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Solar Aided Power Generation: Generating "Green" Power from Conventional Fossil Fuelled Power Stations

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1. Introduction

Nowadays, most power is, and will continue to be, generated by consumption of fossil fuels (mainly coal and gas) which has serious negative impacts on our environment. As a clean, free, and non-depleting source, solar energy is getting more and more attention. However, owing to its relatively low intensity, the application of solar energy for power generation purpose is costly, and the efficiencies of the solar thermal power systems having been developed in which solar energy is used as the main heat source are not satisfactory. In addition, solar energy utilisation is subject to the change of seasons and weather. All of these impede the solar energy's application. How to use solar energy to generate power steadily and efficiently is a problem that needs to be addressed.

In this chapter a new idea, i.e. Solar aided power generation (SAPG) is proposed. The new solar aided concept for the conventional coal fired power stations, ie. integrating solar (thermal) energy into conventional power station cycles has the potential to make the conventional coal fired power station be able to generate green electricity. The solar aided power concept actually uses the strong points of the two mature technologies (traditional Rankine generation cycle with relatively higher efficiency and solar heating at relatively low temperature range). The efficiencies (the fist law efficiency and the second law efficiency) of the solar aided power generation are higher than that of either solar thermal power systems or the conventional fuel fired power cycles.

2. Rankin thermal power generation cycles

Thermodynamically, at a given temperature difference, the most efficient cycle to convert thermal energy into mechanical or electrical energy is the Carnot cycle that consists two isothermal processes (ie. processes 2→3 and 4→1) and two isentropic processes ie. 1→2 and 3→4), as shown in Fig. 1. However, almost all coal or gas fired power stations in the world are operated on so called Rankine as the Carnot cycle is hard to achieve in practice. The basic Rankine cycle, , using steam as working fluid, which is shown in Fig 2, is a modification from the Carnot cycle, by extending the cooling process of the steam to the saturated liquid state, ie. point 3 in Fig 2. In Fig. 2 the process 3→ 4 is a pumping process while the process 4→5→ 1 is the heating process in the boiler. Comparing with Carnot cycle, the Rankine cycle is easier to operate in practice. However, the efficiency of Rankine cycle is lower than that of Carnot cycle. To improve the efficiency of basic Rankine cycle, in real power stations, the Rankine cycle is run as modified Rankine cycles. Three common modifications to the basic Rankine cycle are 1) superheating 2) reheating and 3) regeneration.

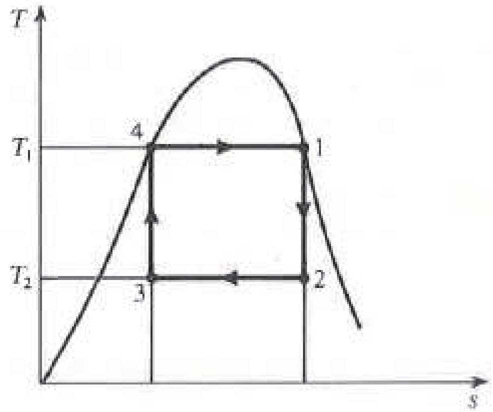


Fig. 1. Carnot cycle for a wet vapour on a T-S diagram[1]

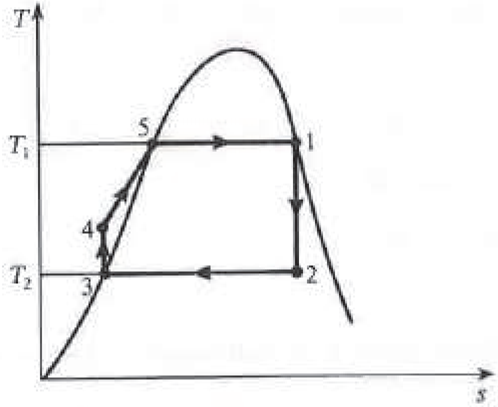


Fig. 2. Basic Rankine cycle using wet steam on a T-s diagram[1]

The regeneration is to extract or called bled off, some steam at the different stages of expansion process, from the turbine, and use it to preheat the feed water entering the boiler. Figure 3 shows a steam plant with one open feed heater, ie. one stage regeneration. In a modern coal or gas fired power station, there are up to 8 stages of extraction and feed water pre-heating existing. Although regeneration can increase the cycle thermal efficiency that is the ratio of power generated to heat input, but the work ratio of the cycle is decreased, which is the ratio of gross work generated to the net power output. In other words, due to the steam extraction or called bled-off, there is less steam mass flow going through the lower stages of the turbine and resulting the power output reduced.

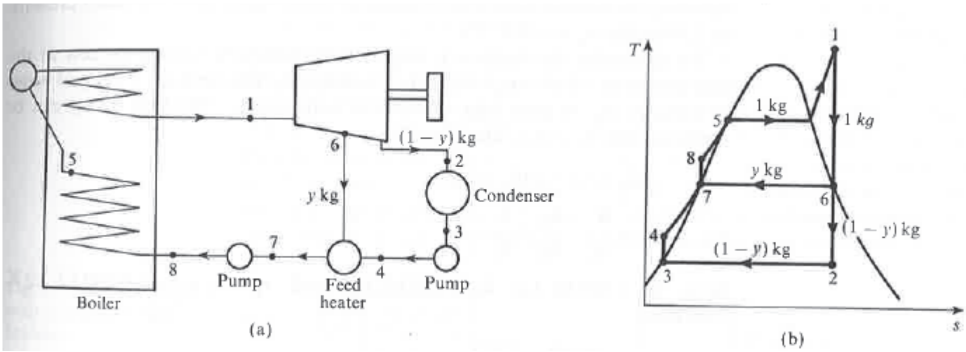


Fig. 3. Steam plant with (a) one stage regeneration and (b) the cycle on a T-s diagram [1]

