

# **National Solar Thermal Power Plant:**

*IIT Bombay*

## **1. INTRODUCTION**

Energy is the driving force for almost everything including the economy, society and technology all around the world. This makes energy generation an important and ever increasing responsibility. Energy generation, however, is mainly done by fossil fuels and is also used in a way that society will not be able to sustain for long, as fossil fuels are limited.

There is an ever increasing effort in commercializing the alternative sources, which are practically never ending and are also difficult to harness. Among the major ones are Solar power, Wind energy, Bio-fuels, geothermal and nuclear. Among these, most available is the solar power. Research in solar power had been happening for long and among all Photovoltaic Solar power and concentrating solar power are among the widely used technologies for commercial electricity generation today.

Concentrated solar power (CSP), of all available technologies, is a promising and very well suited to the hot Indian climate. Solar thermal power is well established and worldwide countries like USA, Spain and Middle-east, among the major ones, have 2500 MW electricity generating power.

### **1.1. MOTIVATION & FEASIBILITY:**

India, however, having no similar CSP facility built, had to come with a pilot project. It poses many challenges such as; availability of technology, adaptations to the conventional power cycles to solar thermal technology, availability of industrial and technological capacity and issues related with indigenous development of technology i.e. creating the Indian industry and the support infrastructure.

It is well established, in India, that Solar energy is available in abundance. Average radiation of 4.5 - 6 kWh/m<sup>2</sup>/day, with average 260 - 290 clear days in a year [R] , provide a very good opportunity to tap this form of energy.

As there is no large scale Solar thermal power plant operating in India, the expertise and workforce related to operation and maintenance of these plants are non-existent. There are also no testing and simulation facilities for research and development of solar thermal power plant.

## **1.2. PROJECT HISTORY:**

In view of the previously mentioned challenges and larger energy capability goals, for solar thermal energy harnessing, foundation of a national research, testing and simulation facility for a megawatt scale grid connected solar thermal power plant was laid on April, 28 2008 in the workshop "National workshop on Solar Thermal Power Generation" at Indian Institute of Technology, Bombay was laid. The workshop was attended by representatives from industry, academics and research organizations. The approach adopted was to form a consortium consisting of industry partners with expertise in detailed engineering and power plant operation and it would be led by Indian Institute of Technology (IIT) Bombay. After detailed groundwork and feasibility studies, the project proposal for "Development of a Megawatt-scale National Solar Thermal Power Testing, Simulation and Research Facility" was submitted by IIT Bombay to Ministry of New and Renewable Energy on January 19, 2009. The project was approved by the Ministry of Non-Renewable Energy on September 9, 2009. Consequently, all the preliminary preparations and activities were initiated.

## **1.3. STUDY OF GLOBAL SCENARIO**

Worldwide, there have been a lot of research and development activities going for Solar energy use and optimization of costs involved. Concentrated Solar Power is a promising one for future. The International Energy Agency (IEA), in its recent study, has made the projections of cost for solar thermal power in comparison with other renewable technologies a concluded that solar thermal power will be one of the cheapest in the years to come compared to the other renewable energy technologies.

Currently, more than 3600 MW capacity power plants are operational around the world. A total of around 2500 MW is under construction, and around 10,000 MW is announced worldwide.

USA, Spain, Middle East, Germany, Morocco are where CSP plants have been installed successfully. Many countries have under construction CSP plants.

## **1.4. INDIAN SCENARIO**

At the time the project was incepted and construction had started, there were no CSP plant operational or under construction, in India. Presently there are many under construction and some operational as well. Table 1 provides the details of presently installed and under construction CSP power plants in India.

Table 1: Presently, under construction and installed capacities of CSP plant in india.

Sr. No.	Name of the Plant	CSP Technology	Owner of Plant	Status of operation
1	ACME Solar Tower, Bikaner Rajasthan	Power Tower	ACME Group.	Operational
2	Godawari Solar Project, Nokh, Rajasthan	Parabolic Trough	Godawari Green Energy Limited	Operational
3	Megha Solar Plant, Anantpur, AP	Parabolic Trough	Megha Engineering and Infrastructure	Under Construction
4	Gujrat Solar One, Kutch, Gujrat	Parabolic Trough	Cargo Solar Power	Under Construction
5	KVK Energy Solar Project, Askandra, Rajasthan	Parabolic Trough	KVK Energy Ventures Ltd	Under Construction
6	Dhursar Solar Power, Dhursar, Rajasthan	Linear Fresnal reflector	Reliance Power	Under Construction
7	Diwakar Solar Power, Askandra, Rajasthan	Parabolic Trough	Lanco Infratech	Under Construction
8	Abhijeet Solar Project, Jaisalmer, Rajasthan	Parabolic Trough	Corporate Ispat Alloys Ltd.	Under Construction

During the time of inception KW scale projects installed in past were present in India. All of the plants were non-operational for many years. No testing facility was present in India and there was very limited amount of experience and expertise available for CSP plants. Resulting to all these, there was no clear path for indigenous development of components and technologies in this field. Hence it was important to develop all the different components for the above mentioned needs to be fulfilled properly.

### 1.5. OBJECTIVES

Overall, the project was planned to impart all blocks of any development process of a solar thermal power plant. These could broadly put as follows:

1. Establishment of a national research facility on solar thermal power (1MWe grid-interactive).
2. Establishment of test facility for component and system characterisation.
3. Development of simulation facility for future scale-up of plant capacity.
4. Facilitate R&D activities for cost reduction of CSP Plants

With this facility, it is aimed to provide technical and infrastructural assistance/ support to increase investment in the solar thermal energy generation. This will be a major milestone for India's shifting direction to Renewable sources of energy production, hence energy sustenance.

## 2. POWER PLANT DESCRIPTION

### 2.1. SITE

Criteria leading to the site

Site which was chosen and allocated is present in Solar Energy Center. The reasons for finalizing this site were as follows.

The two options, which were considered for the development of the overall plant and other facilities were

1. Aurangabad, had all the characteristics for a successful Solar Thermal Power plant to be put.
  - a. It has good connectivity through roads and railways, via all major cities in Maharashtra. With Mumbai port and JNPT near to Aurangabad, it was easy for all supplies to reach site on time. Also the Mumbai International Airport is capable for receiving and sending international goods through air freight.
  - b. Solar Power received is high, in terms of the DNI-received and the total clear days.
  - c. Proximity to IIT Bombay: As both cities, Mumbai & Aurangabad, are located in the same state the travel time is 6 hrs by road, which is very useful as Establishment and construction activities at the site can be easily monitored from IIT Bombay.
2. Gwalpahari, Solar Energy Centre, Haryana. It was proposed by MNRE. As a part of National Solar Mission, there were many small and big projects and research work initiated. As a requirement to facilitate these initiatives, a dedicated center was made. Solar Energy Centre is the result of these efforts. The area is dedicated for research and development projects using solar energy and many projects and nurtured under this umbrella presently. A dedicated land was made available for the project. The following are the reasons for its selection.
  - a) Connectivity and transportation: Solar Energy Centre being situated in the northern plains of India, midst of Gurgaon & Faridabad, is very close to the national Capital New Delhi. Hence it is very well connected and have good transport. New Delhi Airport which is capable of receiving international cargo is also roughly 35 Km from the airport.
  - b) Solar power intensity: The site is situated such that it receives high influx of radiation of about 600 KWh/hr. The clear days are around 250- 280 days each year.

- c) Solar energy center, established in 1982, is dedicated for development and demonstration of solar energy power generation. As the land is already available in hand, problems such as acquisition & all other related permissions and works are significantly reduced.
- d) The plant at a later stage, after commissioning, has to be used for providing knowledge and expertise of CSP power plants. It has to be operated and maintained by the Ministry. So for a long term, Solar Energy Center provides a good option for the development of plant.

As mentioned above, the plant and the testing facilities has to be operated by the ministry after commissioning and the other advantages of choosing, it was decided keeping a long term goal in mind, to open the CSP plant in Solar Energy Center, Gwalpahari, Haryana.

The land at Solar energy center, was made available for the construction of Solar Thermal Power plant and the Testing & characterization facility, on January 10, 2010 and inaugurated by Honorable Minister, MNRE Dr. Farooq Abdullah .

### **2.1.1. Preparation of site**

Preliminary preparations involved cutting trees after permission from Haryana government authorities was done and leveling of fields was completed as a preliminary requirement.

Soil testing activities were taken for checking the load carrying capacities of the soil. This is an important activity for carrying out further design activities of the plant structure

## **2.2. DESIGN**

A solar thermal power plant, essentially contains a solar field and a thermal power generation unit– similar to the one used in thermal power plants using coal or other fossil fuels.

The solar field raises the temperature of a thermal fluid, which in turn provides necessary heat for producing saturated steam in the steam generator. The saturated steam is superheated and fed to the turbine for steam generation.

A detailed parametric study was carried out to ascertain the operating temperature and pressure. The result of study is shown in Fig 1.

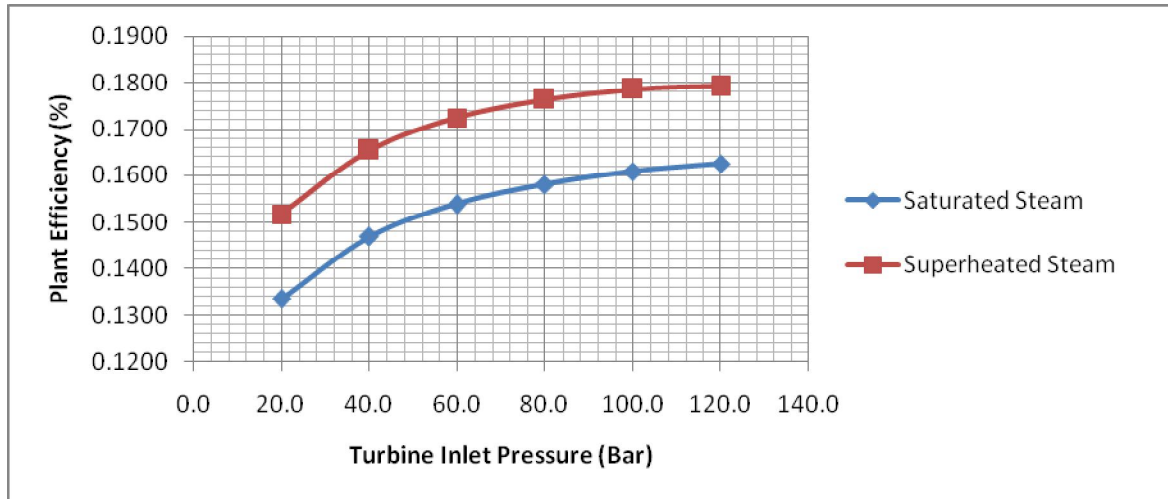


Fig 1: Comparison of plant efficiency when using Saturated Steam and Superheated Steam.

