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INTEGRATED SOLAR-THERMAL POWER PLANTS: TPP BITOLA CASE STUDY

Vlatko Cingoski, Saso Gelev*, Goce Stefanov* and Vasilija Sarac**

Keywords: *Emission reduction, Photovoltaic effect, Solar energy, Solar-thermal power plants.*

Abstract: The potentials for usage of the solar energy as a renewable energy source, whether by its conversion only into heat, indirect conversion into electricity using a prior generated thermal energy, or direct conversion of solar energy into electric energy using the photoelectric effect, are enormous. This paper presents a study for the development of an integrated solar-thermal power plant (ISTPP) for repowering the existing goal-fired TPP Bitola. In the proposed plant, firstly solar energy is concentrated and converted into thermal energy. Then, two potential scenarios for utilization of the obtained thermal energy are investigated: (1) for direct heating of a working fluid and electricity production in new thermal power plant, or (2) as a partial heat energy source which could replace the existing thermal energy generated by burning coal for steam and electricity generation in the existing units of the TPP Bitola.

1. INTRODUCTION

The main energy topic of the debate today is providing an adequate solution to the main question: *How to achieve sustainable energy development?* [1] In this context, sustainable energy development means how to meet consumers' energy requirements when taking into account:

- steady increase in energy consumption needs,
- steady increase of prices of primary and secondary energy resource,

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- reduction of fossil fuel energy resources worldwide,
- emission reduction of greenhouse gases, and
- protection of the environment and our planet as a whole.

Today, it is mainly considered that the solution of this energy problem could be sought into two potential directions:

1) increasing energy efficiency, or reducing of the energy consumption, and/or

2) increase utilization and continuous include additional renewable energy sources, primarily the energy of the Sun and its derivatives such as wind energy, tidal energy and water waves in a suitable package of economic acceptable energy sources.

Because the last two types of energy are strictly locationally limited, the wind energy and the solar energy really represent a significant energy potential, which unfortunately today is either totally neglected or only modestly appears on the energy market.

In this paper a brief analysis of new and potential technology for utilization of solar energy as a natural and theoretically inexhaustible renewable energy source is presented. The recently developed study for repowering of the TPP Bitola [2] by means of a new so-called integrated solar-thermal power plant (**ISTPP**) technology is based on hybrid utilization of solar power and any other mostly desirable fossil fuel, in our case coal. Firstly, harvesting of the solar energy is done by means of a concentrated solar power plant. Later, using adequate heat exchangers the harvested solar energy could be used for water heating, either directly for production of steam and generation of electricity in the whole new, however TPP with smaller installed capacity, or as a partial heat source that would be reheated burning coal (or other fossil fuels), to produce steam and to generate electricity using the existing unit of the TPP Bitola.

Evaluations of major technical and economical benefits are presented in this paper. The cost of investment is also given and compared against achieved environmental benefits and fossil fuel savings. Finally, the influence which the increased investments and O&M cost of such integrated power plant might have on the electricity prices is also presented, showing that this new and emerging technology deserves further investigations in the future as a potential model for the development of contemporary and more environmentally friendly upgrades of the existing fossil fueled based TPP.

2. SOLAR ENERGY UTILIZATION

The Sun is the main primary energy source on the Earth. As a result of the thermonuclear reactions occurring deep in its interior, huge amounts of energy is distributed radial from the Sun's surface in all directions. It is assumed that every second the Sun emits energy with a value of about $400 \cdot 10^{24}$ W, and that will last in the next 5 billion years. From this huge amount of energy, the Earth gets a very small portion, but still considerably large amount of energy on average of 1.37 kw/m^2 annually.

Presently known technologies for utilization of the solar energy schematically are shown in Fig. 1. In general, there are three main technologies for harnessing solar energy:

1) Direct conversion into electricity using photovoltaic effect (i.e. PV cells),

2) As an alternative fuel to other fossil fuels for heating using solar heat collectors, and

3) By means of the so-called solar-thermal power plants that can be found in various appearances [2].