3. Solar aided power generation

The basis of solar aided power generation (SAPG) technology/concept, is to use solar thermal energy to replace the bled-off steam in regenerative Rankine power cycle. In contrast to other solar boosting or combined power systems, solar energy generated heat (or steam), in SAPG, does not enter the turbine directly to do work. Instead, the thermal energy from the sun is used in place of steam normally extracted from turbine stages for feedwater pre-heating in regenerative Rankine cycles. The otherwise extracted steam is therefore available to generate additional power in the turbine. Therefore the SAPG is capable of assisting fossil -fuelled power stations to increase generating capacity (up to 20% theoretically if all feed heaters are replaced by solar energy) during periods of peak demand with the same consumption of fuel, or to provide the same generating capacity with reduced green house gas emissions.

The SAPG technology is thought to be the most efficient, economic and low risk solar (thermal) technology to generate power as it possesses the following advantages:

- The SAPG technology has higher thermodynamic 1st law and 2nd law ie, exergy efficiencies over the normal coal fired power station and solar alone power station. Preliminary theoretical studies is presented in the following sections.
- Utilizing the existing infrastructure (and existing grid) of conventional power stations, while providing a higher solar to electricity conversion than stand alone solar power stations. Therefore a relatively low implementation cost, and high social, environmental and economic benefits become a reality.
- The SAPG can be applied to not only new built power station but also to modify the existing power station with less or no risk to the operation of the existing power stations.
- The thermal storage system that at present is still technically immature is not necessary. The SAPG system is not expected to operate clock-round and simplicity is another beauty of the SAPG. The pattern of electricity demand shows that nowadays air conditioning demand has a great impact on the electricity load. Afternoon replaces the

evening to be the peak loading period in summer. This means that the extra work generated by this SAPG concept is just at the right time. Namely, the solar contribution and power demand are peak at the same time ie. during summer day time.

- The SAPG is flexible in its implement. Depending on the capital a power station has, SAPG can be applied to the power station in stages.
- The SAPG actively involves the existing/traditional power industry into the renewable technology and assist it to generate "green" electricity. It is the authors' belief that without the engagement of existing power industry, any renewable energy (power generating) targets/goals set by governments are difficult or very costly to fulfil.
- Low temperature range solar collectors eg. vacuum tubes and flat plate collectors, can be used in the SAPG. It is a great new market for the solar (collectors) industry.

The benefit of SAPG to a power station can come from either additional power generation with the same fuel consumption ie solar boosting mode, or fuel and emission reduction while keep the same generating capacity ie. fuel saving mode, shown in Fig.4.

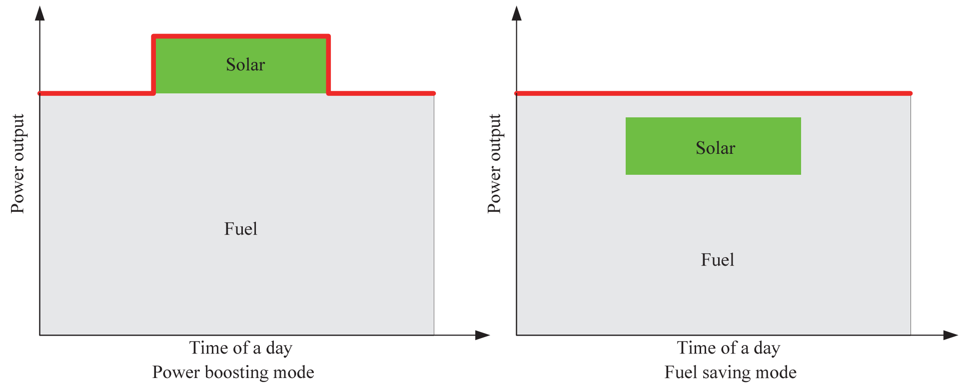


Fig. 4. Two operation modes of solar aided thermal power generation [2]

4. Energy (the first law) advantages of SAPG

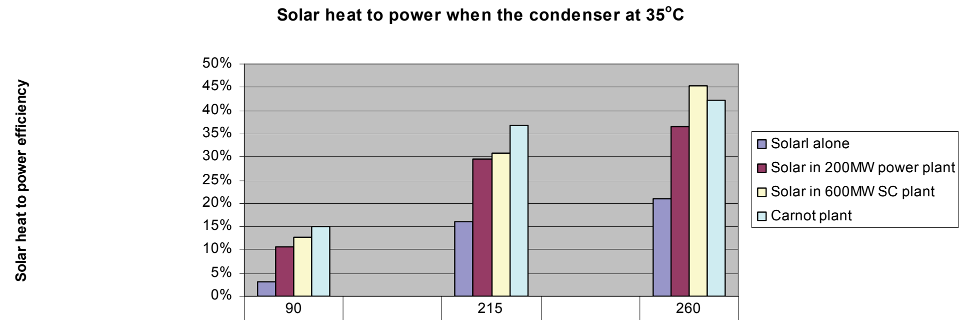
In the power boosting operation mode, the thermal efficiency of solar energy in the SAPG system is defined as:

$$\eta_{solar} = \frac{\Delta W_e}{Q_{solar} + \Delta Q_{boiler}} \tag{1}$$

where ΔW_e is the increased power output by saved extraction steam, Q_{solar} is the solar heat input; ΔQ_{boiler} is the change in boiler reheating load, accounting for increases in reheat steam flows. For ΔW_e, Q_{solar} and ΔQ_{boiler}, the unit is kW or MW. In the formula above, no losses (eg. shaft steam loss etc.) have been considered, ie. it is an ideal thermodynamic calculation.

