Design Approach, Experience and Results of 1MW Solar Thermal Power Plant


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Concept/Objectives

- **1MW Solar Thermal Power Plant**
  - Design & Development of a 1 MW plant.
  - Generation of Electricity for supply to the grid.

- **National Test Facility**
  - Development of facility for component testing and characterization.
  - Scope of experimentation for the continuous development of technologies.

- **Development of Simulation Package**
  - Simulation software for scale-up and testing.
  - Compatibility for various solar applications.

Project funded by Ministry of New and Renewable Energy, New Delhi @ Solar Energy Centre (SEC), Gwal Pahari, Haryana
Role of IIT Bombay

• **Design of solar thermal power plant of 1MWe capacity**
  – Plant configuration designed by IITB
  – Turbine selection, study of its characteristics by IITB
  – Storage design and operating strategy conceived by IITB
  – Heat exchanger design and operating strategy conceived by IITB
  – Design of controls conceived, detailed and executed by IITB

• **Engineering of solar thermal power plant**
  – By IITB with some support from TCE, L and T and other experts

• **Procurement for solar thermal power plant**
  – As per IIT Bombay’s procedure through different vendors

• **Design and installation of Testing Facility** by IITB

• **Development and testing of simulation package** by IITB

• **Organizational structure**
  – Consortium under the leadership of IIT Bombay
  – Team of engineers and managers at IIT Bombay
  – Team of professors from IITB across different departments
Consortium under the leadership of **IIT Bombay**

**KGDS**

**KIE Solatherm**

**LT**

**TCE**

**TATA**

**TATA POWER**

**Clique**

**SECONDARY MEMBERS**

**INDUSTRY**

**TESTING**

**RESEARCHERS**

**ACADEMICS**
Plant configuration design

- Use of widely used thermodynamic cycle
  - 40 bar 350°C steam Rankine cycle
  - 1 MW (Mega Watt range)

- Combination of low and high cost solar concentrators
  - Site and technology specific
  - Design DNI 600 W/sqm !! Near Delhi !!
  - Minimum temperature requirement, characteristics of concentrators available, sizing
  - Technologies available locally: Advantage of low cost and local technical support
  - Technologies available globally: Advantage of experience
  - Procured through open tender process under specifications prepared by IIT Bombay
Heat Exchanger Network Analysis

Cumulative Heat Transfer Rate (kW)

Temperature (°C)

- Preheater
- Steam Generator
- Super-Heater

Water

Therminol VP1
High temp short time storage and Hx designed by IIT with L and T

PTC field loop 3 MW<sub>th</sub>
Without storage
Supplied by Abener

LFR field loop 2 MW<sub>th</sub>
Direct steam generation
Supplied by KGDS Renewables

Turbine and generator block (1 Mwe) supplied by Maxwatt
Balance of plant designed and procured by IIT Bombay

Process flow diagram
Turbine, storage and Hx: Operating strategy and controls

- Willans’ line for turbine
- Performance of plant at low radiation
- Design of Hx
- Operating strategy for Hx
- Sizing of HT storage tank
- Operating strategy for HT storage tank
Attainable Region for Hx at different operating levels of PTC and LFR

Oil Temperature (Inlet to Superheater) = 390°C

Turbine Inlet Pressure = 40 bar

Power (kW) vs LFR Flow Rate (kg/s)

- Oil Flow Rate 2.7 kg/s
- Oil Flow Rate 3.7 kg/s
- Oil Flow Rate 4.7 kg/s
- Oil Flow Rate 6.2 kg/s
- Oil Flow Rate 7 kg/s
- Oil Flow Rate 8.1 kg/s
- Oil Flow Rate 9.38 kg/s
Performance of the plant during low solar radiation or cloud cover

Source: Desai et al. (2013)
Control Philosophy and operating strategy

• Starting up strategy: Starting auxiliaries, without auxiliary fuel
• Operate Hx at desired level to get turbine-acceptable conditions with flow rates from two solar fields under given solar radiation
  • to effect continuous power generation from T-G unit
  • The minimum power level at which the turbine should be operated: 250 kW
  • For safety, minimum power level : 320 kW
• Control HT vessel flow rates when the radiation drops to a level which is too low
  • oil will be withdrawn from the high temperature (HT) vessel until the higher radiation level is achieved
  • or the oil level in the HT vessel reaches the minimum (20%) value.
• Plant shutdown: when HT vessel level reaches minimum and the radiation is not enough to run the plant at a minimum rating
• When radiation is good: Charge storage
Plant layout
At SEC, Gwal Pahari
About 13 Acres
Test facility
on 0.46 Acres
PTC: 8075 sq.m
on 6.348 Acres
LFR: 7020 sq.m
On 2.968 Acres
Power Block
on 1.544 Acres
Free area in between
1.503 Acres
Site preparation, Land leveling
TURBINE DECK FOUNDATION
Arial view of

1 MW Solar Thermal Power plant
And Test Facility by IIT Bombay
at Solar Energy Centre (SEC), Gwal Pahari, Dist Gurgaon, Haryana

PARABOLIC TROUGH SOLAR FIELD
PARABOLIC TROUGH SOLAR FIELD

- Mirror
- Receiver Tubes
- Structure
- Tracking mechanism
- Heat Transfer Fluid
- Pressure Vessels
- Piping
ERECITION OF COLLECTOR
Incorporating Storage Vessel

• 30 minutes storage at minimum turbine load (320 kW) : Designed by IIT B
  – Incorporating HT tank pump

