Procedure for controlling the temperature and power of a thermal solar power plant

Abstract

The current method intends to maximize the solar heated medium to the optimal level to increase efficiency and obtain more electrical energy from a thermal solar power plant. The construction of solar power plants is well known and may consist of several types of structures. However, the principles of optimization in each design are the same. In both types, the idea is to maximize the effect $P_{sun} = \ (P_{out} - P_{in})\ Cp\ \dot{V}$. We want to maximize the power P_{solar} to achieve maximum efficiency electric current. A simulation study has been made to get a more accurate picture of the method and simulation of the sun's intensity and effect at different times of the day. The simulation study has also been done to show that the idea behind the method is consistent with previously made calculations and that an increase in electricity production can be demonstrated and that the method is economically viable. As a control method, many control strategies have been proposed to optimize the solar power plant. It was difficult to try to estimate the solar intensity, but sufficient data could still be obtained. The method is based on a proprietary optimization method that suits the solar reflexion.

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Introduction

An innovation has been made with good and simple technical solution but difficult to formulate so that it is simple to understand. An application has been made to save the innovation and for a so real as a possible investigation has been made to see that it’s advantages really work with a simulation study the result of the simulation study gave that it’s work as expected and it’s profitable. Also, the hole power plants equipment where simulated but maximizing the temperature for the T_{out} , heated media from the sun and input temperature to the exchanger gave the best result.

T_{in} = input temperature of the medium to the solar reflector
T_{out}= heated media from the sun, input temperature to the heat exchanger
C_p = heat capacity of the medium
ρ = density
$\dot{V}$ = volume flow

The patent in question concerns the control of the medium heated by the sun to an optimal level in order to increase power and obtain more electricity from the thermal solar power plant. The design of the solar power plant is well known and can consist of several types of constructions, but we concentrate on a couple of types of constructions. However, the principles of innovation in each design are the same.

Thermal solar energy became known in the 80s in the United States and has spread around the world concentrated around the warm latitudes with a lot of sun. We describe two types of thermal solar power plants. In the first, solar energy is captured by long solar reflectors where the sun is reflected on a tube that goes into the solar reflector (there may be several connected in series). A medium of molten salt or oil flows into the tube and is heated by the sun. The medium can reach a temperature of 350 - 550^{o} C. The medium then goes through heat exchangers, where the heat is utilized. The heat vapor in steam turbines that drive generators, which supply electricity. The system also includes heated molten salt or oil layers for use at night. After the steam turbines, the water temperature is about 20^{o}C in condensed form. In the second type of reflectors, the sun's rays are reflected from reflection towards the top of a tall tower where the top is heated and heated, the medium is transferred to an expansion vessel, and then to turbines and generator that generate electric current.

In both types, the idea is that the effect $P_{sun} = (T_{out} - T_{in})Cp\dot{V}$ is maximized[2]

We want to maximize the effect of P_{sun} achieving the greatest impact.

V_{in} = input temperature of the medium to the solar reflector
T_{out} = heated media from the sun, input temperature to the heat exchanger
C_p = heat capacity of the medium
ρ = density
$\dot{V}$ = volume flow

We have two variables T_{out}= heated media of the sun, input temperature to the heat exchanger and $\dot{V}$. We locatek T_{out} as and control with and $T_{out\ setp}$ maximize P_{sun} with $\dot{V}$ and $T_{out\ setpoint}\dot{V} \cdot T_{reflector}$[2]

The flow or volume flow is controlled with an optimized PI or PID controller suitable for the reflector part of the power plant. The product $T_{out} \cdot \dot{V}$ is maximized by the solar intensity by adjusting the value $T_{out\ setpoint}$.[2]

The essence and possibilities of the method for optimization are given below:

Maximizing the effect, where you maximize the product with $P = (T_{out} - T_{in})\ cp\dot{V}$ the help of some kind of regulation or with some optimization $T_{out\ setpoint} \cdot \dot{V}$, method: for example, feed forward that works quite well, but you can do it better.