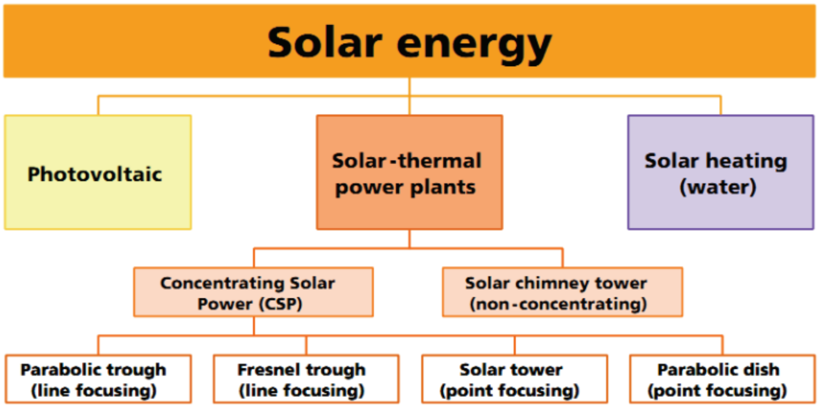

Fig. 1: Methods for solar energy harnessing.

The oldest method for harnessing the solar energy was probably using this energy for substituting energies obtained from other energy sources. Today the most promising method for harnessing solar energy on large scale is probably the technology based on solar-thermal power plants. Recently, the PV cells appeared on the energy market as emerging power source, unfortunately only on limited scale. It is obvious that their role on the energy market could not be significant, mostly due to the following reasons:

- Photovoltaic energy converters (PV cells), provide conversion of a direct energy of the sunlight into electricity, thus this kind of power generation practically works only in the period when there is a direct sunlight i.e. only during the day. It is an inefficient system for energy production because electricity is needed during periods when there is no sunlight, too. Therefore, special storage devices are needed for storing electricity during the daylight in order to be used in other periods. On the other hand, the heat storages are much simpler, cheaper and more efficient than electricity storages, thus the thermal energy stored during the day without large losses could be turned into electricity at night, making solar thermal power plants economically the most favorable way to convert solar energy into electric energy.
- Solar-thermal power plants operate on the principle of concentrating the solar energy to create a high temperature of the working fluid which is later used for the propulsion of the corresponding turbine connected to an electrical generator and producing electricity. The working fluid might be liquid or gas, such as water, oil, various molten salts, air, nitrogen or helium, while as turbines usually could be used steam or gas turbines. These plants are more efficient than PV cells, (30% to 40%) and with a capacity of 10s and up to 100s MW, which is very important in electricity generation.

Having all these in mind, a study was performed to investigate the possibility of full or partial replacement of the coal as fossil fuel in the TPP Bitola [3]. Since The Republic of Macedonia has large global solar irradiation value of approximately 1.53 kW/m^2 annually, the general aim of the study was to perform technical and financial investigation of the potentials for the development of ISTPP as a repowering scheme of the existing TPP Bitola, as shown in Fig. 2.

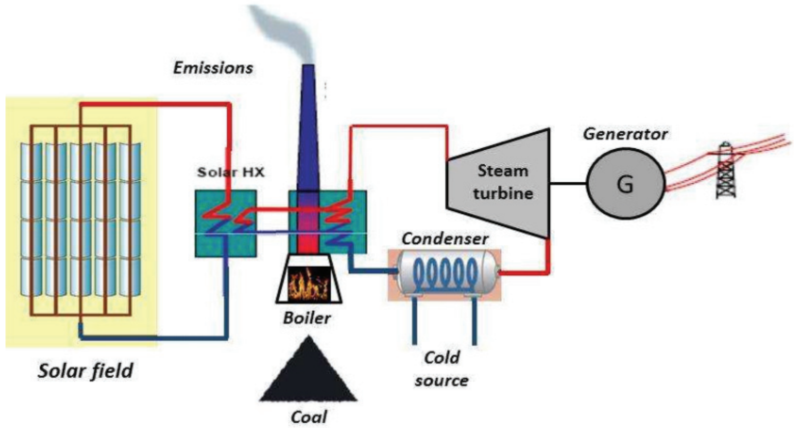

Fig. 2: Scheme of the integrated solar-thermal power plant.

