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Research Article

Efficiency Improvement, Emission Control & Energy Saving in NGCC Power Plant by using Advanced Solar Techniques

V S R Kishore[†], Y V Ramana Murthy[†] and B S S Phanisankar[†*]

[†]Mechanical Engineering Department, JNTUK, BVC Engineering College, Odalarevu, India

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Abstract

Efficiency Improvement, Emission Control and Energy Saving i.e. Fuel Consumption (EEE) these three factors are play a very key role in every power generation Industries but as per the Surveys majority of industries world over are still failure to achieve these factors at a time once the industries are really ignore these factors, future generation face a lot of problem so theses mainly concentrate on this area to saving this EEE at a time with some endless natural resources i.e. solar energy. A solar thermal assisted NGCC power plant was developed to investigate the impact on plant efficiency, output and CO2 emission with addition of solar thermal energy. An exemplary NGCC power plant was selected as Base Case of this study it is a Saudi Electricity Company PP12 Combined Cycle Power Project. Here I conducted an audit to know about the efficiency of power plant and identify, where the losses located and reasons for that & Find the end solutions to that problem. The power plant capacity is 2050.9 MW. In this Model a solar thermal energy input of 26 MW to the Heat Recovery Steam Generation (HRSG), the duct firing should be shut off, up to 2350 kg/h natural gas would be saved and 6.5 t/hr. CO2 emission would be eliminated. However, there would also be some loss in power from combined cycle i.e. approximately 4.08 MW. Another solar input approach shows 14.30 MW additional electricity would be generated with 42 MW solar thermal addition. The thermodynamic analyses in this theses demonstrated the possibilities to utilize the solar thermal energy to reduce fuel consumption and CO2 emission at the same time to increase the efficiency of a NGCC power plant.

Keywords: *NGCC Power Plant, Solar Assisted, Efficiency Improvement, Emission Control, Energy Saving.*

1. Introduction

Solar thermal power plants produce electricity in much the same way as conventional power Stations. The difference is that they obtain their energy input by concentrating solar radiation and converting it to high temperature steam or gas to drive a turbine or engine. Four main elements are required: a concentrator, a receiver, some form of heat transport media or storage, and power conversion. Many different types of systems are possible, including combinations with other renewable and non-renewable technologies.

Current trends show that two broad pathways have opened up for large scale delivery of electricity using solar thermal power. One is the ISCC-type hybrid operation of solar collection and heat transfer combined with a conventional state-of-art combined cycle gas-fired power plant. The other is solar-only operation, with a conventional steam turbine, increasing use of a storage medium such as molten salt. This enables solar energy collected during the day to be stored and then dispatched when demand requires.

A major benefit of solar thermal power is that it has little environmental impact, with none of the polluting emissions or safety concerns associated with conventional generation Technologies. There is no pollution in the form of exhaust gases during operation. Decommissioning a system is unproblematic. Each square meter of surface in a solar field is enough to avoid the annual production of 200 kilograms (kg) of carbon dioxide. Solar power can therefore make a substantial contribution towards international commitments to reduce emissions of greenhouse gases which contribute to climate change.

A scenario prepared by Greenpeace International and the European Solar Thermal Power Industry Association projects what could be achieved by the year 2020 given the right market conditions. It is based on expected advances in solar thermal technology coupled with the growing number of countries which are supporting projects in order to achieve both climate change and power supply objectives.

Over the period of the scenario, solar thermal technology will have emerged from a relatively marginal position in the hierarchy of renewable energy sources to achieve a substantial status alongside the current market leaders such as hydro and wind power. From a current level of just 354 MW, by 2015 the total installed capacity of solar thermal power plants will

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*Correspondig author: **B S S Phanisankar** have reached 5,000 MW. By 2020 additional capacity would be rising at a level of almost 4,500 MW each year.

2. Energy Audit

"The strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems"

The objective of Energy Management is to achieve and maintain optimum energy procurement and utilization, throughout the organization and:

- To minimize energy costs / waste without affecting production & quality
- To minimize environmental effects.