One can imagine some kind of optimal control or cascade control with two loops, but the cascade control probably does not work. I have chosen to do it best with maximizing the set point for $T_{out\ setpoint}$ online with a try. Simulation work has been carried out to find out the possibilities of the entire power plant as well. But the possibilities seem to be the best for the reflectors for optimizing the effect according to the innovation and the easiest, as well as the cheapest to implement.

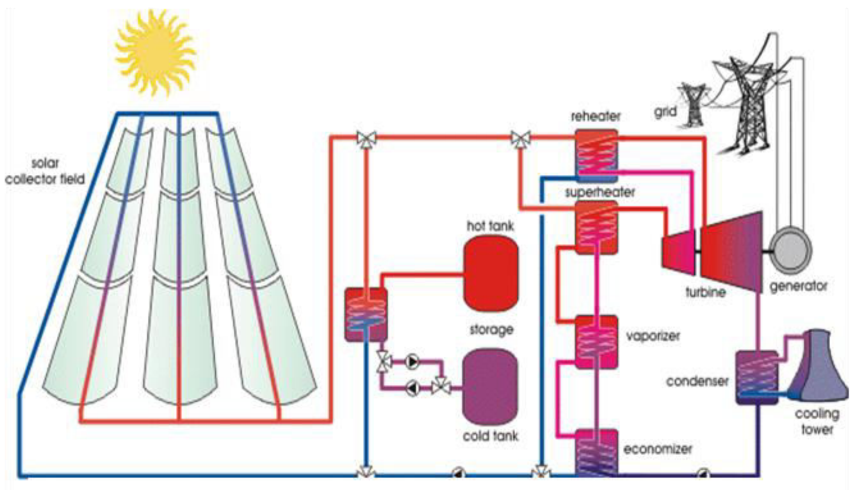
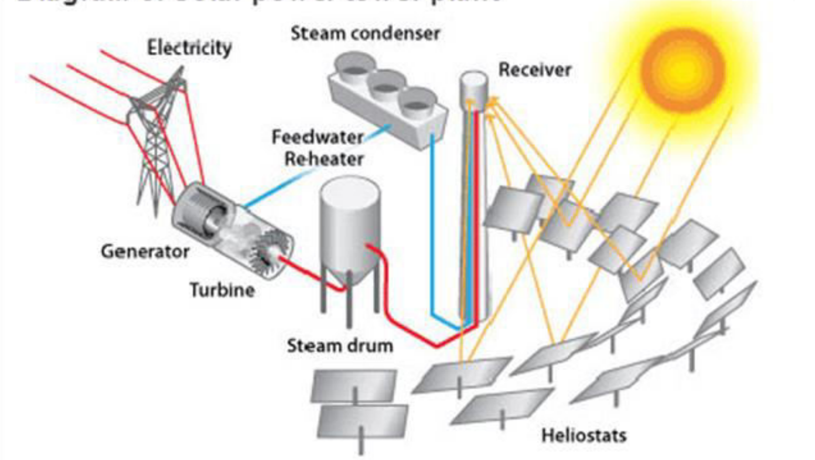


Diagram 3. Solar power tower plant



Evaluation of the effect of control strategies for the thermal solar power plantet

Summary[1]

Control of the flow of circulation affects thermal solar power plants. This is based on two findings, the main potential improvements coming from

a) At high solar intensities, the highest possible temperature of the circulating brine is optimal. Having tight control as close to the maximum allowable temperature as possible improves efficiency.

b) At low solar intensities, it is not worthwhile to have high circulation temperatures, as this results in much higher heat loss from the surface of the solar collector. Thus, having a lower setpoint at lower solar intensities improves efficiency.

1. The simulator

The simulator consists of the following parts:

1. A lookup table for solar intensity as a function of time of day (see Figure 4). The solar intensity is believed to follow the UV index, which was readily available on the internet. The maximum UV index of 12.7 was adopted at 1 p.m.

2. The solar collector, which is a heat exchanger that transfers, transfers solar heat to the circulating brine. The energy flow is assumed to be directly proportional to the UV index and heats the surface of the solar collectors. Heat lost to the environment is proportional to the difference in surface ambient temperature. The heat transfer to the brine is also proportional to the temperature difference between the surface and the brine. The brine is heated in three stages.