3. POTENTIALS FOR DEVELOPMENT OF ISTPP

The first step towards developing such integrated or hybrid TPP was to define the potential for solar energy harvesting and the available free space in the vicinity of the TPP to be used for that purpose. Today, on the solar market for the concentrated solar power (CSP) there are two commercially available technologies:

1) Parabolic trough (PT) technology, and
2) Liner Fresnel trough (LFT) technology.

Both use a so-called line focusing on the solar energy in the piping system through which a working fluid that extracts solar energy flows and transports it into suitable thermal reservoirs or thermal storage system. The major difference between these two systems is the shape of the solar mirrors, which in case of PT mirrors have curved parabolic shape, while in case of LFT mirrors are flat, yet with appropriate spatial position to focus the solar energy into a linear piping system. The other two technologies mentioned in Fig. 1, and Fig. 3, the solar tower and parabolic dish were not taken into consideration because they are still not in commercial use.

Obviously, to obtain the large amount of harvested solar energy, it is necessary to have a huge amount of reflecting mirrors, and consequently a large available area for locating them. Surrounding TPP Bitola, several potential free areas were investigated as shown in

Fig. 4. As the most suitable the location field n°1 was selected for several reasons, such as closeness to the existing power plant, accessibility, available space and distance from the local pollutants, such as flying ash, coal dust and other emission particles, etc. This field has a total available area of 390,000 m^2 which, in accordance with the study could be enough for installation of concentrated parabolic solar panels with maximal capacity of 50 MW_{th}.

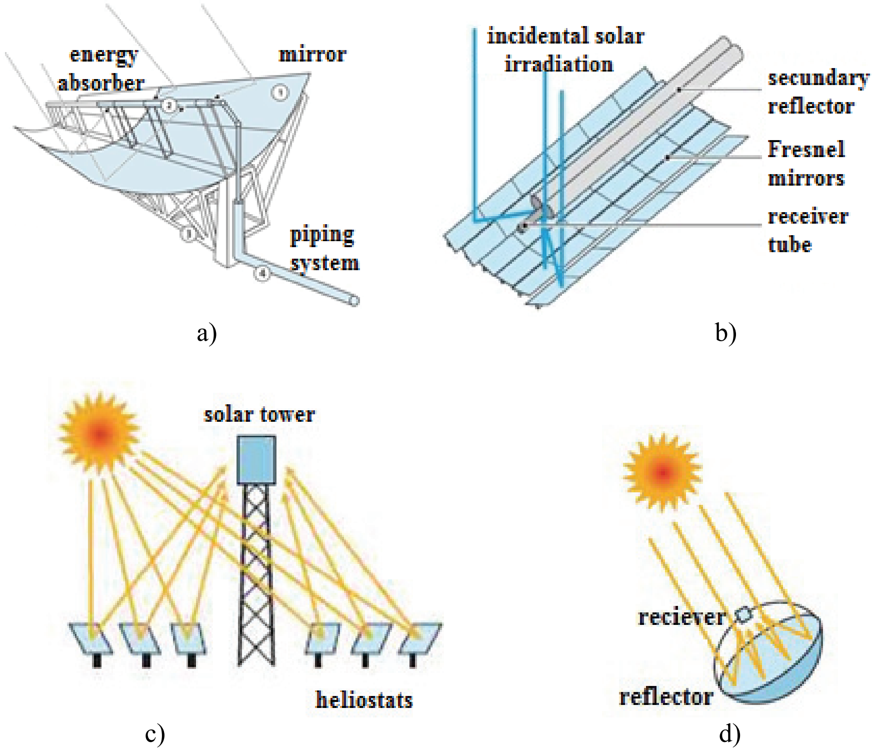

Fig. 3: Concentrated solar power: (a) Parabolic trough (PT), (b) Linear Fresnel trough (LFT), (c) Solar tower, and (d) Parabolic dish.