1. Plant efficiency improves with increase in the turbine inlet pressure. Beyond 80 Bars the efficiency does not very significantly increase. Hence 40- 80 Bars is the appropriate operating pressure.
2. The upper limit to Oil temperature at the exit is fixed at 325 C in accordance with the oil being used.
3. Pinch point- minimum temperature difference between hot oil and saturated steam- is taken to be 15 C with superheated water at 250 C and oil at 265 C

A total of 5 configurations were laid down, taking different possibilities of using single or double fields, Trough – Dish Combinations and direct or indirect preheat. The comparison of various feasible configuration is presented below (Table 2).

Table 2: Costs for various configurations

Configu ration	Area (m <sup>2</sup> )		Annual Energy Output (MWh)	Approximate Capital Cost Rs (Lakh)	Energy Cost (Rs / kWh)
	High Temperature	Low Temperatur			
<b>I</b>	14400	-	1922	2895	26.5
<b>II</b>	11100	3300	1959	2696	24.7
<b>III</b>	11100	3300	1960	3189	29.5
<b>IV</b>	<b>11650</b>	<b>3150</b>	<b>1960</b>	<b>2765</b>	<b>25.2</b>
<b>V</b>	11700	3300	1961	3248	26.1

All the configurations give almost equal Energy Output and hence option 4 is selected in view of its minimum cost per kWh.

Before the tendering process, some changes were incorporated on the configuration finalized on the basis of following

- i. The maximum operating temperature of the oil in the collector field was raised to 390 C, as a consequence of the inputs received from the Nevada Solar One—A CSP Plant operational since 2007.
- ii. Hot oil storage was included in the plant design to take care of the turbine functioning and operation in low DNI conditions.
- iii. As the strategy was to include some more technologies in Solar thermal collector, an option of direct steam generation by Linear Fresnel Reflector (LFR) was included in the design

Hence after implementing the above changes, the final block diagram of the process flow is shown in Fig 2.

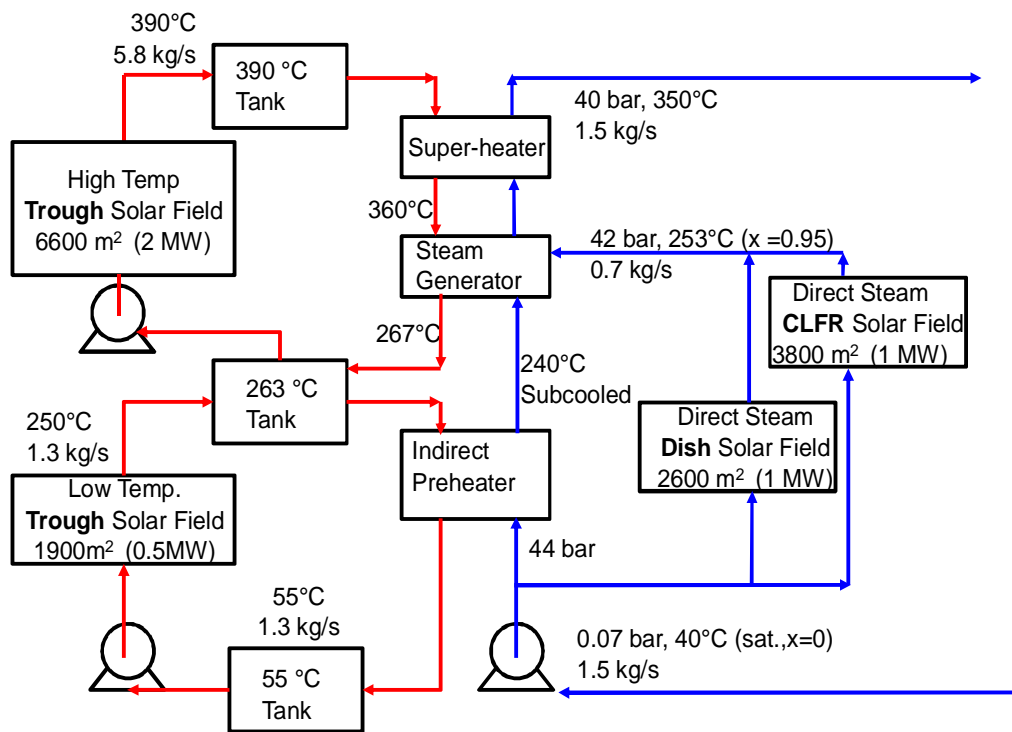


Fig 2 : Final Block diagram for the configuration selected.

## 2.3. DETAILS OF FIELD INSTALLATIONS

### 2.3.1. Solar fields

There are many technologies available for Solar thermal power plants. Among these many, the following Solar collector's were used:

1. Parabolic Trough: These use parabolic shaped polished mirrors to focus the energy to a straight line where thermal fluid is flowing to absorb heat which can be used to produce steam and run a turbine to produce electricity.

The contract between IITB and Abener Engineering India, the contractor finalized after the competitive tendering process, was signed on 14<sup>th</sup> September 2010. 3 MWth energy will be supplied by the PTC field at the design solar insolation of 600 W/m<sup>2</sup>.



Fig 3: Parabolic trough Field

The parabolic shaped mirrors collect the sunrays and concentrate them to a focal line where the HTF (high temperature fluid) oil is pumped. This HTF is then used to transfer the heat to get superheated water. The oil used is Therminol VP1, and a 20 tonne of it has been charged in the oil circuit.

Trough field has three loops each with output of 1 MWth at design DNI, which have been tested for an exit temperature of 390 C.



## 2. Linear Fresnel Reflector (LFR)

Linear Fresnel reflectors use long, thin segments of mirrors to focus sunlight onto a fixed absorber located at a common focal point of the reflectors. The heat concentrated to fixed receivers is then transferred to fluid, water itself here, and then is charged to produce electricity. Unlike the parabolic trough field; where the heat is transferred to HTF and then, through a heat exchanger, transferred to water, here the heat is directly being transferred to the water.



Fig 4: The LFR field installed at site.

KG Design Services was selected, after the tendering procedure, for the installation and commissioning of the LFR field. LFR installation design uses 2 MWth energy at the insolation of 600 W/m<sup>2</sup>.

This field is directly connected to the power block for generation of electricity as it does not involve any HTF oil as a transfer media, hence no heat exchanger involved.

### 2.3.2. Heat Exchanger

A heat exchanger, in a solar power plant, is used to generate steam. The HTF carries heat from the parabolic trough field to a heat exchanger where it is used to produce high pressure steam (Fig 5). This high pressure steam is required for the steam turbine that drives the electrical generator. The heat exchanger tender was floated and after a thorough bidding procedure and Larsen & Toubro was selected as the vendor for this component.

A shell and tube type heat exchanger consists of three separate components namely, the preheater, the steam generator and the superheater. All the design was done by the contractor and approved by IIT Bombay for execution.

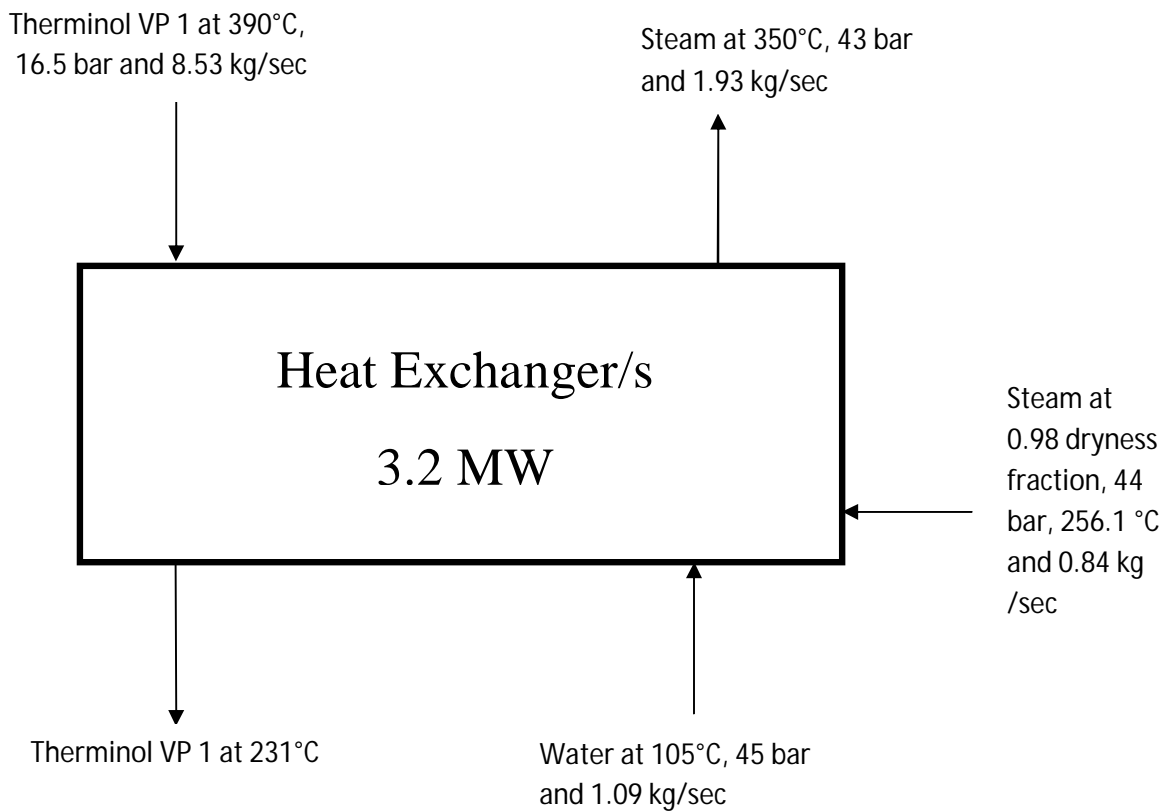


Fig 5: Heat exchanger design.

The water supplied to the heat exchanger is treated in a softener plant installed for controlling water quality. The installed Heat Exchanger is shown in Fig 6.