3. A steam generator, which generates steam in three stages:

   a. Heating

   b. Evaporation

   c. Overheating

4. A turbine that has a steam head, where steam is collected. The steam flow to the turbine gradually opens between 14 and 15 bar steam pressure.

5. A condenser, in which steam coming out of the turbine condenses at low temperature.

The overall picture of the simulator is given in Figure 1.

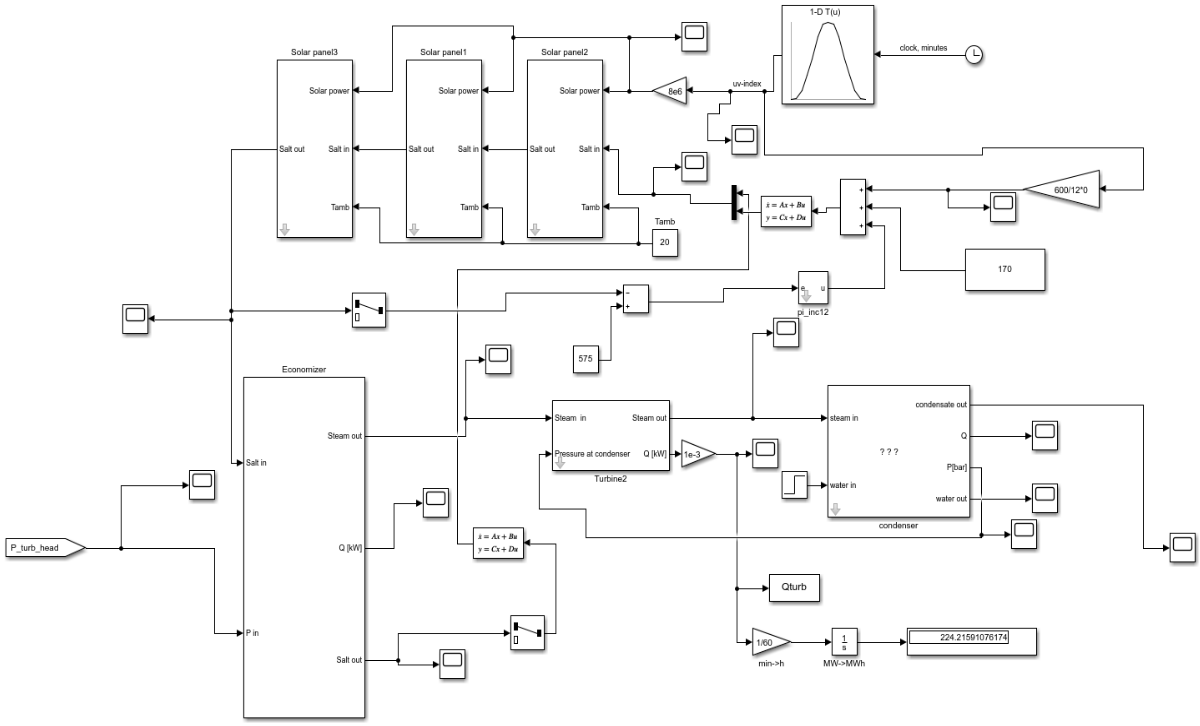


Figure 1: Main view in the thermal solar power plant

2. Temperature control

The solar intensity varies greatly during the time of day, so it is obvious that feedback control of the circulating saline solution is needed. In this study, the temperature of the brine coming from the last heating stage is controlled by means of circulatory flow.[1]

The first study was to test how the total turbine shaft power varies as a function of the set point of the circulating saline. Table 1 and Figure 2 illustrate this, and as can be seen, the higher the temperature the better. There is an upper limit to how hot the brine can be heated, and that will be the limiting factor. Tight control improves efficiency, for example, a 5°C higher setpoint means about 1% higher production.