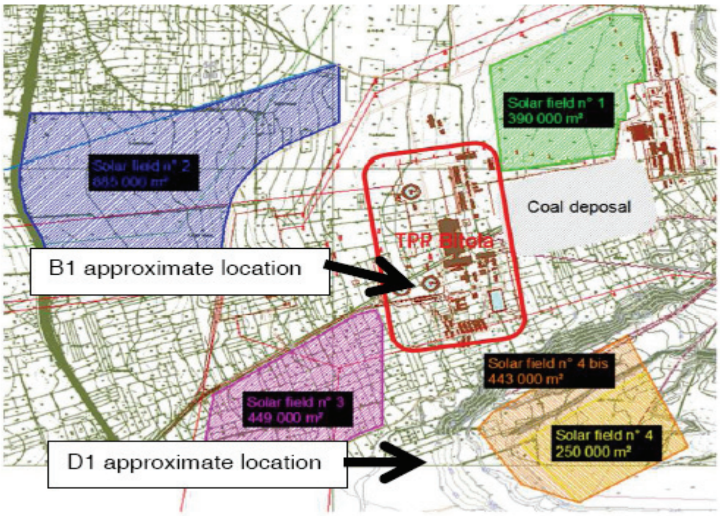

Fig. 4: Investigated potential location for concentrated solar fields (n°1 to n°4) and geological bore logs (B1 & D1).

Since the installed electric power unit at TPP Bitola has capacity of 225 MW, it is readily seen that the total thermal capacity of 50 MW_{th} obtained by the concentrated solar field is not enough to entirely replace the existing fuel. Therefore, two possibilities remain, either: (1) to construct an entirely new TPP with much lower installed capacity, or (2) to use the generated solar energy as partial replacement for the thermal energy needed by the existing thermal power plant, currently supplied by the coal firing.

The second approach seemed more viable and was accepted as preferred. However, even with this approach, several possible options for integration of the generated solar heat generated with the existing TPP had to be considered, such as:

1) Injection in the cold reheat stream,
2) Boiler preheating,
3) HP feed water heater (FWH) by-pass, and
4) LP feed water heater (FWH) by-pass.

Options for remodelling of the existing power plant are summarized in Table 1. For safety reasons and after detailed consultation with the producers of the boiler and turbine, the Option 2 was selected since it was easier to perform a modest remodelling of the boiler instead of a huge and uncertain remodelling of the turbine.

Table 1: Considered solar heat integration options.

Integration options	Temperature of the primary fluid	Pressure of the primary fluid	Conventional equipment impacted
Option 1	340°C	30 bar	Turbine
Option 2	285°C	155 bar	Boiler
Option 3	250°C	155 bar	Turbine
Option 4	160°C	7.2 bar	Turbine

In the selected Option 2, the solar-thermal energy is used to raise the feed water temperature between the last feed water heater and the inlet of the boiler, as shown in Fig. 5. This aims at decreasing the thermal power of the boiler during the sunny hours, avoids any modifications on the operating parameters of the turbine and does not impact the boiler efficiency.

4. EXPECTED TECHNICAL PERFORMANCES

In accordance with the measured data, the performance of the solar field is modeled and presented on Fig. 6. As expected, during the summer months when the amount of solar energy and the number of solar hours is larger, the heat production is larger and the energy substitution is also larger, as can be seen from Fig. 7. The major ISTPP performance data is presented in Table 2.