2.1 NGCC Plant Audit Details

PP-12 Project is a new green field combined cycle plant. The project consists of eight (8) GE PG7241 (FA) gas turbines with a nominal capacity of 140-170 MW each one at rated site conditions, capable of operating in a simple cycle mode, plus eight (8) Heat Recovery Steam Generators (HRSGs), two (2) steam turbine generators (STGs) and the necessary balance of plant auxiliary equipment to provide a complete combined cycle (CC) power plant operation from fuel and raw water receiving to high voltage interconnection. With the above equipment's, the basic configuration will be based on two blocks, each one with 4 GT´s+4 HRSG´s+ 5 feed water pumps+ 1 ST+ 1 ACC, and with a set of common auxiliary systems such as:

- Liquid Fuel unloading, treatment and storage system (ASL and distillate).
- Fuel gas conditioning and compression system.
- Water pre-treatment systems (Raw water, Demi water, potable water, service water).
- Effluent treatment systems (Oily water, chemical drainage, sanitary drain, quenching water).
- Chemical dosing system.
- Closed Cooling Water system.
- Hydrogen system.
- Compressed Air system.
- Medium Voltage and low voltage system.
- Emergency diesel generators
- Overall Control systems and instrumentation.

It is important to point out that this power plant configuration also includes a bypass stack with diverter damper between the GT and the HRSG, being these devices the main equipment to separate the simple cycle from the combined cycle.

3. Model Description

CSP Collection system was chosen to perform this investigation, in the solar collection system HTF will be heated up to 550˚C and goes into solar steam generator (SSG) to produce system. Then, the cold HTF flows back to cold storage tank at 300˚C.

Table 1 Solar Thermal Power Plant Base Data

Parameters	Units	Values
Technology	-	Power Tower
HTF Type	-	Molten Salt
Receiver Inlet Temperature	˚C	300
Receiver Outlet Temperature	˚C	550
Thermal Collection Efficiency	%	77

3.1 Power Tower Solar collection systems

In power tower concentrating solar power (CSP) systems, numerous nominally flat, sun-tracking mirrors, known as heliostats, focus sunlight onto a receiver at the top of a tall tower. The basic elements of a power tower configuration. Two commercial solar tower system configurations are in active commercial development today. In one configuration, called the indirect configuration, a working fluid7 other than water or gas is heated in the receiver, held in a TES system if present, and then sent to a steam generator train to produce steam that, in turn, drives a conventional turbine generator to produce electricity.

Current commercial designs using this concept are using molten nitrate salts 8 as the working fluid because of its superior heat-transfer and energy-storage capabilities. In the other configuration, called the direct configuration, water/steam is used as the working fluid, heated in the receiver and sent directly to the Rankine turbine inlet. The direct steam solar receiver may have separate receiver sections for steam generation, superheating, and even reheating if applicable. Another direct configuration, not yet commercialized, is to use a gas working fluid like air or CO2 to drive a Brayton or Rankine cycle power system.

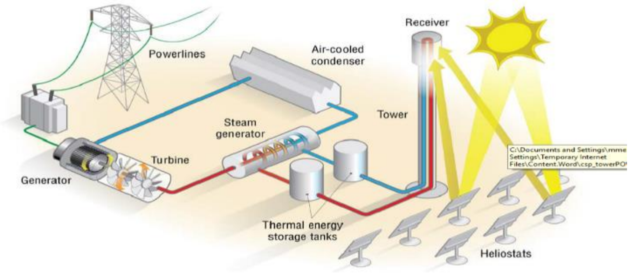


Fig.1 Basic subsystems of a molten salt power tower configuration

3. Solar thermal energy assisted NGCC power plant

Through calculations it is possible to determine the critical parameters of a power plant. In this work, such calculations were carried out to evaluate the impact of changes in the boundary conditions, the introduction of a new component or the modification of a component.