As the SAPG approach is actually makes the solar energy "piggy-backed" to the conventional coal fired power plants, if the power plant itself has a higher efficiency, eg. in a supercritical or ultra-supercritical modern power plant, the solar to power efficiency in the SAPG system can be expected higher.

For example, let's consider three typical temperatures of solar thermal resources at 90°C, 215°C and 260°C. If the solar heat at these 3 temperature levels are utilised to generate power in a solar stand-alone power plant, with SAPG in a typical 200MW subcritical power plant and in a 600MW supercritical (SC) steam plant, respectively, the (the solar to power) efficiencies in these cases are given in Fig. 5. [3]



	90	215	260
Solarl alone	3.0%	16.0%	21.0%
Solar in 200MW power plant	10.7%	29.5%	36.6%
Solar in 600MW SC plant	12.75%	30.94%	45.33%
Carnot plant	15.2%	36.9%	42.2%

Temperature of solar liquid oC

Fig. 5. Comparison of solar heat to power efficiencies in various cycles

In Fig 5, the Carnot efficiency of renewable energy generation is also shown, assuming a heat sink temperature of 35°C. It can be seen that the SAPG approach allows η_{solar} to exceed a Carnot efficiency if the temperature of the solar fluid was the maximum temperature of the Carnot cycle. This demonstrates that η_{solar} is no longer limited by the temperature of the solar fluid, but rather by the maximum temperature of the (power station) cycle.
The advantage of the super-critical power cycle with SAPG is also evident, resulting in a significant increase in efficiency relative to the subcritical cycle, as shown in Fig 5.

5. Exergy (the 2nd law) advantages of the SAPG

There are two ways to evaluate the exergy (the 2nd law) advantages of a SAPG system, ie. net solar exergy efficiency method and Exergy merit index method.[4 and 5]

5.1 Net solar exergy efficiency

To illustrate the exergy advantages of the SAPE, let us examine a single-stage regenerative Rankine cycle with open feedwater heater (Figure 6).
In energy system analysis, not only the quantity, but also the quality of energy should be assessed. The quality of an energy stream depends on the work (or work potential) available from that stream. The capacity for the stream to do work depends on its potential difference with its environment. If a unit of heat flows from a source at a constant temperature T_H to its environment at temperature T_a, with a reversible heat engine, the maximum work the heat energy can do, is called the Availability and also called Exergy of the heat at the temperature T_H. In the case of using solar energy (heat), the exergy in the solar irradiation, Ex_s, is [6]:

$$Ex_s = \left[1 - \frac{4Ta}{3Ts}(1 - 0.28\ln f)\right]Qs \tag{2}$$

where the Ta is the ambient temperature and the Ts is the temperature of the sun, f is the dilution factor which equals $1.3\text{x}10^{-5}$, and Qs is the solar heat.

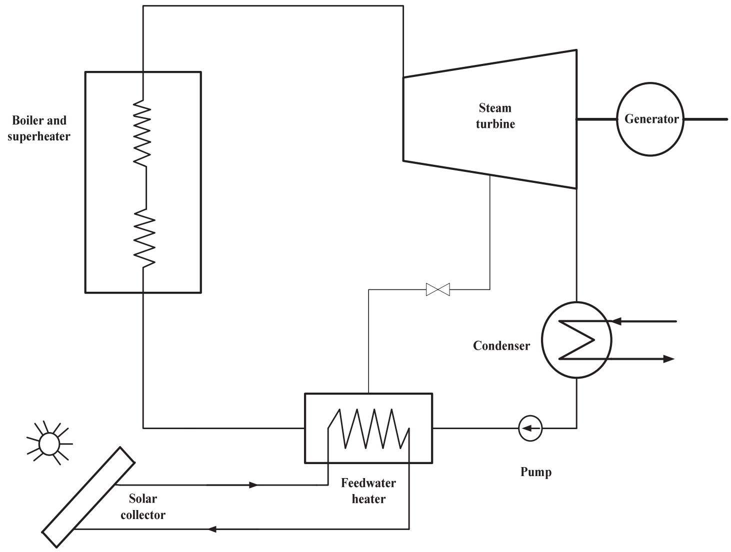


Fig. 6. Single-stage regenerative Rankine cycle with open feedwater heater

In SAPG, the solar heat is used to replace the bled-off steam and heat feed water, so that the solar heat Qs equals:

$$Qs = m \cdot \Delta h = m \cdot c(T_H - T_L) \tag{3}$$

where m is the mass (or flow rate) of the feedwater in the feedwater heater, *c* is the mean specific heat capacity of the feed water, Δh is the specific enthalpy change of the feed water cross the feedheater.
The net solar exergy efficiency of the SAPG system is then:

$$\eta_{sex} = \frac{\Delta W}{Ex_s} \tag{4}$$

Where ΔW is the extra work generated by the turbine due to the saved bled-off steam.