• Nitrogen blanketing and pressurization:
  – Equalization line between HT and LT vessel
  – Novel control strategy to minimize consumption of Nitrogen
PLANT COMMISSIONING

- Cleaning the lines
- Pressure testing
- Chemical treatment

- Charging N2
- Filling Oil

Dirty water coming from headers
EXPANSION VESSEL PIPING FROM STORAGE VESSEL
PARABOLIC TROUGH SOLAR FIELD
LINEAR FRESNEL REFLECTOR
An artistic view of LFR system
LFR Solar field components by KGDS Renewables

- Receiver
- Stay wire
- Reflector
- Side stay wire base
- Reflector base
- A – frame base
- Reflector base support
Piping network: Thermal expansion

Flow balancing: Critical for 2-Phase flow
POWER BLOCK
FIRE AND RAW WATER TANK
SOFT WATER AND DM WATER TANK
FIRE WATER SYSTEM
DEMINERALISATION AND WATER SOFTENER
COOLING WATER PUMPS
DEAERATOR
BOILER FEED PUMPS
HEAT EXCHANGERS
HEAT EXCHANGER
STEAM TURBINE
CONDENSER
STEAM EJECTOR
STEAM EJECTOR CONDENSER
ELECTRICAL PANELS
HT AND LT PANELS
WEATHER STATION
DIGNITARIES AT PROJECT SITE
OPERATIONAL PROBLEMS
Leakages in the Superheater - 10/03/2013

Steam Leakage
RECEIVER GLASS WINDOW BREAKAGE THE LFR SYSTEM

**Breakage of the receiver window glass**

*Interruption in power supply to the tracking motors, focus shifted partially*
EQUIPMENT PROBLEMS

Dry run of the boiler feed pump

• Malfunction of Level transmitter on the Deaerator led to dry running of boiler feedwater pump (BFP)
COMMUNICATION PROBLEM BETWEEN LEVEL I AND LEVEL II

Control System Hierarchy for the solar thermal power plant
STEAM SYSTEM VALVES

• Problem in complete closing of the valve
• Manual closing of Valve – Not possible
• NRV leakages, allows return flow
• Leakages in control Valve in the Steam Line – problems in regulating the pressure

Control Valve without Handle  Control Valve with Handle
SYSTEM PROBLEMS
Ambient temperature profile at the project site on February 24th, 2013

- Crystallization temperature of HTF Therminol VP1 is 12°C
PUMP SEAL FAILURE: FEBRUARY, 2013
MIRROR BROKEN BY NEEL GAI
MIRROR BREAKAGE IN LFR
COMMISSIONING AND PROBLEMS IN CHRONOLOGICAL ORDER
SITE ISSUES

• Low radiation
• IBR
• Cleaning the steam line for turbine
• Dirt and dust at site:
  – Land treatment needed, done
  – Problems in mirror cleaning
• Theft and Robbery: Security problems
• No grid power at site for 8 months
  – Use of DG sets
COMMENTS AND STATUS: PERFORMANCE

• Performance of both solar fields being tested since April 2013
• Electrical power of 100 to 200 kW fed into local grid of SEC from Sept to Nov 2013
• Performance hampered by
  – Dust on mirrors and issues related to cleaning
  – Low and intermittent radiation
  – Imbalance of fluid flow in solar field loops
  – Non-perfect focusing
  – Daily starting without auxiliary firing
  – Non-availability of grid power
  – Issues with grid power connectivity
Solar Thermal Simulator

- **Unique features:**
  - Simulation of user defined plant configurations
  - Design point as well as off-design simulations
  - Cost analysis

- **Simulator predict:**
  - Performance of each equipment of the plant
  - Annual power generation
  - Capital cost
  - Cost of energy
How Simulator is useful

- preliminary sizing and cost estimation
- heat balance design
- parametric studies
- performance evaluation of a small subset of a complete plant or a complete plant
- optimize the plant configuration through multiple simulations
- devise the overall control strategy

- using different control options
- determine the start-up procedures
FEATURES

• Graphical user interface

• Freedom to construct flow sheets using any of the equipment
  o Flexibility to simulate user defined small subset of a complete plant or a complete plant

• Equipment model library with database as well as manual entry of the parameters

• Model library for solar insolation and different climatic parameters

• Model library for different working fluids

• User defined time step and time horizon for the simulation

• Results in the form of tables and graphs

• Facility to export results to MS Excel file
User Interface: Main Window

Open Sample Process Flow Diagram

- Sample PFD1: Thermic Fluid based Indirect Steam Generation Power Plant with Regeneration
- Sample PFD2: Thermic Fluid based Indirect Steam Generation Power Plant with Reheat
- Sample PFD3: Thermic Fluid based Indirect Steam Generation Power Plant with Reheat and Multiple Regeneration
- Sample PFD4: Direct Steam Generation Power Plant (assisted by auxiliary boiler) with Regeneration
- Sample PFD5: Direct Steam Generation (assisted by auxiliary boiler) for Process Heat Application
- Sample PFD6: Direct Steam Generation (assisted by auxiliary boiler) for Process Heat Application

Getting Started

- Open any of the six sample process flow diagram for steady state simulation.
- Double click the equipment and stream node to know its parameters and to make changes.
- Parametric study can be done by changing the system parameters, such as, location, stream parameters, control variable, equipment model parameters, etc.
- Save the file (even if no changes are made) and click 'Run Simulation' for getting results.
- The results will be displayed in tabular format.

* Usage of this Software is governed by the license agreement.
GENERATION OF USER DEFINED PROCESS FLOW DIAGRAM USING USER INTERFACE
REFERENCES