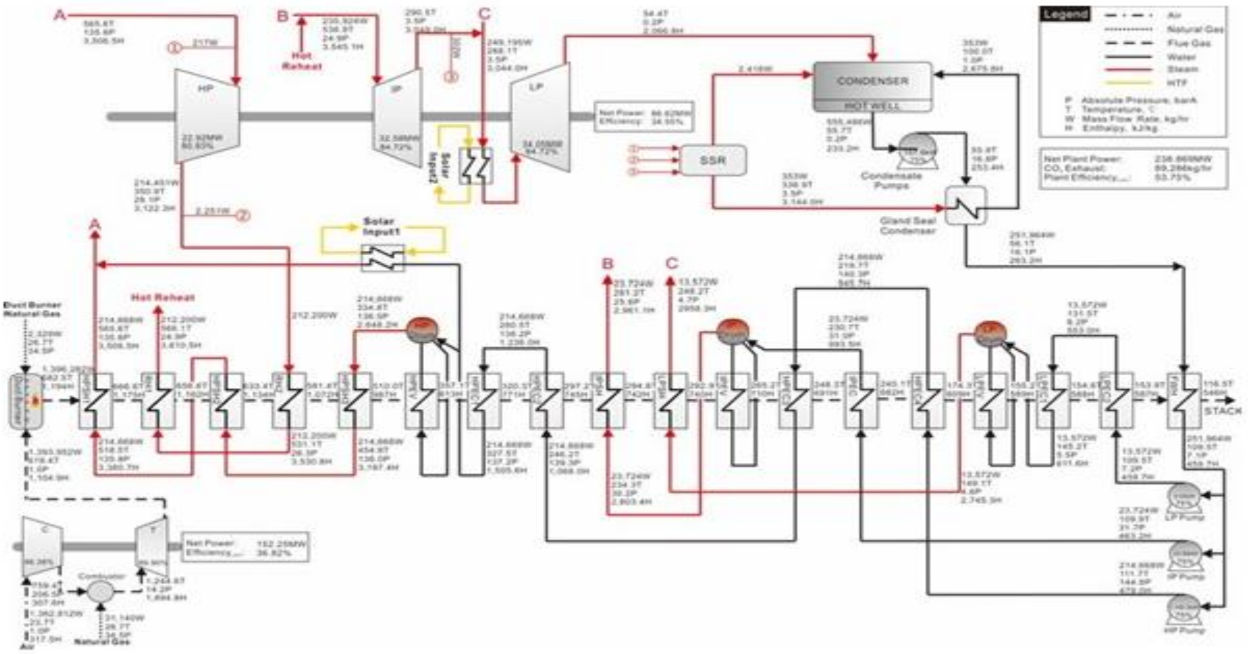


Fig.2 A detailed process diagram for gas turbine and steam turbine cycle portion of NGCC power plant with no solar thermal energy input at PP12 Combined Cycle power plant

One-dimensional steady-state modelling is suitable to study the effects on the whole power cycle. This type of modelling does not provide any details on the dynamic events taking place in the components, but is excellent in giving a more global view of the performance. The principle is that each component has a set of inlets and outlets at which the stagnation properties are calculated using thermodynamic equations.

Table 2 Plant Maintenance Data

Parameters	Units	Values
Ambient and plant performance		
Ambient pressure	Bar	1.01
Ambient temperature	˚c	25
Total plant power output	Mw	2050.9
Gas turbine		
Natural gas, lhv	Kj/kg	45570
Compressor inlet pressure	Bar	1.09
Compression ratio	-	15.1
Compressor efficiency	%	37
Turbine efficiency	%	33
Gas turbine cycle output	Mw	170
Steam cycle		
Steam turbine efficiency hp/ip/lp	%	60
Steam cycle output	Mw	370
Condenser temperature	˚c	36
Hrsg		
Duct firing natural gas flowrate	Kg/s	11.7
Hrsg flue gas inlet pressure	Bar	0.9-1
Hrsg flue gas inlet temperature	˚c	690
Hrsg flue gas outlet temperature	˚c	110
Hrsg flue gas flowrate	Kg/s	Na

Heat Recovery Steam Generator In the design of an HRSG, the first step normally is to perform a theoretical heat balance which will give us the relationship between the tube side and shell side process. We must decide the tube side components which will make up our HRSG unit, but only it considers the three primary coil types that may be present, Evaporator, Super heater and Economizer. Evaporator Section: The most important component would, of course, be the Evaporator Section. So an evaporator section may consist of one or more coils.

Once Observe the Process Diagram given below then we have clarity about the solar panel location and efficiencies differences.

The plant performance was evaluated by Combined Cycle Efficiency as

$$\eta_{\text{cc}} = \frac{W_{\text{GT}}+W_{\text{ST}}}{(\dot{m}_{\text{NG,GT}}+\dot{m}_{\text{NG,Duct Burner}})\cdot LHV_{\text{NG}}}$$

3.1 Solar Thermal Energy Integrated Strategies

The processing diagram illustrates the complexity of the NGCC systems and raises the issue of where to add the solar thermal energy such that the performance of power plant is improved as much as possible. In this investigation, the possibilities to integrate solar thermal energy to HRSG and the steam cycle were discussed. For the gas turbine, the potential of being added thermal energy to improve its performance is less. Therefore, only the HRSG side and steam Rankine cycle side have been investigated.

