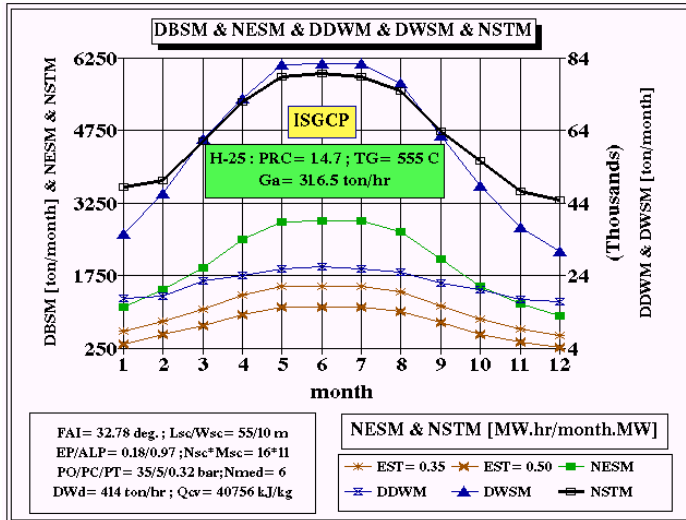


Figure 7: The monthly variation of the rate of fossil fuel saving per month due to solar thermal power contribution (DBSM), solar electrical power generation (NESM) and distilled water production (DWSM), and the augmentation in distilled water production (DDWM) for various electrical power generation efficiency (EST) in EPG.

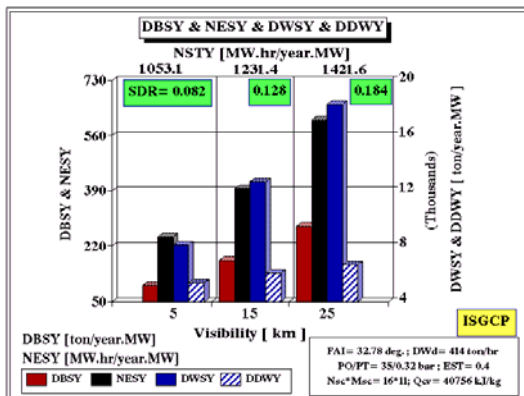


Figure 8: The annual specific, fossil fuel saving due to solar thermal power contribution (DBSY), solar power generation (NESY), solar distilled water production (DWSY), and augmentation in plant distilled water production (DDWY) versus the visibility in the sky.

As can be seen from figures 8 there is an increase in ST power output (NSTY) as the visibility in the sky rises, caused by the increase in daily period of the ISGCP operation at integrated solar mode of operation due to the rise in the solar radiation intensity on the surface of PSCA. For the same reason the augmentation in plant distilled water production (DDWY) is higher at higher visibility in the sky.

Conclusions and Recommendations

From the results and analysis given in the previous section the following conclusions and recommendations could be made:

7.1 The effectiveness of proposed ISGCP design for the countries usually have abundant seawater resources and a good level of solar radiation, which could be used to produce drinking water from seawater. This technology can provide the necessary amount of clean energy to achieve the targets for optimizing the consumption of fossil fuel in EPG, minimizing the environmental impact, and climate stabilization. For the case study (*ISGCP with annual solar shear of distilled water production 17.3 % and the efficiency 40 % of electrical power generation in EPG*) the annual specific rate of fossil fuel saving due to solar energy contribution amount 227.2 ton fuel/year for each MW design thermal power consumption of TC-MED and the analogous decrease in exhaust gases emission (Nitrogen oxides (NO_x) 289,4 ton/ year.MW, carbon dioxides (CO₂) 691.5 ton/year.MW).

7.2 For the proposed ISGCP design , increasing the live steam pressure from PO= 15 bar to 35 bar rises the possible annual share of solar distilled water production to 18.4 % and subsequently the thermal and environmental effect in section 7.1 will increase by 23.9 %.

7.3 Implementation of the proposed ISGCP design (section 7.2) for modification of grid connected GTCP (specified for electrical power generation and seawater desalination by six effects TC-MED) will increase the annual specific rate of distilled water production by 6631 ton/year.MW besides boosting 1421.6 MW.hr/year.MW of surplus high voltage electricity in EPG.

7.4 The proposed IGSCP design is a promising technology for climate compatible power with such enormous potential that modified TC-MED unit would allow 24 hr economical dispatch of desalted water with high maneuver of boosting electrical power in EPG, specifically for daytime-demand peaks. Furthermore, the increase in the output of PSCA and, subsequently, in solar power generation, will also useful to offset the normal reduction in performance experienced by GTU during the summer season.

7.5 In the present work a thermal and environmental analysis for the proposed ISGCP design has been carried out, and no thermo-economical evaluations are made, and in this respect, especially the PSCA, modern GTU, backpressure ST options, and modified TC-MED are of interest.

Nomenclature

D_{cw}, D_{drain} — The mass flow rate of, cooling water to the heat rejection condenser for, and blow down brine (drain) from, the Thermo-Compressor Multi Effect Distillation (TC-MED) unit.

DDW, DW_d — The distilled water productivity, and design distilled water productivity, for TC-MED unit.

EP, ALP — Emissivity and Absorbivity of Parabolic Solar Collector Array (PSCA) absorber surface.

EST – The electrical power generation efficiency in Electrical Power Grid (EPG).

FAI – The latitude angle of reference site for proposed plant design.

FP, KP – The feed water pump for Steam Separation Vessel (SSV) and the condensate pump.

Ga – The air mass flow rate in air compressor for the Gas Turbine Unit (GTU).

MS – External steam moisture separator.

Msc – The number of parabolic solar collectors in one row of PSCA.

Nsc – The number of parallel rows in PSCA.

Nmed – The design number of effects for TC-MED unit.

PC – The design motive steam pressure for TC-MED unit.

PO – The live steam pressure at the inlet of Steam Turbine (ST).

PRC,TG – The pressure ratio of air compressor, and the combustion gases temperature at exhaust of gas turbine, for the GTU.

PT – The steam pressure at the inlet of the first effect for TC-MED unit.

Qcv – The heat value of fossil fuel.

WHB – Waste heat boiler.

Wsc, Lsc – The aperture width and the length of parabolic solar collector.

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