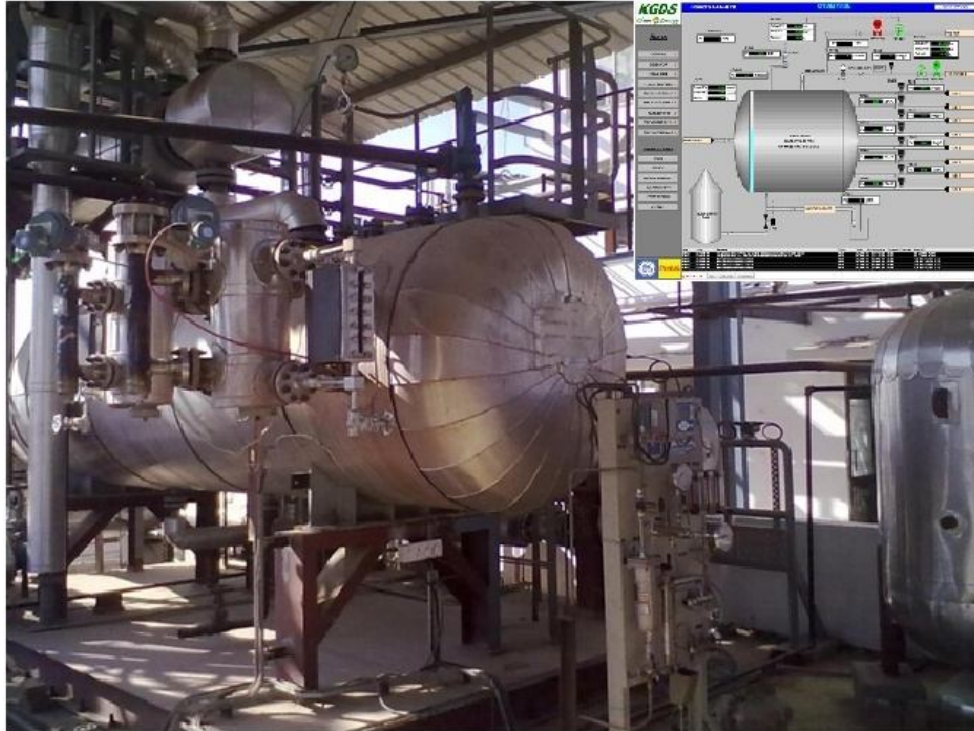


Fig 6: Heat Exchanger and SCADA.

### 2.3.3. Power Block:

This section is responsible for converting the pressurized steam into electricity using the steam turbine (Fig 7) and other accessories. These include an alternator and condenser (Fig 8). The assembly is similar to what is found in any conventional thermal power plant using coal or other fossil fuels.



Fig 7: Steam Turbine system with accessories



Fig 8: Condenser



A control system is put in for operating all the parameters of the electricity generation (Fig 9).



Fig 9: LT PCC Panel

#### 2.3.4. Weather station

To track the effects of wind and radiation received for proper functioning of the plant, a weather station is installed as shown in Fig 10. It consists of the following instrumentations

1. **Direct Normal Insolation**—The amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. It is typically measured by tracking the sun, to keep the incoming rays perpendicular to the surface and maximize the irradiance, through the day.  
This is done by using a **pyrheliometer**, which is installed at the site.
2. **Global Radiation**—It is the amount of total amount of radiation received directly as well as in diffused form, resulting from scattered light. **Pyranometer** is used for measuring global radiation.
3. **Diffused Radiation** is the amount of radiation received in diffused form and not directly. A **Pyranometer** is used for measuring diffused radiation.

4. Wind speed and direction—Wind speed and direction play a very important role in functioning of the plant. It measured at site by an anemometer and a wind vane.



Fig 10: Whether station installed at site

### **3. Civil Structures and other supporting infrastructure.**

Building, roads and other support infrastructure is important for any power-plant of industry. The plant installation involved various civil structures which are primarily used to support of accommodate various entities in the plant including the people.

- The main structure comprises of a RCC building housing the turbine, control units, whether station and has operation control area from where all the operations of the plant is handled. Around the structure various steel structures are fabricated and erected to accommodate all the piping, heat exchanger, water treatment plant, condenser, Oil storage tanks and numerous other small parts (Fig 11).

- The testing facility constructed, also required to carefully build the RCC structure around the testing equipments, which are difficult to install and commission in a closed space (Fig 12).
- The roads built use the **Terrazyme** technology. Terrazyme soil stabilizer is a safe, effective and non-corrosive liquid enzyme soil stabilizer that significantly enhances the properties of the soil used in the construction of road infrastructure. It increases the Load bearing capacity and reduces the soil permeability which increases the strength. This reduces the overall maintenance and rehabilitation costs in long run.



Fig 11: a) The under construction Building along with other support structures. b) The completed structures.



Fig 12: Testing Rig Building

### 2.3.5. Piping and other supporting installations

Piping is done in the plant to transfer HTF and water from field to the turbine block and vice versa. Piping is done with industry standard Insulated pipes.

A **Water Demineralizing plant** has been put in order to prevent corrosion, in all the metallic parts. The demineralization of water is achieved with the help of ion exchange demineralization plant. Water at the rate of 250 liters per hour is pumped through the water softening plant, which removes the hardness of water to a value of less than 2500 PPM. Continuous monitoring of the purity of water going to the boiler is carried out by measuring electrical conductivity of water flowing out of the ion exchange chamber.

**Storage tank** is provided for storing HTF oil at high temperature. It is required to store excess oil and also to cater the surplus supply required in times of oil leakage. When the solar fields are getting sufficient energy from the sun, the oil is released for circulation and absorbing heat to produce electricity.



### 3. TESTING FACILITY

A Test Rig has been designed, fabricated, installed and commissioned at the site to test the thermal performance of oil based concentrated solar collectors. Solar Collectors upto a maximum temperature of 350 C can be evaluated in the present facility.

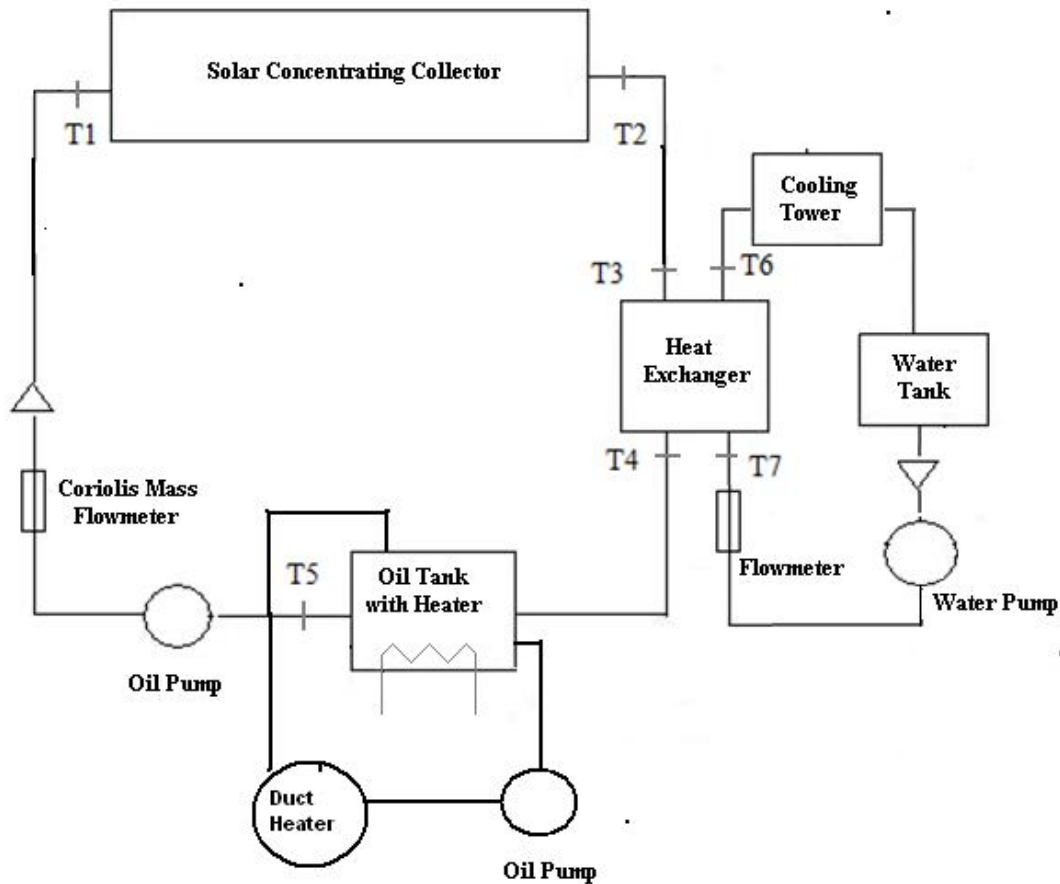


Fig 13: The schematic of the test Rig

The test rig is installed to test the performance of collectors developed indigenously, and hence these technologies can flourish and make a successful products at later stages.

As a first step in this development; **Arun Dish**—A paraboloid shaped dish system (Fig 14); designed, manufactured and supplied by Clique Developments Ltd. was evaluated. The system was tested and thermal performance evaluated for temperatures upto 200 C and for instantaneous efficiency of the receiver. The evaluation is complete now.



Fig 14: Arun Dish installed

The **Testing Facility Building** (Fig 15) is constructed separately for facilitating the process of data collection, calibration, storage, and whether recording instruments. The building is constructed with the following in mind

1. For storing testing instruments, replacement items, back-up equipments and other consumables.
2. Data logging and analysis. The data has to be analysed, stored and presented in a meaningful manner for which there are provisions and area's inside the test building.



Fig 15: The Test Facility control building

A **Flux mapping system**, designed by IIT Bombay, is a low cost novel technique used for measuring the concentrated flux obtained in Linear focus solar collectors. This is presently implemented in Solar Energy Laboratory, IIT Bombay and a Patent is filed. The final system is being built and will be useful in laboratory testing and research of Linear focus collectors.

For the purpose of adding the capabilities of the Testing facility, which presently is only equipped to test oil based solar collectors, a preliminary design for testing **water based solar collectors** has been finalized (Fig 16). This is also being built and tested in solar energy lab in IIT Bombay. Based on this exercise and the results achieved, a final design and implementation will be done at the testing facility at the site. This will enhanced the testing and evaluation ability of the test rig present.

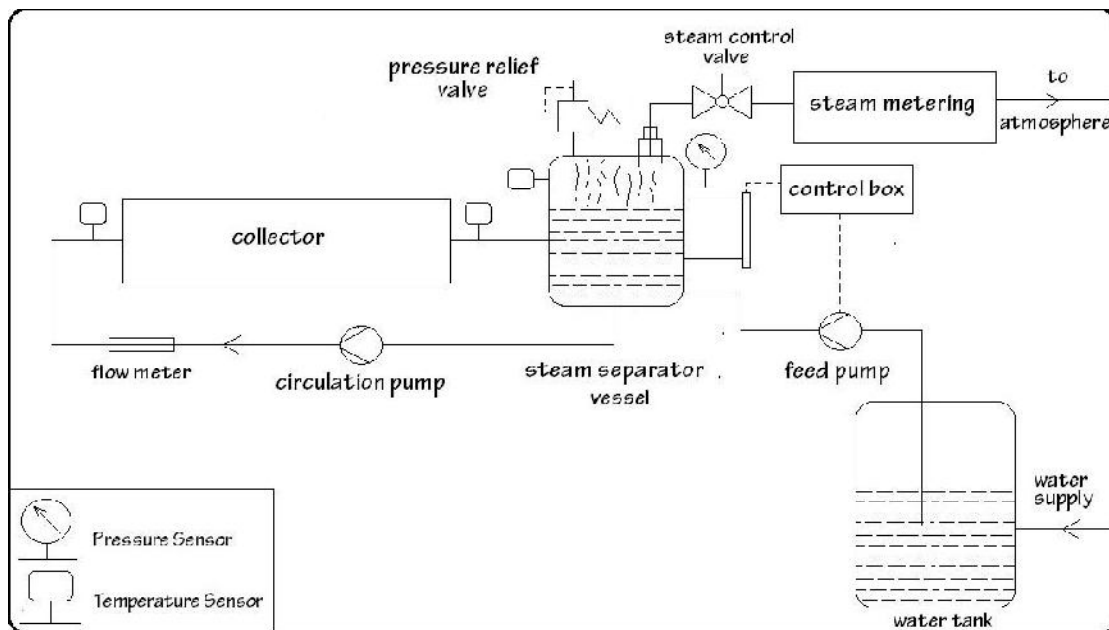


Fig 16: Preliminary design of the test rig for water based solar collectors.