5.2 Exergy merit index [5]

In the same system shown in Fig 6, the exergy in the extraction steam at T_H is assigned by "e_x", i.e.

$$e_x = w_{\max} = q(1 - \frac{T_0}{T_H}) \tag{5}$$

If the temperature of the steam decreases from T_H to T_L, the exergy change of the steam is

$$\begin{aligned}\Delta e_x &= \int_{T_L}^{T_H}(1-\frac{T_0}{T})\delta q = q - T_0\int_{T_L}^{T_H}\frac{cdT}{T} = q - T_0 c\ln\frac{T_H}{T_L} \\ &= c(T_H - T_L) - T_0 c\ln\frac{T_H}{T_L}\end{aligned} \quad (6)$$

where c is the mean specific heat capacity of the stream in the temperature range of T_L—$T_{H.}$ This exergy change of the temperature-changing heat source can also be expressed approximately by a simple form

$$\Delta e_x \approx q(1-\frac{T_0}{\frac{T_L+T_H}{2}}) \quad (7)$$

To grasp the main points, assume that the steam extracted from the saturated vapour state or from the wet steam region, so the temperature of the extracted steam keeps constant when it transfers heat to the feedwater, while the temperature of the feedwater increases.
If the specific heat capacity of the feedwater c is assumed to be constant (i.e. it is not affected by the temperature's change), then the ratio of exergy increase E_x to heat Q obtained by feedwater (denoted by subscript "w") is:

$$\begin{aligned}\left(\frac{E_x}{Q}\right)_W &= \left(\frac{e_x}{q}\right)_W = \frac{\int_{T_L}^{T_H}(1-\frac{T_0}{T})\delta q}{h_H - h_L} \\ &= 1-\frac{T_0}{T_H-T_L}\ln\frac{T_H}{T_L} \approx (<) 1-\frac{T_0}{\frac{T_H+T_L}{2}}\end{aligned} \quad (8)$$

where T_0 is the ambient temperature in K.
The ratio of exergy E_x to heat Q of the extracted steam (at the constant temperature of T_H, denoted by subscript "v") is

$$\left(\frac{E_x}{Q}\right)_V = 1-\frac{T_0}{T_H} \quad (9)$$

From the heat balance we know that the heat rejected by the extracted steam Q_v equals the heat absorbed by the feedwater Q_w . In addition, the exergy of the extracted steam is very near to the work the steam can do in the turbine. So

$$\frac{\left(\frac{E_x}{Q}\right)_V}{\left(\frac{E_x}{Q}\right)_W} = \frac{Ex_V}{Ex_W} = \frac{W}{Ex_W} \quad (10)$$

From this equation it can be seen that if we supply to the feedwater the same amount of heat with solar energy as the extracted steam did, the saved steam can do work W. If the heat exchange in the heater is reversible, i.e. the heating fluid only releases the same amount of exergy as the feedwater obtained $Ex_{w,}$ the Equation 10 virtually expresses the ratio of the work we can gain to the exergy cost. In order to assess the merit of using the solar energy in such multi-heat source systems from the view of exergy, we define the available energy efficiency of such scheme as the Exergy Merit Index (*EMI*), which is

$$EMI = \frac{Work_{gain \quad from \quad steam}}{Exergy_{pay \quad by \quad solar}} = \frac{W}{Ex_W}$$
$$= \frac{1 - \frac{T_0}{T_H}}{1 - \frac{T_0}{T_H - T_L} \ln \frac{T_H}{T_L}} \approx (>) \frac{1 - \frac{T_0}{T_H}}{1 - \frac{2T_0}{T_H + T_L}} \qquad (11)$$

Since T_L is always less than T_H, the value of *EMI* is always greater than unity. This means that by using the low grade solar energy to replace the high grade extracted steam to heat the feedwater, the work gained from the steam is greater than the available energy given by the solar energy. This is unmatched by any other power systems driven by a single high temperature heat source. Needless to say, this concept is a super energy scheme.

If the solar collector generates vapour, when the temperature of the vapour equals that of the correspondent extracted steam, the *EMI* of the solar energy is unity, which is also unmatched by any other power systems heated by a single high temperature heat source.

Owing to the irreversibility, no matter which way we use to evaluate the exergy advantages of a SAPG system, the benefit will be certainly less than the above values. The study of the following case demonstrates the exergy advantage of the concept in practice.

Here is an example of using the solar energy in a three-stage regenerative Rankine cycle. Assuming that the state of the working fluid at every point of the system does not change with or without solar-aided feedwater heating, only the flow rate changes (with the solar energy aided, the flow rate will increase in the turbine). The pattern is shown in Figure 7. Some important properties are listed in Table 1.

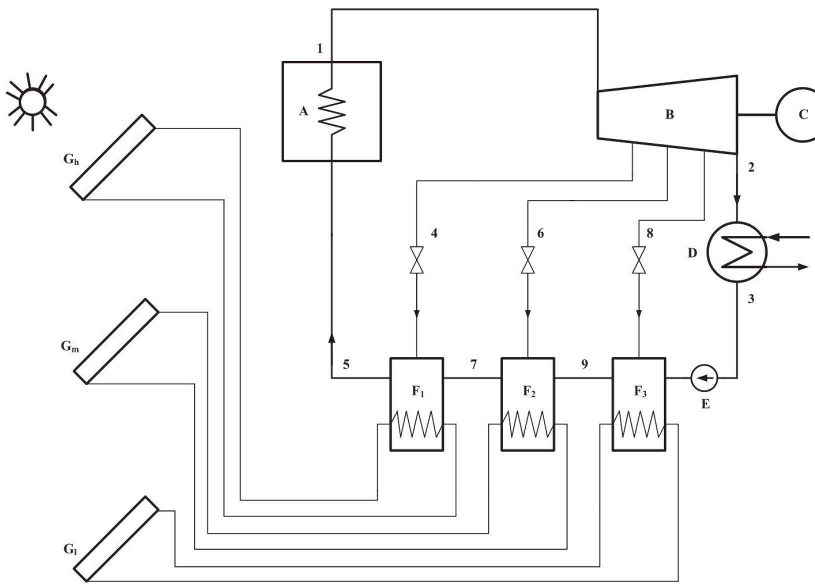


Fig. 7. A three-stage regenerative condensing-steam Rankine cycle

A. boiler and superheater, B. turbine, C. generator, D. condenser, E. pump, F_1, F_2, F_3. feedwater heaters, G_l. low-temperature collector, G_m. medium-temperature collector, G_h. high-temperature collector