Table 1: Production as a function of the temperature setpoint of the circulating saline solution

Set point	450	475	500	525	550	575	600	625
Production (MWh)	200.8	206.2	211.1	215.9	220.3	224.2	227.8	231.2

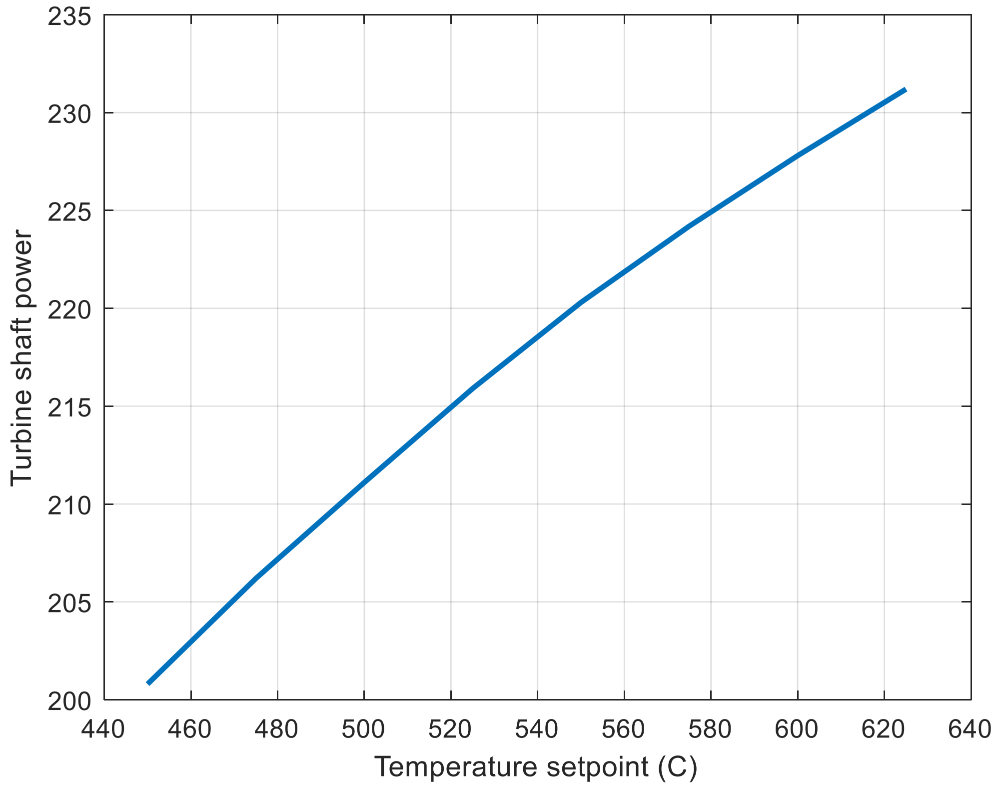


Figure 2: Production as a function of the temperature setpoint of the circulating brine

Figure 3 shows the variations in production, as a function of time of day, and for different setpoints.