### 3. SOLAR THERMAL SIMULATION SOFTWARE

#### 3.1. INTRODUCTION

Any power plant, before its installation, has to be conceived and designed with best market practices. Many practical considerations should also be taken account of to hedge out errors in the final installation. This involves engraining the theoretical concepts into practice, by creating a easy to use software dedicated for designing Solar Thermal Power Plants and model it

effectively with very detailed and accurate design, which could be readily used for a development of a Solar thermal power plant.

Simulator had a dedicated team working for it and they have already released 2 versions.

- i. A **Preliminary version** was released in July 2011. It was downloaded in 150 unique institutes and 230 unique industry & other organizations.
- ii. An **evaluation version**, released in November 2012. The evaluation licence has been given to Fichtner India Pvt. Ltd., which will evaluate and test the version for further improvements and additions.

The evaluation software, in particular, allows quasi-steady state simulation of the complete plant or a, user defined, smaller subset of the plant.

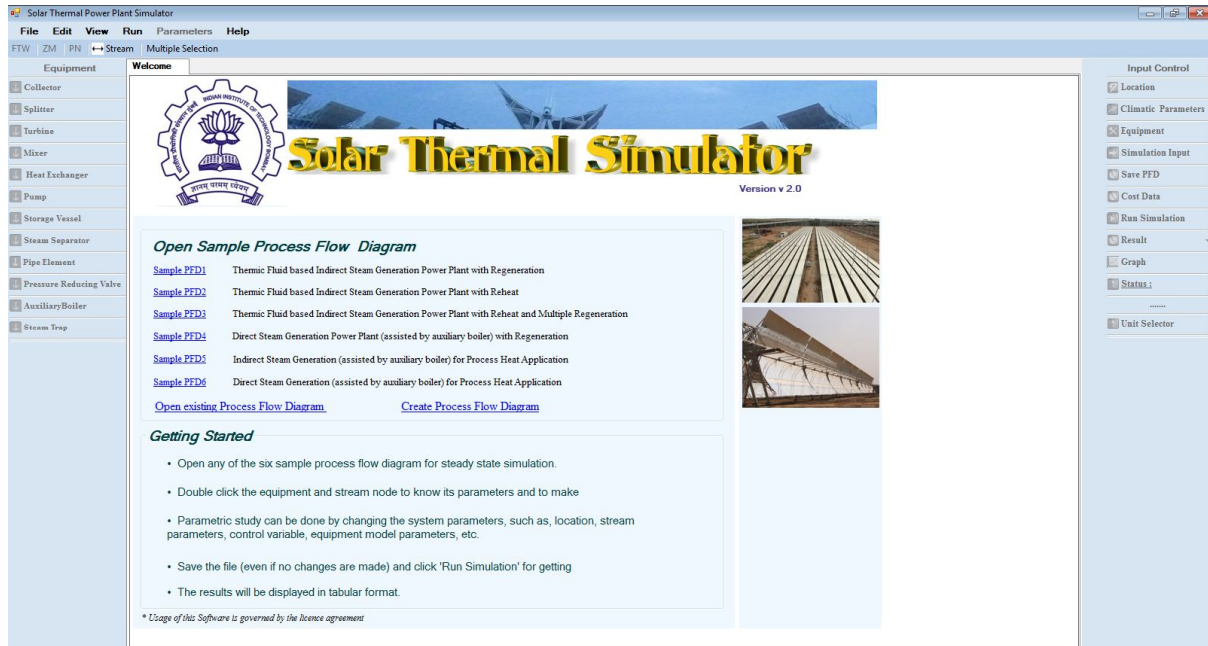


Fig 17: User- Interface of the Solar Thermal Simulation Software, Evaluation version.

Once a power plant is designed, it gives detailed results, such as, output of all equipments for each time step, annual power generation, capital cost and cost of energy. The results are very well displayed in graphs and tables which can be easily imported to MS Excel/ OpenOffice formats. With the simulator parametric studies are possible by changing the process/system parameters, such as, control variables (i.e. temperature, pressure etc), location, stream parameters and equipment model parameters.

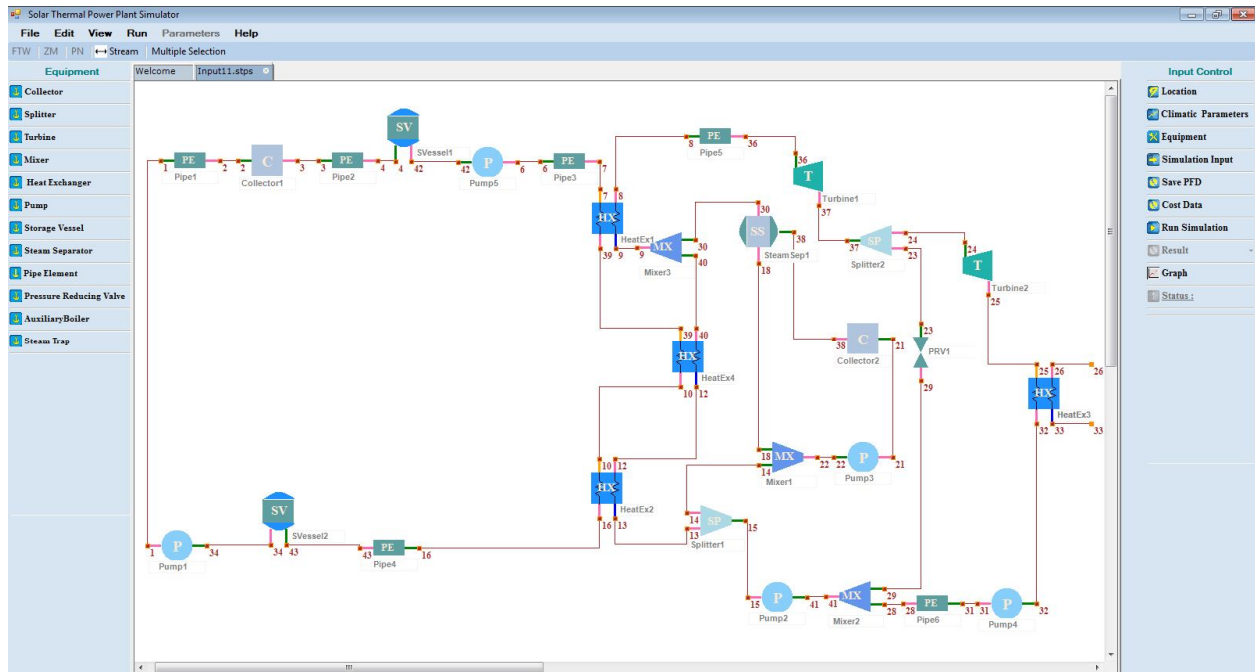


Fig 18: User defined process flow diagram in the simulator.

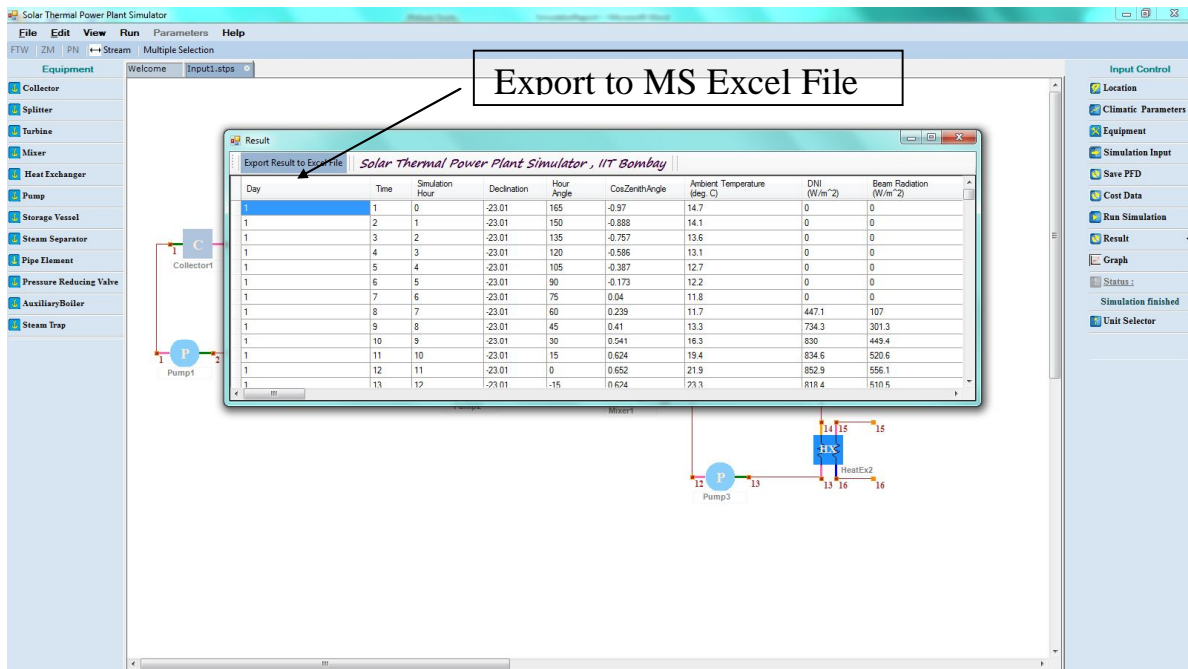


Fig 19: Tabular Results, which can be exported to MS Excel formats.