Without the solar energy aided, the conventional regenerative Rankine cycle yields work:

$$W_0 = h_1 - h_4 + (1 - m_1)(h_4 - h_6) + (1 - m_1 - m_2)(h_6 - h_8)$$
$$+(1 - m_1 - m_2 - m_3)(h_8 - h_2) = 1084.96 \quad kJ/(kg \;\; steam \;\; in \;\; boiler)$$

Assuming the ambient temperature is 25°C (298K), and the temperature difference for heat transfer in the condenser is 10°C. When aided heat is used, assuming the average temperature difference for heat transfer in heaters is 10 °C for liquid heat carrier, let us investigate the following cases.

Point in Fig. 7	P (kPa, absolute)	t (°C)	h (kJ/kg)
1. turbine inlet	16500	538	3404.78
2. turbine exhaust	7	38.83	1993.92
3. condensed water	7	38.83	162.7
4. high pressure extracted steam	6000	369.82	3097.15
5. high-stage heater outlet	6000	275.6	1213.4
6. medium pressure extracted steam	1000	179.9	2701.53
7. medium-stage heater outlet	1000	179.9	762.81
8. low pressure extracted steam	101.3	100	2326.44
9. low-stage heater outlet	101.3	100	419.04

Note: the weight fraction of the extracted steam m_1=0.193 m_2=0.1215, m_3=0.0812.

Table 1. Some Properties of the Cycle

From above cases, it can be seen, in Table 2, that using the low temperature thermal energy to heat the feedwater in the regenerative Rankine cycle, the values of exergy efficiency is quite high, comparing to other solar thermal power generation systems.

From the thermodynamic point of view, generally using liquid as the heat carrier for solar energy in these systems is better than using vapour. With SAPG, we can use water (liquid) rather than other low-boiling point substance as working fluid and do not need to use the more sophisticated vapour-generating collectors.

With a little advanced collector, the medium and even high temperature fluid can be made easily. When high temperature heat carrier of the solar energy can be provided, it is suggested to install the multi-stage collectors with different temperature levels to heat the feedwater serially in the multi-stage heaters (see also Figure 7). One advantage of this multi-stage design is the system can be made more flexible so particular stage(s) of extracted steam can be closed according to the load demand in practice. If the vapour/steam can be generated by the (solar) collectors, the pattern of multi-stage collectors with different temperature levels is preferable as the solar net exergy efficiencies of the multi-stage systems are much higher than that of the one-stage system, and the more the stages, the higher the efficiencies.

	Case 1	Case 2
Phase of the heat carrier of the aided energy	liquid	liquid
Highest temperature of the aided energy, °C	110	286
The stage(s) closed	stage 3 only	all stages
Extra work done by the saved steam ΔW, kJ/(kg steam generated in boiler)	27	325.9
The aided solar heat input Qs, kJ/(kg steam generated in boiler)	175.72	1050.7
Thermal efficiency of the solar energy in the aided system η_I (η_I=ΔW/Q), %	15.37	30.12
Exergy contained in the aided solar energy Ex_s, kJ/(kg steam generated in boiler), using eq (1):	163.1	975.4
Net solar exergy efficiency in the SAPG, %, η_{sex} in eq (3)	16.6	33.4
Exergy cost (payed by the aided solar energy) E_x, kJ/(kg steam generated in boiler)	26.746	321.4
EMI of the solar energy in the aided system (EMI=ΔW/E_x), %	101	101.4
Work increased (Comparing with the conventional regenerative Rankine cycle), (ΔW/W_0), %	2.5	30.04

Table 2. Analyses on solar aided systems

6. Solar percentage

In the SAPG case, the relative contribution of solar energy to the total power output from the plant is shown in Fig. 8 when the solar energy is assumed to be available around the clock with storage. These calculations show that for a solar-fluid at 215 °C, which is not very high and relatively easy to achieve, the solar contribution to total power is about 16%.

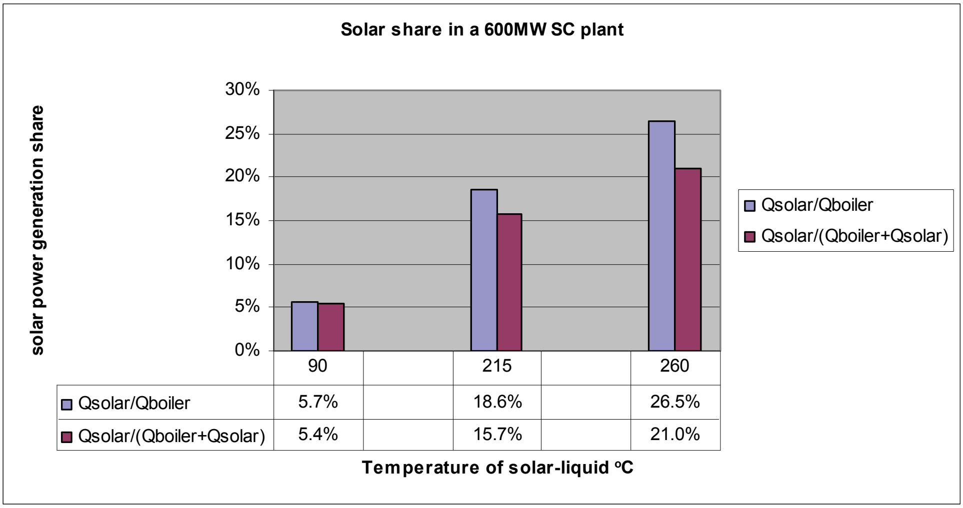


Fig. 8. Solar thermal share of power generation in a RAPG 600MW supercritical plant