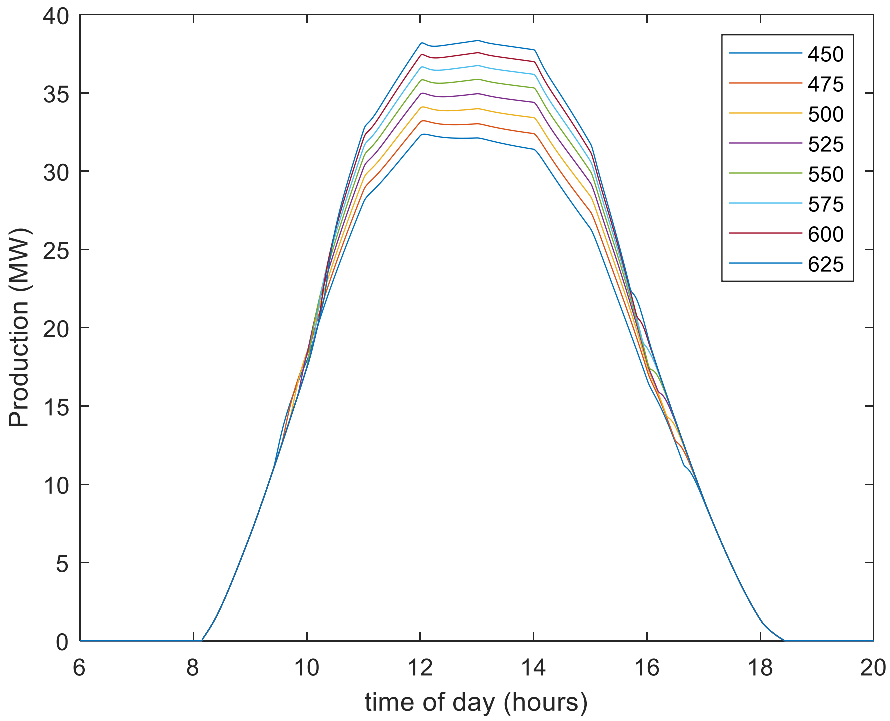


Figure 3: Production as a function of the temperature setpoint of the circulating brine at different times of the day.

It is clear that feedback control is needed to limit the maximum temperature of the brine. A couple of additions were also considered, which are discussed in the following subsections.

2.1 Feedforward

The solar intensity is easy to measure, so it may be possible to use for feedforward control to improve control performance. This would strongly depend on how quickly a change in solar intensity is transferred to the temperature of the brine. This would be due to the mass heated in the solar collectors. Probably, the answer is quite fast, and the solar intensity does not change so quickly, so feedforward is probably not so important for this system. But it's possible to tighten control, and therefore better efficiency, by using feedforward, so that's something to keep in mind.[1]

2.2. Set point at lower temperature at lower solar intensities

A higher temperature means a higher surface temperature of the solar collector, so at certain solar intensities it will likely cost more to raise the temperature. Table 2 shows productions as a function of the brine temperature setpoint, assuming that the UV index is constant 4 from 9:00 to 17:00.

Table 2: Production as a function of brine temperature setpoint, with UV index limited to 4.

Set point	300	325	350	375	400	450	500	550	600
Production	65.6	67.3	68.2	68.3	67.6	64.1	57.6	47.9	34.0

You can see that now we get a maximum at 375°C. This, of course, is highly dependent on the assumed heat loss coefficient chosen for the surface. Table 4 shows the optimal setpoints (with 25 °C accuracy) for different maximum UV indices (the nominal UV index is limited to that value).

Table 2 also shows that it can be an advantage to steer with higher flow with lower setpoints when the temperature is lower, for example in the evening and morning and cloudy weather and slightly higher T_{setp} daytime. Then the effect is maximized depending on the product $T_{setp} \cdot \dot{V}$. Online action from the appropriate point from the reflector can make it possible.

Table 2.1 Further shows that better production can be achieved with on-line measurement in real plants through accurate calculations without the simulation program with calculations from a figure approximately. (OLM) is online measurement. But the best thing should be to do the experiment in a real scale facility. For comparison, an open loop case also has included.

Table 2.1

	Open loop	FB 580°	FF	OLM
Production kWh	368,9	405,8	415	440

Furthermore, it can be said that Feed Back is about 10% better in production than open-loop and feed forward and OLM is 4-10% better in production than Feed Back. Some papers say that open loop can be used in some cases when the control of flow is too slow, especially in large solar power pants or for other reasons, Eduardo F. Camacho; IFAC symposium on advanced control of chemical processes. International Federation of Automatic Control, Singapore, 10-13 July 2012.[3]

Table 2.2: Production as a function of brine setpoint for different UV index caps.