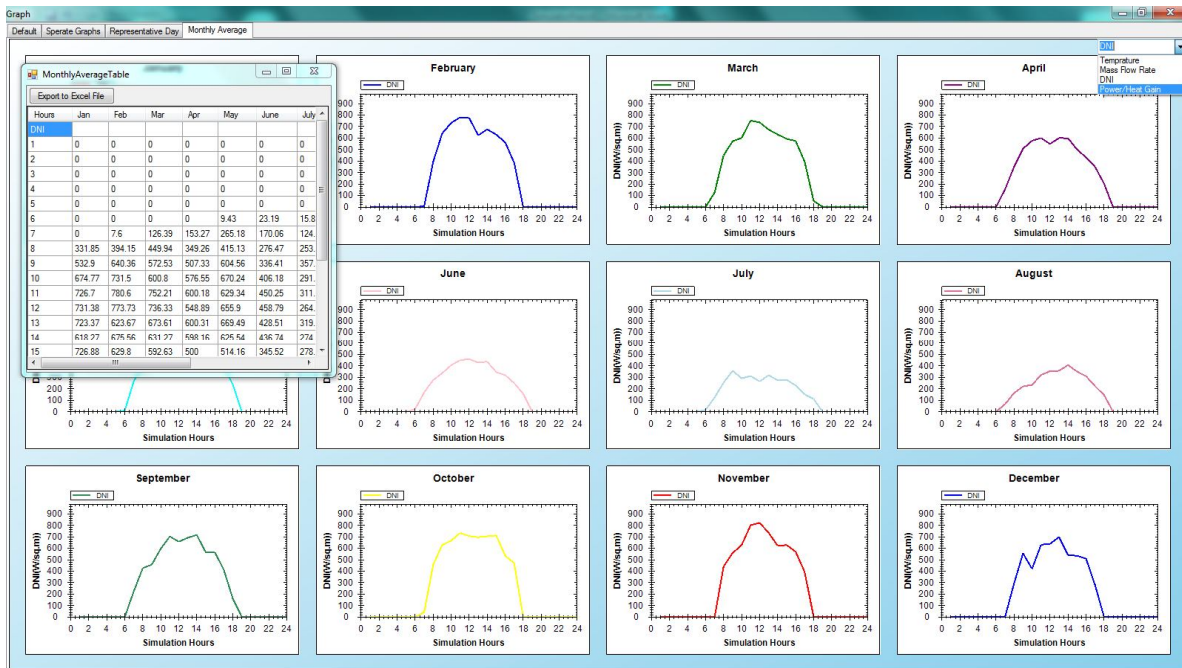


Fig 20: Multiple Graphs displayed by the simulator.

### 3.2. FEATURES OF SIMULATORS

Current Status and salient features of the evaluation version are as follows:

- i. The **Graphical Process Flow Design (PFD)** approach, as shown in Fig, can be generated for the simulation. As evident from the screenshot, it is much more understandable and user friendly. Any Bug/anomaly in the design can be easily detected and fixed by this approach.
- ii. Solar collector, splitter, mixer, turbine, pump, heat exchanger, pressure reducing valve, steam trap, auxiliary boiler, pipe element and storage vessel are incorporated in the **equipment library** which can be readily used. These equipments have parameters which define the properties of the block, which can be fixed as per the design requirements. Fig gives a sample input window for a solar collector.
- iii. Splitter and Mixer can be used to arrange collector in **series and parallel** combinations.
- iv. Pressure drop and heat loss through the piping are evaluated using piping element.
- v. User defined **Time Step** and **Time Horizon** for the simulation can be incorporated.



- vi. The simulation is based on the **Sequential Modular Approach**. Hence it can be easily broken down into sub –systems and designed in parts, which can be easily integrated in the software.
- vii. The PFD can be saved at any stage of making. It is saved in a folder which contains files related to input parameters and geometry data of a PFD.

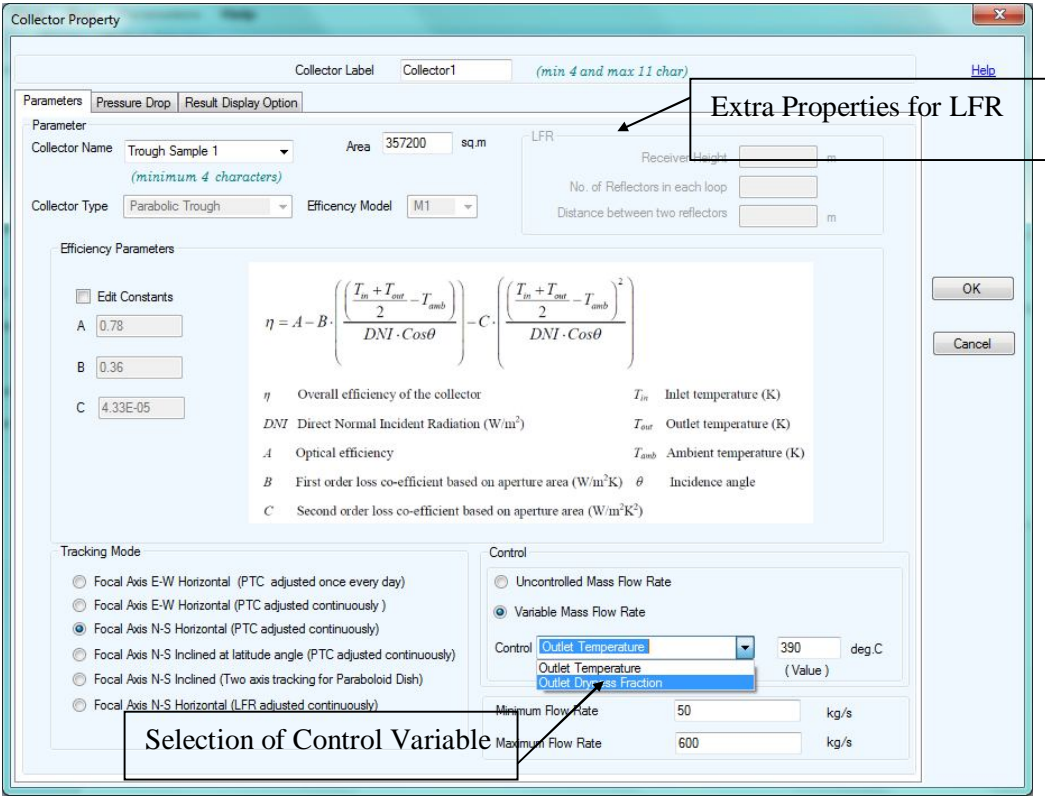


Fig 21: properties window for a Solar Collector.

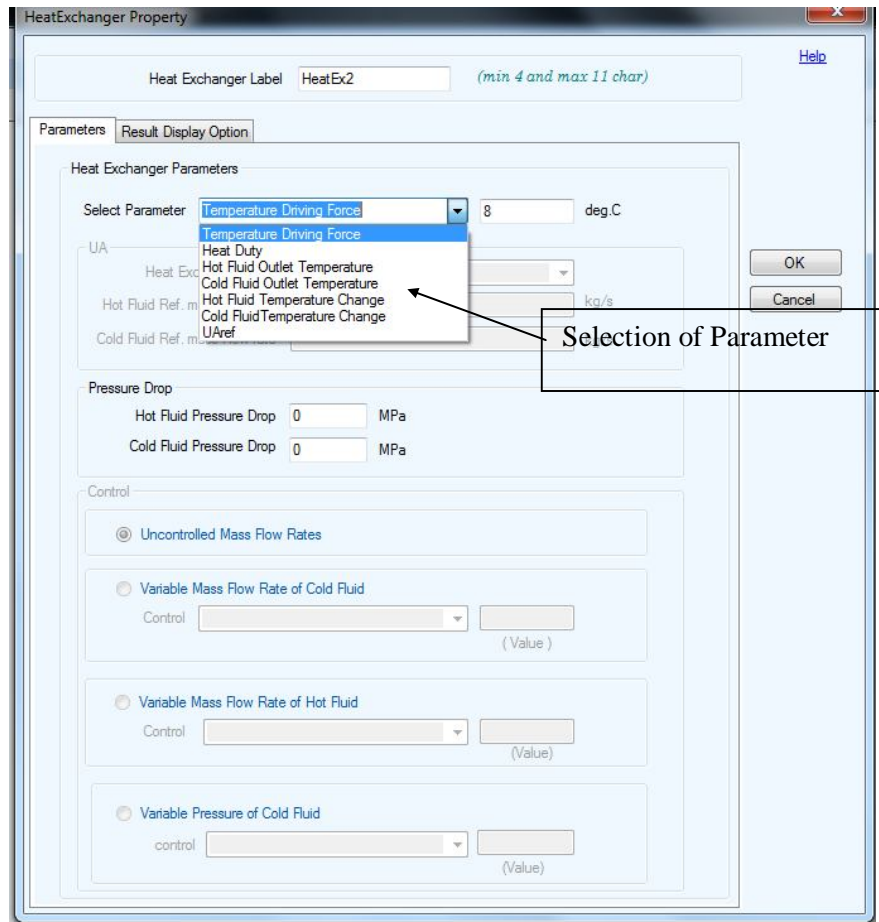


Fig 22: Properties window for a heat exchanger.

### 3.3. FUTURE DEVELOPMENTS OF SIMULATOR

The future developments intended and worked upon are

- **Power Tower** type CSP design, which is considered to be the most efficient implementation of solar collectors known. Design and evaluation of this type of CSP plant will be added. It is the technology behind the Ivanpah Solar power Facility, USA—the largest CSP plant in world.
- Increasing the control aspects
- Enhancement of existing solver and the GUI (Graphical user Interface).
- Finally, it is important to validate the simulated/ designed power plant for increasing the accuracy of the models used for simulations. These will be done through data collected from the actual site.



## **4. CONSTRUCTION & OPERATION PHASES**

After the proposal was submitted to MNRE, and subsequently approved, the team had started doing detailed research for the various challenges which the project will have. This was crucial as it was the first effort for a megawatt scale grid connected power plant with CSP technology.

The various stages of construction are as follows

### **4.1. PHASE I: ENABLING WORK**

#### **4.1.1. Finalization of site;**

The site was required to have as much as clear days as possible and also should have a high Insolation.

As the reasons stated previously, Solar energy center (SEC) was an ideal location for execution of project. The land was already acquired by SEC and it had a high insolation.

SEC is also very well connected with it falling along the Gurgaon-Faridabad Highway, not far from Countries capital New Delhi, in Gwalpahari. Adjacent to SEC, the area also houses a huge campus of "The Energy and Resources Institute (TERI)"—A premier Research institute of Energy, Environment and Sustainable Development. This environment, with various solar energy technologies housed in the SEC and TERI, is very much favorable for growth of CSP and other solar energy projects in the area.

#### **4.1.2. Leveling & fencing of Site;**

After finalization of site, fencing work was initiated. The permission for tree cutting from the respective authority of Haryana state was obtained with assistance from SEC and MNRE. This was followed by tree cutting over the entire site. Land leveling activity was then carried out.



Fig 23: Leveling of Site.

#### **4.1.3. Soil Testing and other preliminary tests;**

As soon as land leveling was completed, soil survey and testing was done. The testing was done for finding quality of soil and bearing capacity, required for any structural design on the site.

Testing of underground water was also done to assess the quality of water which is to be used for running of plant.



Fig 24: Soil testing

## 4.2. PHASE II: PLANT CONSTRUCTION

### 4.2.1. Design and Tendering process

As the technology was new and it was expected that there are very few possible vendors available for the work and also the expertise is bound to vary with each technology. The Tendering was done in such a way, including all CSP technologies, that it could be found out that using which technology will give best results in India. Of all the available technology for which the tender showed interest in, 2 technologies—the parabolic Trough & The Linear Fresnel Reflector, were found to be feasible, both technically & financially, and were finalized. These technologies, expectedly, are among the most used technologies for CSP Plants worldwide.

### 4.2.2. Procurements

The final contract, Among the Bidders, was awarded to Abener Engineering Pvt. Ltd. for supplying 3MW Parabolic Trough Solar Field and to KG Design Services Pvt. Ltd. for supplying 2MW of LFR Solar Field.