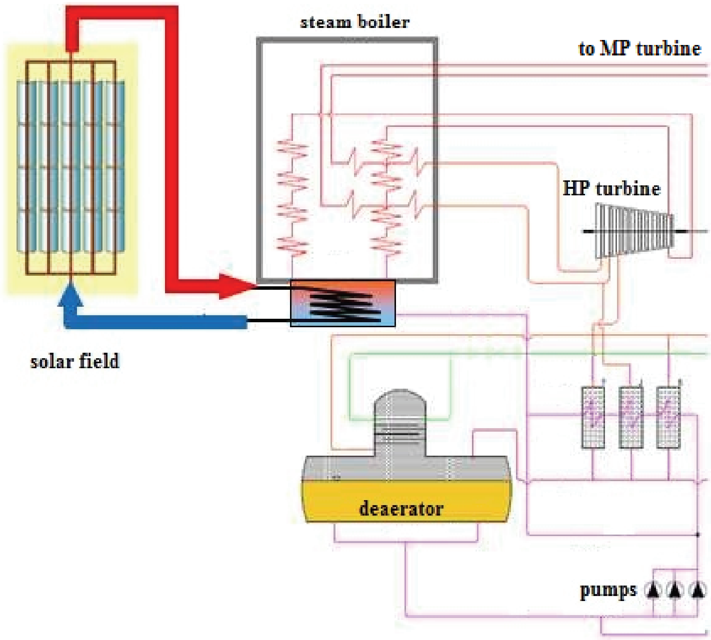

Fig. 5: Basic scheme of the boiler preheating integration option.

Table 2: Major ISTPP performance data.

Annual average solar heat production	53	[GWh $_{th,solar}$]
Solar heat to elec. conversion eff.	48	[%]
Solar electricity produced	25	[GWh $_{el,solar}$]
Elec. produced by one coal-fired unit	1,500	[GWh $_{elec}$]
Solar elec. production / one unit	1,67	[%]
Elec. produced by TPP Bitola	4,500	[GWh $_{elec}$]
Solar elec. production ratio / TPP Bitola	0,55	[%]

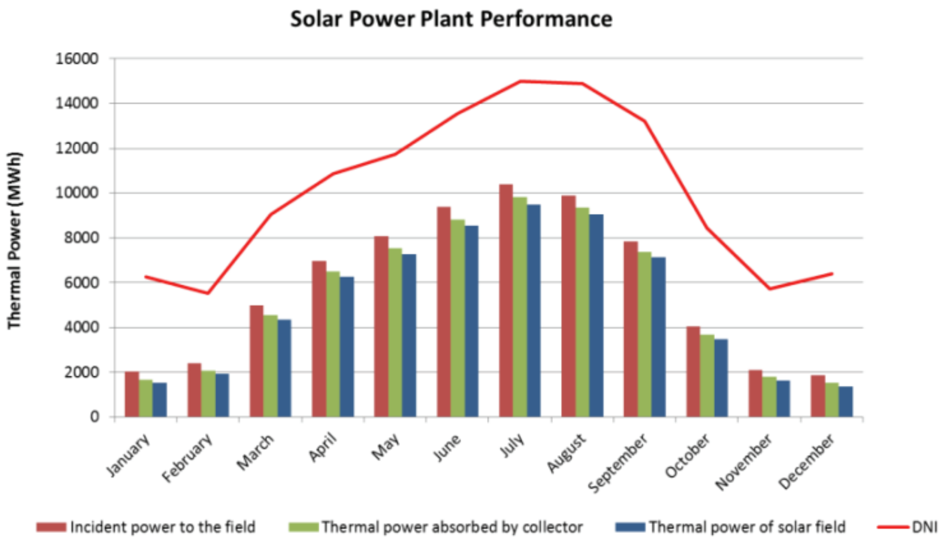

Fig. 6: Thermal performance of the solar field.