Increasing the solar input temperature to 260 °C increases the contribution of solar energy to about 21%. For the reduced solar input temperature of 90 °C (from a non-concentration solar collector), the SAPG case provides a much lower total contribution to power, at about 5%. For the solar-thermal case, a time fraction needs to be considered when calculating the solar contribution to total power out put, because the availability of solar depends on seasons and locations.

7. A real case study [7]

The solar heat at various levels can be used in this SAPG system. The high temperature solar heat from the parabolic trough solar collector at nearly 400°C can be easily used in the first couple of stages of high pressure feedwater heaters, while the low temperature solar heat from flat vacuum collectors at 200°C or less can be used in the lower stages of low pressure feedwater heats. The solar heat can be used in either closed or open (deaerator) types of feedwater heaters and can replace the extraction steam either fully or partly in a particular stage. Therefore, the SAPG technology is sometime also called multi-points and multi-levels solar integration.
A typical regenerative and reheating Rankine steam system has been shown in Fig. 9, which is N200-16.8/530/530 system made by Beijing Beizhong turbine factory in China. The boiler is composed of furnace, drum, risers, superheaters, feedwater heaters and economizer. The combustion of coal takes place in the boiler. The unsaturated feed-water from condenser enters the boiler after going through four low-pressure feedwater heaters (3-6 in Fig.9), two

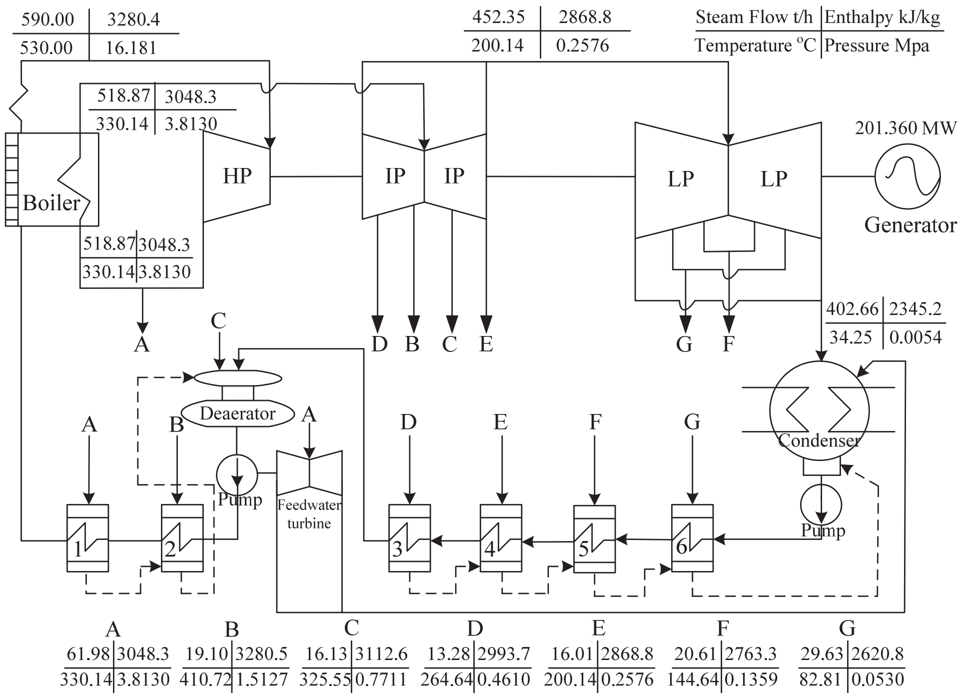


Fig. 9. Schematic diagrams and thermal balance of a 200 MW coal-fired thermal power plant

high pressure feedwater heaters (1 and 2 in Fig.9) and a deaerator. The superheated steam from the boiler enters the high pressure turbine to generate power. After reheated in the boiler, the steam expands further through intermediate pressure and lower pressure stages of the turbine. In the end, the final exhaust steam is condensed in the condenser. The deaerator is actually an open type feedwater heater to preheat the feedwater and remove the oxygen. The feedwater heaters are closed type heaters. The aim of extracting steam from turbine to preheat feed water is to increase overall thermal efficiency of the system.

As stated before, the flexibility is one of advantages the SAPG has. In the SAPG, the solar replacement of extraction steam in a particular feedheater does not need to be 100%, instead it can be any percentage from 0% to 100%.

In terms of working fluids (in solar collector) selection, there are two options, one is using boiler quality of water/steam directly and the other is using something like thermal oil. The additional heat exchangers need to be installed in parallel with the feedwater heaters in the later option. However, in terms of the energy analysis later in the paper, the two options have no fundamental differences.