For Parabolic Trough and Linear fresnel Reflector, the following procurement and work responsibility was assigned and was completed by the respective Contractors

Table 3

Sr. No.	Type of Solar field	Items	Activity/ Work
	Parabolic Troughs	Storage Tanks	Civil Construction
		CCP assembly modules	Excavation for electrical building
		HTF pumps	CCP modules installation
		Basket filter and Y strainer	Piping fabrication & Installaton
		Controllers	
		Receiver tubes	
		Ball joints	
		Hydraulic tracking system	
		Mirrors	
		Earthing material	

	<b>Linear Fresnal Reflector</b>	Reflector unit	Piping installation
		Linear Cavity Receiver	Erection of collector & Receiver
		Tracking System	
		Civil Structures	
		Gear box	
		Steam drum, encoder	
		stepper motor,	
		PLC with SCADA	

### 4.3. PHASE III: TESTING, O&M AND HANDING OVER

#### 4.3.1. TESTING BEFORE HOT COMMISSIONING.

##### 1. Solar fields:

- i. Parabolic Trough Field

The following sequence was followed for cold commissioning of the parabolic trough field in the plant.

1. Erection of solar fields: The erection of parabolic trough was completed on July 2012.
2. Parallel and Subsequently; the solar collector assembly, pressure vessels, oil pumps, associated piping and instruments for monitoring and SCADA were installed at the site.
3. To enable cold commissioning, 20 Tonnes of Therminol VP1 oil was charged in the oil circuit.
4. A test run was conducted for cold commissioning. The trough fields consisted of three loops, each gave an output of approximately 1 MW<sub>th</sub> at the design DNI. All loops were tested under the exit temperature of 300 C.
5. The temperature of the oil was further kept above 45 C to avoid any freezing in the circuit, during the time until hot commissioning has been done.



Fig 25: The Parabolic Trough Solar Field.

ii. Linear Fresnel Reflector Field

The LFR solar field was tested for steam generation at  $50 \text{ kg/cm}^2$ . Fig shows the steam generation from the field. The mirror cleaning system for the field has been commissioned and is cleaned on a regular basis.



Fig 26: Linear Fresnel Reflector Solar field



Fig 27: The steam generated by the LFR solar Field, during testing.

A typical display screen showing relevant parameters of the field is shown in Fig.

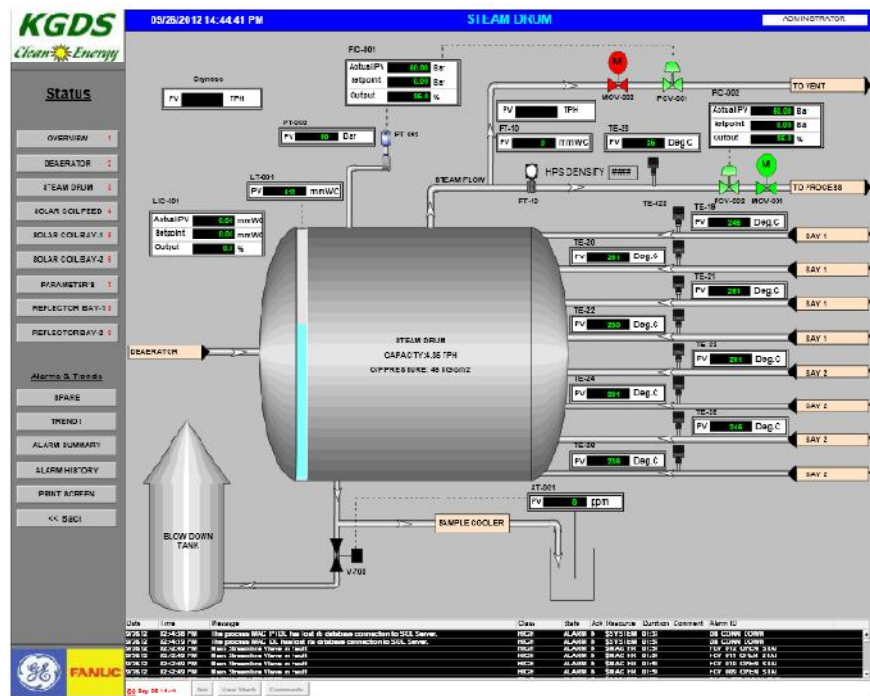


Fig 28: Steam parameters from the LFR Field.



## 2. Heat Exchanger

Testing of the installed Heat Exchanger was done with **part load thermal duties**, i.e. without reaching the operational temperature studying the operation of heat exchanger before hot commissioning. For this purpose, the exchanger was pressurized up to  $44\text{kg/cm}^2$  using hot oil at  $300\text{C}$ .

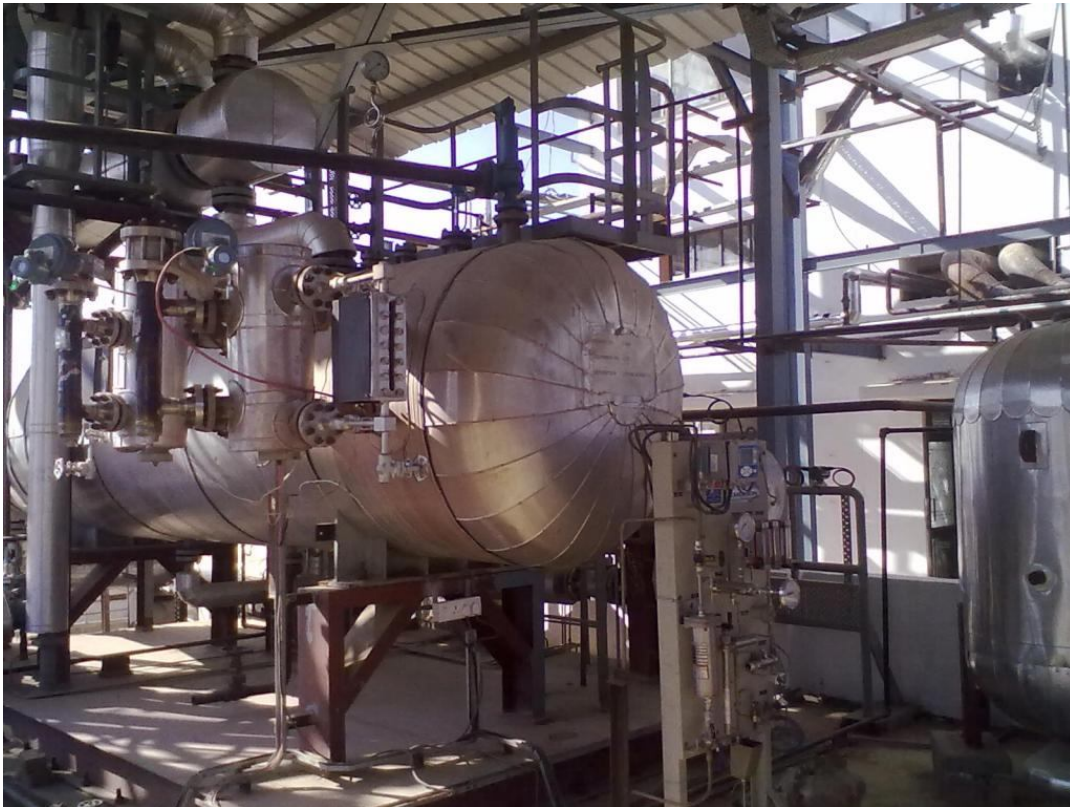


Fig 29: Heat exchanger in operation at site

## 3. Steam Blow-off

The turbine inlet line has to be cleaned with steam at  $40\text{kg/cm}^2$  and  $350\text{ }^\circ\text{C}$  to remove any particle that might damage the turbine blades. The steam blow off was achieved with hot oil pressurizing the heat exchanger to  $44\text{ kg/cm}^2$ . Fig shows the steam blow-off at  $44\text{ kg/cm}^2$ .



Fig 30: Steam blow off at 44 Kg/cm<sup>2</sup>

#### **4. Other Utilities**

All other utilities, namely air compressors, cooling water pumps, Demineralisation and water softener plants were installed and were tested individually for their required capacity and functionality. The operational accuracy of these utilities were established on hot commissioning of plant.

#### **5.4. CHALLENGES OVERCOME DURING THE COMMISSIONING**

At the time of tendering and establishment of plant, it was found that, there were many vendors with experience of supplying of individual components. However, there were no vendors having overall experience in installing, commissioning and operation of a solar thermal power plant. This initiative was aimed to gather experience with commissioning and operations for this technology.

There were numerous hurdles and challenges faced.

Site preparation started in January 2010. After which construction phase started on January 2011 and was completed on June 2012. After cold commissioning, hot commissioning started on October 2012 and was completed on June 2013. The plant is running and operations maintenance in being monitored from 2013. Various other problems were identified and rectified in the process during operations and maintenance.



## 5.1. Description of commissioning problems

The challenges faced during the commissioning were mainly of three types

- i. Operational Problems: These problems occurred during the operation of plant.
- ii. Equipment Problems: These problems occurred with the equipment itself. Errors in equipment specifications and non compatibility of some parts to the operation raised these problems.
- iii. System Problems: These are the problems occurred due to scarcity of resource to construct and commission the plant. Water and power are important for the plant to operate properly initially, but due to non availability of previously decided untapped dedicated line, the power was taken from the nearby sub-station. This turned to be unreliable due to heavy load shedding during construction.

Fig shows the various problems occurred with their classification. Fig shows the chronological order of their occurrence.

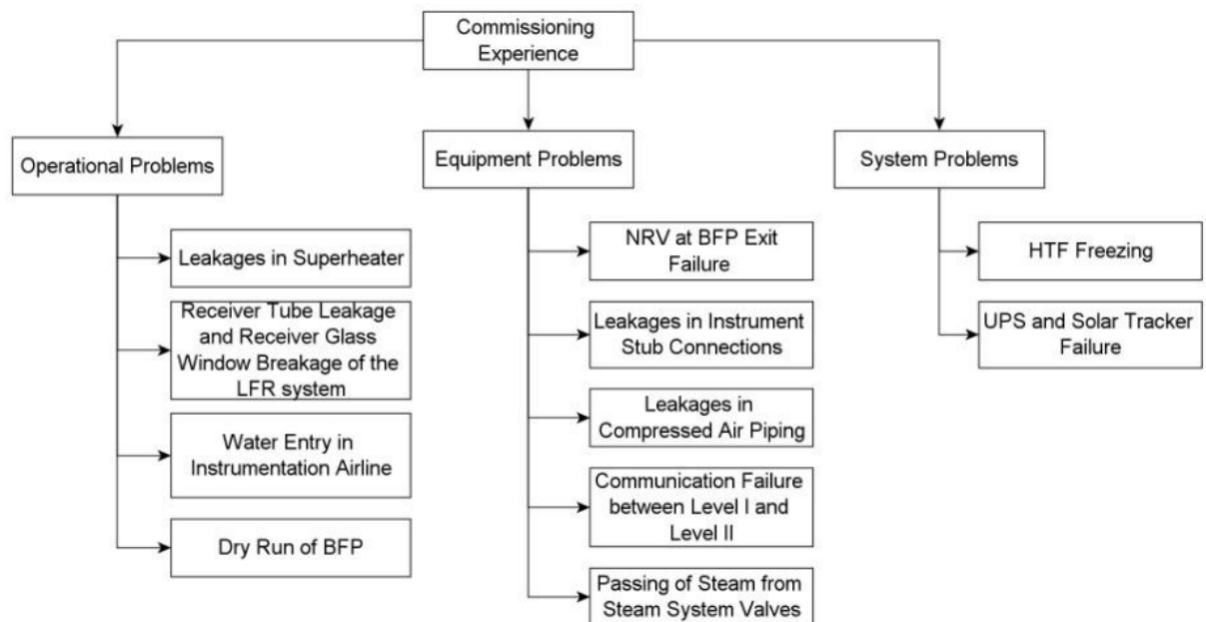


Fig 31: Various hurdles and challenges faced during commissioning.