3.2 Heat Recovery Steam Generator Side (Solar Input 1)

With solar heat available at a maximum of 550˚C and minimum of 300 ˚C, potential location for getting highest converting rate of solar thermal energy to electric energy is HP Circuit. To avoid steam being generated in the economizer, which would cause a flow blockage, it is reasonable to add solar thermal energy downstream of economizer.

The HPEV in HRSG has largest heat transfer rate and temperature difference between steam and flue gas. To withdraw saturated water then send to solar steam generator will reduce the enthalpy change of flue gas passing through the HPEV and less fuel burning in the duct burner.

The location of solar input 1 marked in process diagram shows saturated water extracted from HPEC1 outlet goes to SSG then it is injected back to HP turbine inlet. The consequence is heat transfer rate in HPEV decreasing lead to duct burner could be shut off as no duct firing case in this theses. However the flue gas temperature entering the HRSG, main steam and reheat steam temperatures would also decrease which will cause plant power loss as penalty.

Table 3 Solar Input 1 Results

Parameters	Units	Base Case	Solar Input1
Solar thermal energy Input	MW	0	26
Duct Firing Natural Gas Flow rate	Kg/s	11.7	0
Gas Turbine Output	MW	170	170
Gas Turbine Efficiency	%	33	33
Steam Cycle Output	MW	370	361
Steam Cycle Efficiency	%	60	68
Total plant Output	MW	2050	2042
Plant Efficiency	%	56	61.4
CO2 Emission	Kg/s	42	38
HRSG Flue gas Inlet Temperature	˚C	690	625
HRSG Flue Gas Outlet Temperature	˚C	110.2	110.2
HP Steam Inlet Temperature	˚C	570	556

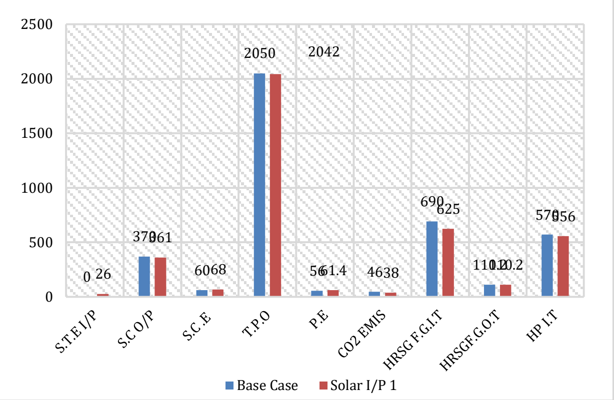
3.3 Steam Turbine Side (Solar Input 2)

On the steam side, the solar thermal energy source with temperature range from 300˚C to 500 ˚C determine the LP turbine would be the only possible location to inject solar thermal energy with feasible design. The LP turbine inlet steam with temperature of 326 ˚C would be heated to increase enthalpy then goes into a solar steam super heater. This approach will increase the LP turbine output and increase the steam quality at LP turbine outlet. The maximum level of solar thermal energy addition to location of solar input 2 is as power boost case.

4. Simulation Results

To compare the impact of two different solar input approaches on combined cycle efficiency, net power output and CO2 emission intuitively, the assumptions made as followed:

The flue gas temperature at the HRSG outlet and pressure distribution in the steam cycle is fixed. The gas conditions are same as the base case. Heat transfer coefficient and heat transfer surface areas are in the HRSG do not change as a result of T

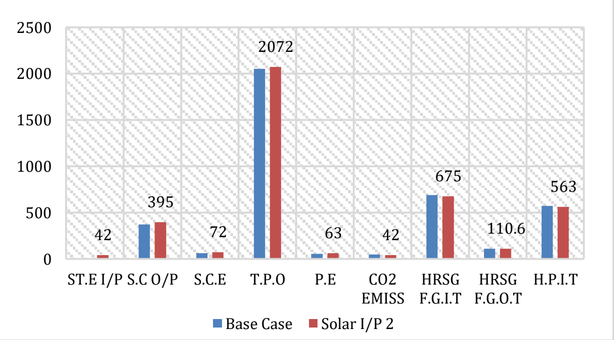


Graph 1 simulation results of base case Vs solar I/P 1

The below table describe the results for the base case, the no duct firing case (Solar Input 2)