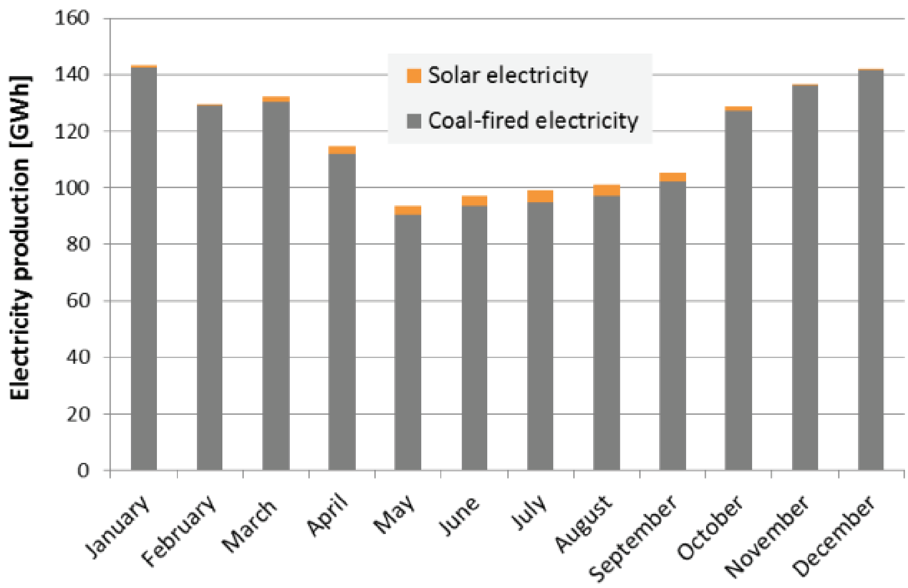

Fig. 7: Monthly net electricity production of the hybrid solar and coal power plant.

5. EXPECTED FINANCIAL PERFORMANCES

The expected financial performances initially were analyzed for parabolic trough (PT) and linear Fresnel trough (LFT) technology, separately. It was found that the differences in the investments are marginal, since the PT technology needs less PT mirrors, less available land and has a little better efficiency than the LFT technology. However, the price of PT mirrors is a little higher than the one of LFT mirrors, and the O&M of the LFT mirrors is easier and cheaper. The expected investment cost and O&M of the solar field based on LFT technology are summarized in Table 3. The expected economical data and their influence on the prices of the generated electricity in the TPP Bitola, are given in Table 4.

As it can be seen from Table 4, the investment in solar field and construction of new hybrid power plants based on integration of solar field energy generation and conventional coal-fired TPP could be a very successful approach towards the substitution of fossil fuels with environmentally friendly renewable energy sources, in this case solar energy. The potentially expected negative financial effects could be observed as a modest increase of prices of the generated electricity for the amount of 0,21, 0,07 and 0,05 €cents/kWh$_{el}$ on the existing production prices of one unit, the whole TPP Bitola (three units), and the entire ELEM’s energy production average prices. If these prices increases are translated into percentage increase in respect to the existing regulated tariff, these price increase amounts for 5,2%, 1,8% and 1,3%, respectively which is financially a very attractive solution compared either with the generation price of PV solar power plants, or investment in other emerging technologies such as carbon-capture storage power plants (CCSPP).

Table 3: Investment and O&M cost for LFT solar field.

Investment cost	
Intermediate heat exchanger	1,500,000 ¤
Solar field preparation	500,000 ¤
Auxiliaries	1,000,000 ¤
Solar field collectors	21,744,000 ¤
Heat pipes (solar field to TPP)	1,200,000 ¤
Contingencies	5,188,800 ¤
Total:	**31,132,800 ¤**
O&M cost/annually	
Maintenance *(1% of the Investment)*	311,328 ¤
Management fee *(8,800 ¤/man/year)*	70,400 ¤
Water consumption	900 ¤
Insurance *(1% of the Investment)*	311,328 ¤
Total:	**693,966 ¤**

Table 4: Marginal cost and tariff changes for the ISTPP.

Annual unit production	1,500,000	MWh_{el}
Annual TPP Bitola production	4,500,000	MWh_{el}
Annual ELEM production	6,000,000	MWh_{el}
Solar electricity production	25,745	MWh_{el}
portion of unit production	1.72	%
portion of whole TPP Bitola	0,57	%
Solar electricity production cost	16,49	€cents/kWh_{el}
Added marginal cost *I1 unit*	0,21	€cents/kWh_{el}
/TPP Bitola	0,07	€cents/kWh_{el}
/total ELEM production	0,05	€cents/kWh_{el}

6. CONCLUSION

In this paper, a new approach for repowering of the existing, especially coal-fired TPP is presented. The concept is based on integrated utilization of the existing heat generation system of coal-fired TPP with the development of concentrated solar field for generation of additional heat utilizing solar energy as renewable energy resource. The technical and economical benefits of such a scheme are presented for the existing TPP Bitola.

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