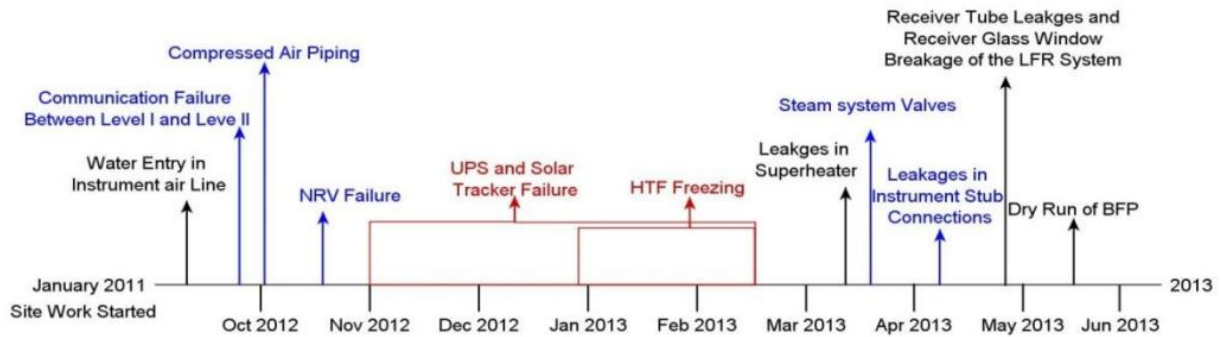


Fig 32: Summary and chronological order of the problem faced during commissioning of plant.

These problems and challenges are further explained here in the order of their occurrence. This details; where the problem occurred? , what the problem was? , How it was solved or scheduled to be solved in future? & what were the lesson learned?

#### 5.1.1. Water entry in instrumentation air line

A Demineralisation plant (DM) was installed to prevent corrosion in the piping and other metallic parts due to the water circulation and leakage.

**The Problem:** It requires air supply for proper mixing of resin in mixed bed unit. It was found during the trial run of the plant that, the water of the DM plant entered into the air pipe present as described above. This resulted in the damage of *electro-pneumatic position-ers* of four control valves present in the DM plant.

**Solution:** The problem was solved after installation of a **Non return Valve (NRV)** in the air line which prevented the water to enter the compressed air supply line at the inlet of the DM plant.

#### 5.1.2. Communication problem between level I and level II

The two solar fields, i.e. Parabolic trough & Linear Fresnel Collector had an independent working. Each one of them were controlled by their respective Level II PLCs. As they were part of the same plant a Level I is present to control both.

**The Problem:** The level II controls of the LFR and trough system were designed to receive command/overwrite from centralized level I system. This required interface of level I with level II of both solar fields. Level I system has port 502 / 503 for communication with level

II of solar fields. The LFR system has a SCADA screen of its own while the trough system doesn't have an independent operating SCADA screen and can be operated from the Level I screen only. As a result, port 502 was allotted to trough field level II; it was however noticed that LFR level II can only communicate with port 502 and not 503. Hence LFR was not linked with Level I.

**Solution:** With further investigation, it was found that the trough system can be operated with port 503. Hence 502 can be allotted to LFR field and 503 to Parabolic Trough. This requires many hardware additions and modifications, so requires long term shut down of plant. As there will be major modifications to the existing control systems, both are presently kept independent. The lesson learned is ensure compatibility of various systems during the design of the PLC system, more importantly while installing a multi level control systems.

### 5.1.3. Compressed air piping; Leakages.

Compressed air is used for operating and controlling the pneumatic valves. A Schematic is in Fig shows the compressed air flow sequence.

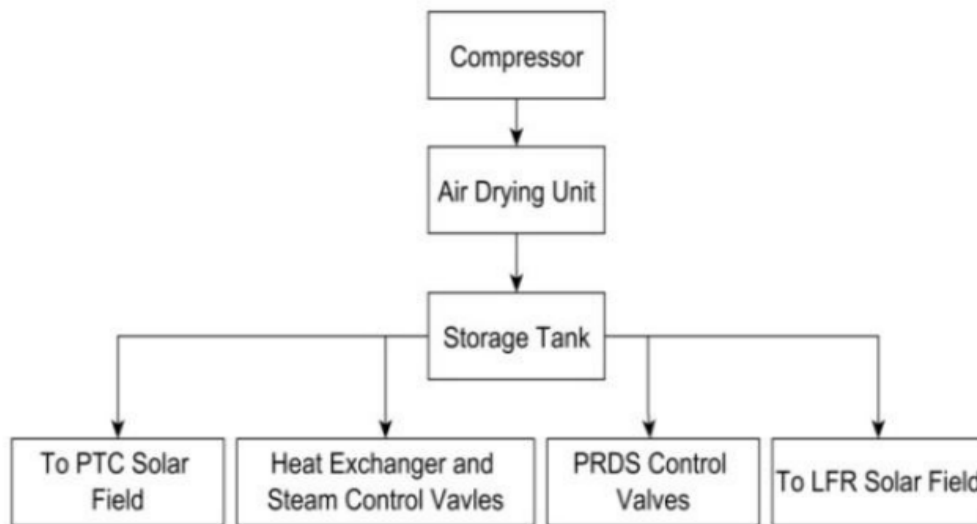


Fig 33: Schematic of compressed air flow.

**The Problem:** The Pneumatic valves work with the operating air pressure of 5-7 Kg/cm<sup>2</sup>. This results in a discharge air pressure of 7.5 Kg/cm<sup>2</sup>. The compressed air piping network at the project site is made of GI with threaded end connection. Ideally, there should not be any

pressure drop from the compressor storage tank discharge to valve inlet. However, it was observed that gradually the pressure at the valve inlet started to drop to 1.5 kg/cm<sup>2</sup> even though the pressure in the air storage tank was 7.5 kg/cm<sup>2</sup>.

**Solution:** After investigation it was found that the threaded ends of the GI Pipes was the reason for leakage. For continuous supply of air, the piping network needed to be tightened routinely. The joints can be welded and the leakages can be minimized. The lesson learnt is that piping network for compressed air line should be completely welded to minimize the leakages. The entire network of compressed air will be replaced by MS welded pipes when the plant will be shut down for longer duration in winter.

#### 5.1.4. NRV at Boiler feed pump exit Failure

**The Incident:** The Heat Exchanger was pressurized for the first time on October 1st, 2012 using steam generated from the parabolic trough solar field. Subsequently, steam was being generated and blown to the atmosphere to clean the turbine inlet steam line. A schematic diagram of water flow from deaerator to heat exchanger is shown in Fig

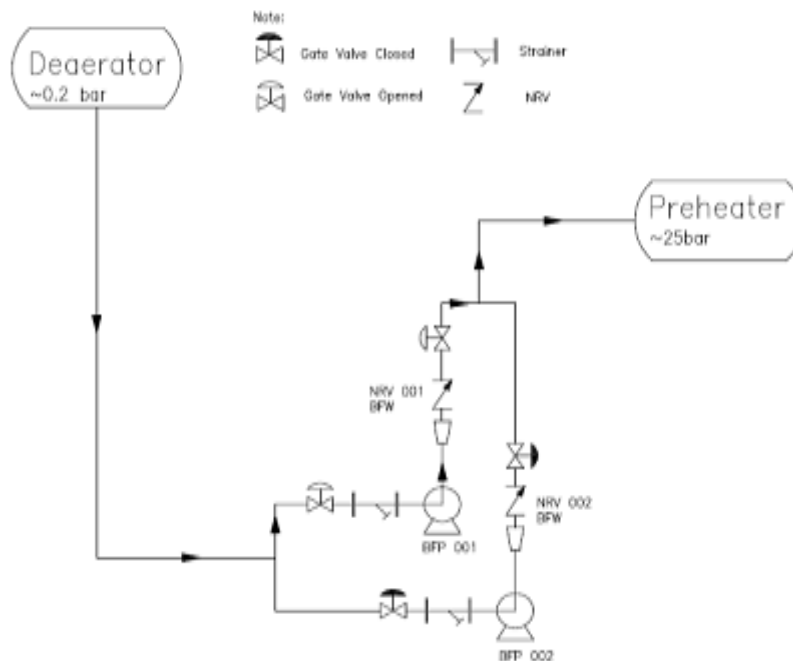


Fig 34: Process flow from deaerator to steam generator.

The BFP is operated based on the water level in the steam generator. When the Steam Generator (SG) water level is  $L_{max}$ , the BFP is tripped and is switched on when the level reaches  $L_{min}$ . On October 27, 2012 at about 02:00 pm when the heat exchanger was being pressurized (SG Pressure -25 kg/cm<sup>2</sup>, hot oil temperature -274°C), smoke was observed from the running BFP. At this moment, the BFP was not running as there was sufficient water level in the SG. When the pump started smoking, vibration was also noticed in the deaerator.

Following actions were taken immediately to prevent possible damage to equipment.

- The boiler feed pump was isolated by closing the outlet gate valve.
- Vent valves were opened to decrease the SG pressure.
- Solar field was defocused.
- Heat Exchanger was bypassed to limit the steam generation.

**The Problem:** It was noticed that the BFP suction line from deaerator to BFP was very hot and water temperature in the deaerator increased from ambient 30°C to 42°C and the pipe supports on the suction line were dislodged. The vibration sound in the deaerator was due to back flow of the steam from the SG and smoke from the pump was steam. Since there was backflow of steam and hot water from SG to deaerator, it can be concluded that NRV 001 BFW at BFP 001 exit failed. The NRV 001 / 002 BFW are welded on a vertical line while upon checking it was observed that the NRVs are suitable for installation only on a horizontal line.

**Solution:** It was evident that the problem occurred because of incorrect specification of the NRV and installation. Subsequently as the correction, the installed NRVs were replaced with NRVs mountable in vertical lines.