UV index lock	2	3	4	5	6	7	8
Optimal setpoint	225	300	375	425	425	550	> 600

This is a clear spot for improvement over constant setpoint strategy. Approximately between 10 and 16, the maximum temperature is optimal, while in the morning and evening the setpoint should be reduced. A simple strategy might be to use setpoint 300 for UV index below 3 and setpoint 550 for UV index 7 or higher, and linearly interpolate in between. This means on a sunny day in July that the strategy affects production between 9 a.m. and 10 a.m. and 4 p.m. and 5 p.m., see Figure 4.[1]

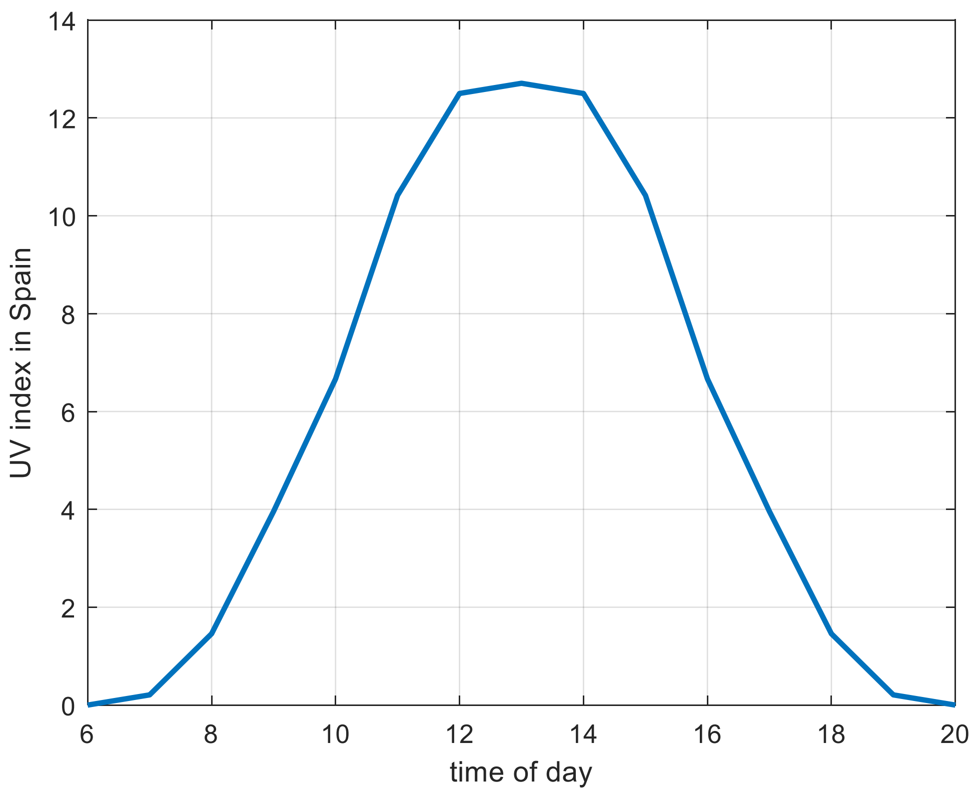


Figure 4: UV index used as the basis for solar intensity.

If the strategy is tested on a case where very low minimum flow (5 kg/min) is used for circulation, the power generation is increased from 210 MWh to 218 MWh compared to having a constant setpoint of 550 °C. If the minimum speed is increased to 200 kg/h, as used in Table 1, an even better daily output (220MWh) is obtained. Having a large minimum flow actually has a similar effect to having a lower setpoint at lower solar intensities, so that's actually the reason why it was found better than having a small minimum speed. Having such a large minimum speed is actually quite counterintuitive, so it's probably not used in practice. So, the production increase of 8MWh (4%) can be realistic. This is what the simulation study says. However, real scale measurements (reflector on-line measurements) can give 4-10% increase in production and be 15% or more compared to open cases, which may be the fact in some practical cases. But even 4% (14% compared to open loop) can be enough.[2,1]

Conclusion

The innovation and control method which is based on a patent application by Tom Forsman[2] where the meaning is to maximize the input temperature to an exchanger in a solar power plant and so to maximize the effect of the solar power plant. A simulation study[1] was made by Dr Jari Böling to verify that the innovation worked as expected and could give some profitable advantages. In the simulation study was also the whole plants with its equipment tested. The heating of the media in the sun reflectors and maximizing the input temperature to the exchanger gave best result. The whole results were positive and wait for a real plant application.

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