A mathematical simulation model has been developed to carry out the case study, the results are shown in Figures 10-12 below[7]:

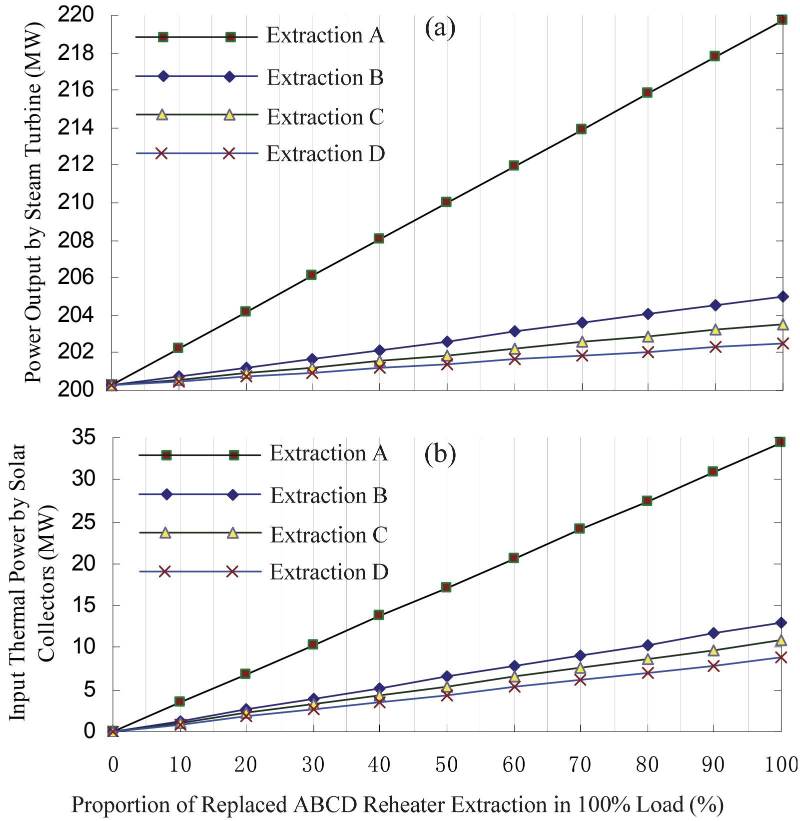


Fig. 10. The output characters vs. solar percentages at A, B, C and D in 100% load

It can be seen from Fig.10(a) that the increased power output is nearly 20 MW, i.e. the total plant power output reaches to 220 MW when the extracted steam (of 62t/h) from A is completely replaced by solar heat. At the same time, the Fig.10(a) shows the additional power generated will be less if the replacement is at locations B, C or D, as expected, because the quality i.e. temperature of solar input required is lower than steam of extraction A. Fig.10(b) shows the solar heat demands for the cases in Fig.10(a). Certainly, more solar input will replace more extracted steam and generate more additional power. For example, when replacing A and D extractions completely, the increased power outputs are 19.72 MW and 2.55 MW, respectively. The ratio is 7.7, much greater than the solar energy input ratio of 3.9. It is concluded that it is more efficient to replace the higher stage of bled-off steam, if the solar heat temperature is able to do so.

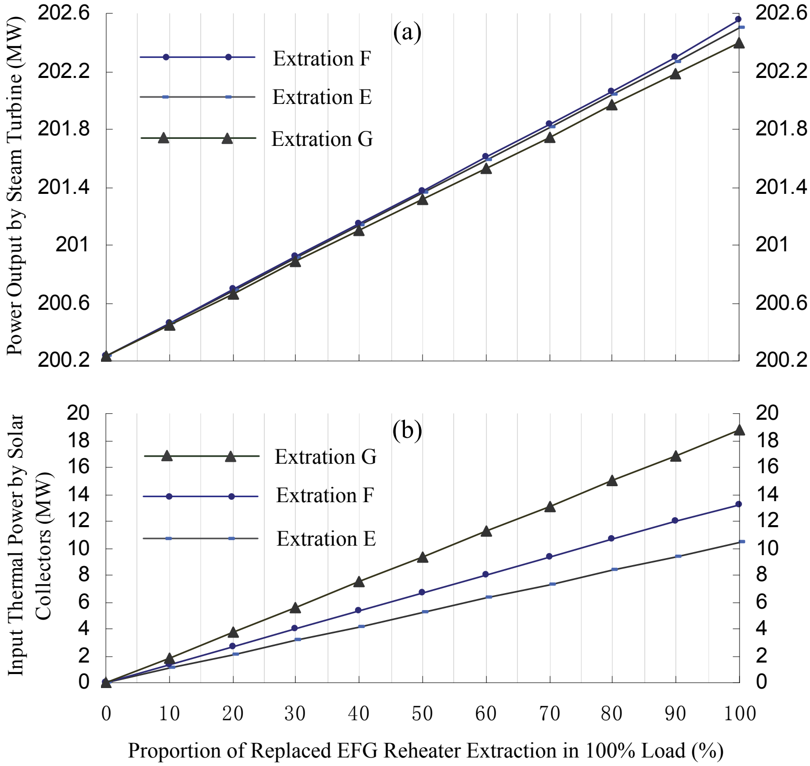


Fig. 11. The output characters vs. solar percentages at E, F and G in 100% load

The extracted steams from locations E, F and G are classified as the low temperature group, the extraction steam temperatures at these locations (in this case) are 200.14°C, 144.64°C and 82.81°C, respectively.