#### 5.1.5. UPS and solar tracker failure

In the plant, Uninterruptible Power Supply (UPS) system is installed for emergency backup to the PLCs and weather station. For the present plant, the standalone UPS system can sustain a load for 6 to 8 hours. Solar tracker is used to track the maximum DNI orientation, which is in-turn used to move the Parabolic Trough Mirrors to get maximum output.

**The Problem:** Many times, the grid power was not available and DG system ran intermittently for anti-freeze mode. Due to this, the solar tracker (measuring the radiation data) used to go off-set, daily. As a result of this daily off-set in the solar tracker, the worm gear in the tracker failed and the tracker stopped working.

The UPS which was supposed to be used for few minutes, was being used for larger duration, in-case of grid failure. This resulted in decreased back-up period of the UPS. The problem could be sorted out only after continuous power back-up.

**Solution:** Both the problems, UPS & Solar tracker Failure, were the result of not getting continuous power supply or scarce Back-up resources. This was sorted out by making sufficient arrangements for continuous power back-up.

#### **5.1.6. HTF Freezing**

HTF Therminol VP 1 is the oil used for heat collection from Parabolic Trough Field to the heat exchanger, where the heat is used for produce steam for turbine.

**The Problem:** The crystallization temperature of HTF Therminol VP1 is 12°C. The plant, located in Gurgaon experiences minimum temperature much below 12°C in winters. On many days, It can be easily found that for most part of the night temperature is below 12°C, in winters. The plant runs in antifreeze mode during winter where the oil is continuously circulated in the solar field and heated to 40°C by an inline heater and electrical heat tracing provided at the pump suction and discharge lines. The HTF pump was being used to circulate oil in the solar fields and pipe lines. However, due to unavailability of electrical power ,a DG set was used to run the plant in antifreeze mode periodically depending on the reading of the temperature gauge at pump discharge. When the oil temperature in the gauge showed below 350 C, main HTF Pump and electrical heating system was switched on. This activity was performed routinely for more than a month. However on December 31st, 2012 evening when the plant operator went to start the pump and heat tracing system, it was noticed that the pump started, went to 150 rpm and the speed dropped to 9-10 rpm. The same procedure was tried again next morning, however the problem persisted. It was observed that the pressure readings at the pump discharge and solar field outlet were 12 bar and 3.2 bar respectively. It was concluded that HTF was crystallized in the circuit and the pump could not circulate the oil in the circuit. The main HTF pump was attempted to run in February when the ambient temperature was more than 20°C in the day. However after multiple runs on February 15th, 2013 the seal in the main HTF pump failed and oil started leaking from the seal pot. Similar problem was experienced when one storage tank pump was attempted to operate.

The oil freezing occurred because the HTF Pump was run based on the observation of one temperature gauge. Since the Level II PLC of the trough system was not working at that time, temperatures in the field and at other locations could not be monitored regularly. As a result, oil circuit crystallization anywhere in the circuit implied that the pump could not be run.

The oil loop consists of storage and main HTF pumps (2 + 2). Following problems were noticed with respect to anti-freeze mode.

- The pump seals do not have anti-freeze protection. As a result only the inline pump is protected from the oil crystallization while the oil in the seals of stand-by pump crystallizes.
- Two storage tank pumps are used only when oil is to be pumped into the circuit. Hence they cannot be run in antifreeze mode because they do not form a loop unlike main HTF Pump.

**Solution:** This problem could have been avoided with running the system for 24 hours but it was not done in order to save on diesel cost. The seals of the main HTF pump and storage pumps were replaced and the pumps were tested after the oil unfreezing in March. It was also made important to monitor the oil temperature at all locations in the circuit. It was also recommended that the system should run in anti-freeze mode round the clock during winters.

#### **5.1.7. Leakages in the super-heater**

Superheating is an important process which gives better efficiency. To carry out super-heating a super heater was installed. The steam from the boiler is fed into a super-heater and then to the turbine.

The Problem: On March 10th, 2013, at a steam pressure of 35 kg/cm<sup>2</sup>, the super heater started to show leakage as shown in Fig



Fig 35: Super Heater

The exchanger operated fine till 35 kg/cm<sup>2</sup> pressure, however once it reached above 35 kg/cm<sup>2</sup> pressure the leak started and it became more intense with the increasing pressure. The exchanger was tested many times however the problem persisted.

**Solution:** The leakages were observed because the bolts loosened due to high temperature. The bolts were tightened at appropriate torque using a torque spanner and the problem was solved.

#### 5.1.8. Steam system valves

The plant uses various kinds of valves to control flow of different fluids and steam. The turbine uses steam to operate and produce power. The turbine inlet steam line has to be cleaned completely by blowing superheated steam at rated pressure.

**The Problem:** Superheated steam is blown in the turbine inlet with pressure to completely clean it. For increasing the pressure, the steam valve at the boiler exit has to be closed. During the blowing of steam, it was noticed that the main pneumatic MSV valve was passing some amount of steam even though the valve was closed. Further, the following issues were observed while evaluating the problem:



- i. The MSV is an ON/OFF type valve. As MSV was passing some amount of steam through it in ON mode, the peak pressure could not be reached in the steam generator. These valves also did not have a manual handle for closing, as result the commissioning work was hindered.
- ii. There are no manual valves in the steam line that could cover for the above mentioned problem of pneumatic valves.
- iii. The MSV being an ON/OFF valve, desired degree of superheat was obtained by opening the steam traps and closing the MSV.

This problem could have been avoided with the MSV being a control valve. Hence the lesson learned was to use MSV valves with a manual handle present so that they can be controlled when required.

#### **5.1.9. Leakages in instrument stub connections on heat exchanger**

Temperature Transmitters are fixed on oil lines going into and out from the heat exchanger. The vapor pressure of therminol VP-1 at 257°C is 1 bar. As temperature increases, the vapor pressure of the therminol VP-1 increases. It should be noted that to keep the Therminol from evaporating, the pressure of the therminol VP-1 in the circuit should be more than the vapor pressure of Therminol. The temperature has to be maintained using nitrogen blanketing on the pressure vessels.

**The Problem:** During operation of plant when the HTF was heated to temperature above 257°C, leakage was observed from temperature transmitter stubs. Upon inspection it was found that HTF vapor was leaking from the screwed connection between the stub and the nipple of the temperature transmitters. The plant was immediately put into shut down mode to prevent further loss of HTF.



Fig 36: Temperature transmitters leakages

As per the Fig, the end connections of the temperatures transmitters stub were screwed. Welding on these screwed connections cannot be done, as the HTF in the line has an ignition temperature of  $621^{\circ}\text{C}$ , whereas the arc temperature of the welding is about  $1000^{\circ}\text{C}$ . Hence Welding cannot be done with the oil still running in the system.

Draining oil from the circuit was also not possible because the circuit was charged with approximately 20 Tonne of oil and removing and recharging such a large volume of oil is not at all practical.

Isolating the heat exchanger and locally removing the oil also meant removal of considerable volume of oil in the heat exchanger. Moreover, the valves isolating the exchanger passed a certain amount of oil due to which the exchanger can never be kept completely dry from oil.

**Solution:** The only option was sealing the leakage area with highly durable sealant. A vendor was recognized for sealing the stub with appropriate chemical. For proper sealing, a metal clamp was put around the stub and the space between the clamp and the stub was injected with a sealant. The leakage is now arrested and plant is working fine.

The lesson learnt from the above problem is that the HTF circuit should have minimum flanges and absolutely no screwed connections. Normally, complete welded connections are preferred for HTF loop and it should be done before charging the HTF oil into the system.

## 6. SUMMARY & DISCUSSION

The document, though briefly, had tried to explain all aspects of the project; The MegaWatt Scale power plant & research facility; The Testing of CSP components facility; and Solar Thermal Simulator for design and optimization. After the foundation laid on April 2008, many milestones were achieved. The proposal was submitted on January 2009 and was approved by MNRE on September 2009. Site was finalized at Solar Energy Center, Gwalpahari, Haryana, midst of Gurgaon-Faridabad region.

Design of **the power plant & research facility** was done by; selecting the optimized configuration for the site available; by taking inputs from selected from existing CSP plants in USA; by studying the feasibility and expertise available in India for proposed design; and by allowing multiple technologies of solar thermal collectors taking into consideration. Parabolic trough Collectors (PTC) and LFR collectors were finally installed. Former used HTF oil for heat collection which was used in a heat exchanger to produce superheated steam to run the turbine and generate power. The latter, directly converted water to steam for power generation. PTC was able to reach higher temperatures due to carefully chosen HTF Oil, which had a high heat capacity than water.

After completing the; fencing, tree cutting, Leveling and preliminary soil & whether tests; the construction of plant began in January 2011. The plant consisted of many individual & sub-systems installations like solar fields, turbine & power block, Piping systems, heat exchanger, demineralization plants etc, each having their specific roles in the whole plant. It was a challenge to monitor all major installation simultaneously so that they do not affect the schedule of plant construction. Individual testing and operations were also done before connecting them for commissioning. A cold commissioning was done to ensure all the sub-systems were working properly and in-sync with each other. This made possible identification of many problems and their rectification. Hot commissioning of power plant posed many challenges, discussed in the above report. The problems were broadly of

- i. Operational: Leakages in superheater, Receiver tube, Dry run problems in BFP, Valve issues in DM plants etc. These are faced primarily during running of plant.
- ii. Equipment related: NRV failures due to incorrect selection, Stub connections leakage, Leakage of compressed air due to threaded pipes, Communication issues of PLCs etc. These are caused due to incorrect selection or installation of some small parts and equipments.
- iii. System related: HTF freezing due to whether, UPS failures due to more power cuts etc.

The solutions for all the problems were found successfully. They were either successfully removed immediately or were scheduled for the right time as some require shut-downs of plant. The plant was commissioned on July 2013 and was monitored while operation for a year. Grid synchronization was completed on March 2014 and is now in process of handing over to MNRE.

The **testing facility**, alongside the Power plant and research facility, was installed and commissioned to test the thermal performance of oil based collectors. The test rig is capable of calibrating various sensors & instruments used in the power plant. It also has the capability of storing the data and analyzing them for inferences.

Further to this facility, IIT Bombay has developed an indigenous technology for testing water based collectors. This is under development phase in solar energy lab at IIT Bombay campus and will be implemented at in the testing facility.

A Flux mapping system is developed for measuring the concentrated flux obtained in Linear focus solar collectors implemented and tested at Solar energy Lab, IIT Bombay.

The **simulator**, first released in July 2011, was downloaded in 150 Institutions, 230 Industry and other organizations across 24 countries. The software allows simulation of a complete plant or a user defined small subset of complete plant in quasi-steady state.

It was a pride and an achievement for IIT Bombay and all organizations & people involved, to be able to design, install and commission the plant successfully.

## **7. ACKNOWLEDGEMENTS**

We are thankful for Ministry of New & Renewable Energy (MNRE), Govt. of India for funding the project. The project would not have been possible, without all the associated faculties, all the project team members (in past & present). The consortium members have shared and contributed positively in their respective expertise and we are grateful to them. We would also thank and congratulate all the Contractors and Consultants for helping us complete the project in time.