Table 4 Solar Input 2 Results

Parameters	Units	Base Case	Solar Input2
Solar thermal energy Input	MW	0	42
Duct Firing Natural Gas Flow rate	Kg/s	11.7	10.8
Gas Turbine Output	MW	170	170
Gas Turbine Efficiency	%	33	33
Steam Cycle Output	MW	370	395
Steam Cycle Efficiency	%	60	72
Total plant Output	MW	2050	2072
Plant Efficiency	%	56	63
CO2 Emission	Kg/s	46	42
HRSG Flue gas Inlet Temperature	˚C	690	675
HRSG Flue Gas Outlet Temperature	˚C	110.2	110.6
HP Steam Inlet Temperature	˚C	570	563

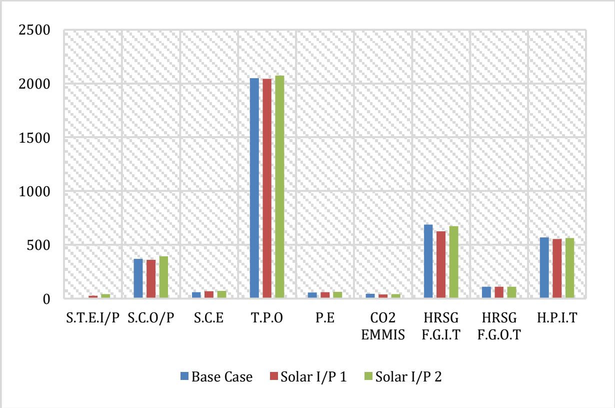


Graph 2 Simulation Results Base Case Vs Solar Input 2

The below Table 5 describe the results for the base case, the no duct firing case (Solar Input 1) and power boost case (Solar Input 2)

Table 5 results for the base case, the no duct firing case (Solar Input 1) and power boost case (Solar Input 2)

Parameters	Units	Base Case	Solar Input1	Solar Input2
Solar thermal energy Input	MW	0	26	42
Duct Firing Natural Gas Flow rate	Kg/s	11.7	0	10.8
Gas Turbine Output	MW	170	170	170
Gas Turbine Efficiency	%	33	33	33
Steam Cycle Output	MW	370	361	395
Steam Cycle Efficiency	%	60	68	72
Total plant Output	MW	2050	2042	2072
Plant Efficiency	%	56	61.4	63
CO2 Emission	Kg/s	46	38	42
HRSG Flue gas Inlet Temperature	˚C	690	625	675
HRSG Flue Gas Outlet Temperature	˚C	110.2	110.2	110.6
HP Steam Inlet Temperature	˚C	570	556	563



Graph 3 Total Simulation Results

Conclusion

The basic concept is not new, in fact, it is believed to be as old as the steam cycle technology itself. The potential benefits of solar-fossil hybrid integration have already been widely recognized and several feasibility studies have been carried out by various authors. A more systematic approach for proper evaluation of efficiency gain is necessary, for several representative types and sizes of conventional utility steam plants, is necessary. Simplified and normalized, but straightforward optimization studies are possible to perform for finding the optimum penetration of solar power in the fossil-fired steam cycle, taking into account both technological and economy values. Integrated hybrid solar configurations help also with avoiding the problems related to frequent start-stop cycles for the steam turbines in solar-only thermal power plants, detrimental to the life of the turbine and increasing its maintenance costs.

The main motto of the analyses were to determine the efficiency improvement i.e. power output of NGCC power plants as a result of addition of solar thermal energy. In addition, the advantages of integrated solar thermal energy at the HRSG side is to reduce fuel consumption (Natural Gas) i.e. Energy saving at the same time to decrease the greenhouse emission. The other consideration needs to be emphasized is that it was assumed that the solar collectors would be added to an existing combined cycle power plant with no physical changes made to various heat exchangers in the HRSG.

If configuration of steam cycle were designed specifically to accommodate solar thermal input, then it is likely that larger cycle efficiencies could be obtained. However, the analysis of a solar assisted NGCC having an optimized steam cycle configuration of the hybrid these two injection strategies. The thermodynamic performance and energy conversion efficiency in solar-augmented feed water preheating for conventional stem cycles is close to the one achieved by large-scale high-temperature advanced steam cycles. Feed water preheating is undoubtedly a viable option for wider solar thermal energy deployment. The overall potential is limited, but technically and economically feasible to utilize.

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