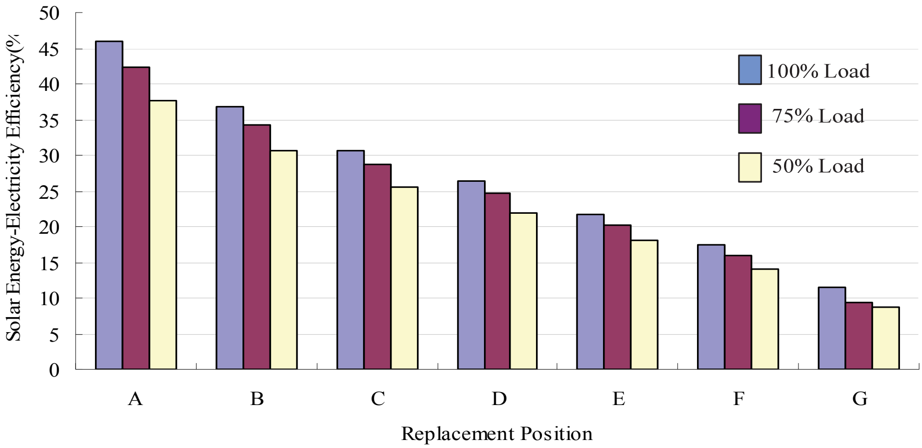


Fig. 12. Solar heat to electricity efficiency in different loads

The solar to power efficiencies in 100% replacement at various generating capacities, as shown in Fig.12, are calculated using Eq. 1. It shows the solar efficiency in the SAPG cases is much higher that in the other solar thermal power generation systems using the same quality/temperature of solar heat.[3,5] The maximal efficiency (45%) occurs at location A where the solar heat temperature is just about 330°C, when the plant operats at full capacity. At the low temperature sections i.e. location G where the solar heat input can be lower than 100°C, the solar efficiency can still be at about 11.5% .

8. Discussions

8.1 Turbine working under off design condition

When the extract steam is replace by solar fluid in SAPG system, the steam mass flows through the lower stage turbines are changed. In other word, the lower stage turbines are actually working at off design conditions. Under this condition, the Stodola's law (Ellipse law) is often used to estimate the pressure changes (due to mass flow change) in the lower stages turbines. The Stodola's law can be written in the form below[8]:

$$\frac{D_1}{D_{10}} = \sqrt{\frac{p_1^2 - p_2^2}{p_{10}^2 - p_{20}^2}} \sqrt{\frac{T_{10}}{T_1}}$$

Where the D_1 is the design flow rate, the D_{01} is the off-design flow rate, p_1 is the pressure inlet pressure at design condition, p_2 is the pressure of outlet pressure at off-design condition, p_{10} is the inlet pressure at design condition, p_{20} is the outlet pressure at off-design condition. T_1 and T_{10} is the inlet temperature at design condition and off-design condition.

However, when estimating benefits of SAPG plant, considering the turbine working at off-design condition or not would not have too much impact. The difference is less than 1% [9]. Therefore the results in the previous sections of this chapter and the literatures did not consider the turbines working under the off design conditions.

8.2 Limits of steam mass flow changes in turbines

For a conventional 200MWpower plant, normally the maximum capacity of turbine is nearly 220MW. If SAPG is used in such a plant, the pant is run at its near maximum capacity, which may impair the safety for the plant.

However, according to the recent statistics (in China), the majority of power stations have retrofitted the trough-flow structure of the turbine to increase the rated capacity. For example, 200 MW coal-fired power plants are retrofitted to 220MW and maximum generating capacity is then increased to nearly 235 MW or more. Therefore, SAPG, ie. the replacement of the extracted steam, can be realized in the retrofitted plants more easily.

9. Conclusions

The advantages of Solar Aided Power Generation concept in the aspects of its energy and exergy, have been shown in this chapter. By using solar energy to replace the extracted steam in order to pre-heat the feedwater in a regenerative Rankine plant cycle, the energy and exergy efficiencies of the power station can be improved. The higher the temperature aided heat source is, the more beneficial the system can generate. It can be seen that the low-grade energy, eg. solar heat from non-concentrated collectors (and other possible waste heat), is a valuable source of work if it can be used properly. This "aided" concept is different from other solar boosting and hybrid power generation concepts as the solar heat in the form of hot fluids (oil or steam) does not enter the steam turbine directly, thus the solar heat to power conversion efficiency would not limited by the temperature of the solar fluid.

The SAPG has special meanings for solar energy. For in summer weather, both the solar radiation and the electrical load demand peak, and it is easy to make heat carrier in different temperatures with different type of collectors. So the increased solar radiation can supply the increased energy to meet the increased power demand. In addition, the solar aided system can also eliminate the variability in power output even without thermal storage system. The concept of the solar aided power system is really a superior energy system and is a new approach for solar energy power generation.

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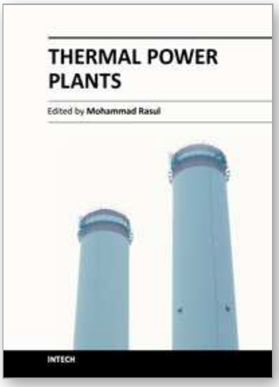

Thermal Power Plants

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Thermal power plants are one of the most important process industries for engineering professionals. Over the past few decades, the power sector has been facing a number of critical issues. However, the most fundamental challenge is meeting the growing power demand in sustainable and efficient ways. Practicing power plant engineers not only look after operation and maintenance of the plant, but also look after a range of activities, including research and development, starting from power generation, to environmental assessment of power plants. The book Thermal Power Plants covers features, operational issues, advantages, and limitations of power plants, as well as benefits of renewable power generation. It also introduces thermal performance analysis, fuel combustion issues, performance monitoring and modelling, plants health monitoring, including component fault diagnosis and prognosis, functional analysis, economics of plant operation and maintenance, and environmental aspects. This book addresses several issues related to both coal fired and gas turbine power plants. The book is suitable for both undergraduate and research for higher degree students, and of course, for practicing power plant engineers.

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