Simulation of Solar Thermal Power Plants

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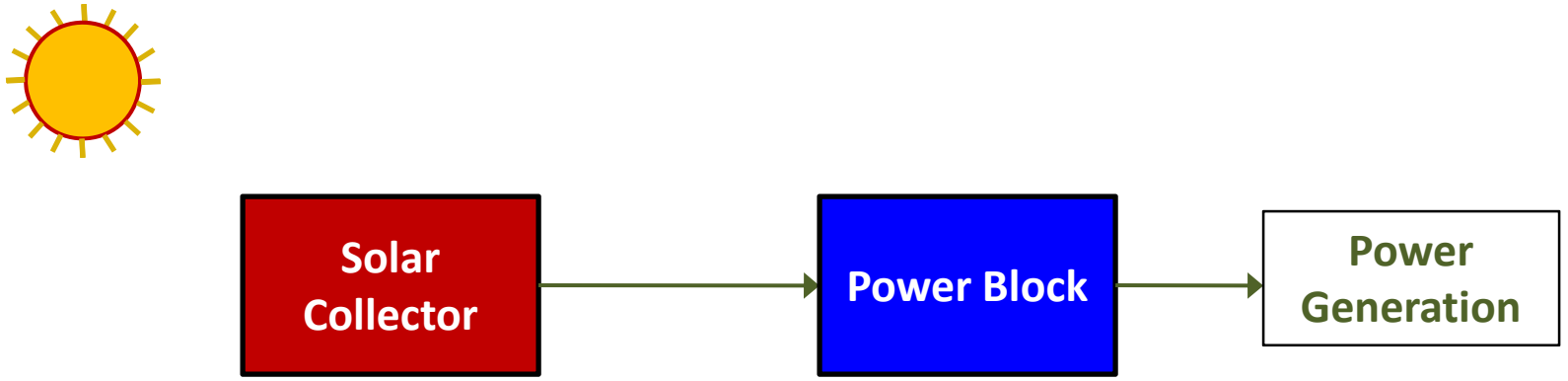
Introduction

- **Concentrating solar power (CSP)**
  - **More than eighty operational plants**
  - **Thermal energy storage**
    - **intermediate and base load**
    - **high capacity factor**
    - **improved grid integration**
  - **Hybrid back up system (auxiliary boiler)**
  - **Integration with existing fossil fuel based plants which uses steam Rankine cycle**
  - **High initial cost**

Introduction



Typical Block Diagram of a Solar Thermal Power Plant

- **Concentrating Solar Collectors**
  - **Parabolic Trough Collectors (PTC): most commercially applied systems**
  - **Linear Fresnel Reflector (LFR): cost reduction potential**
  - **Paraboloid Dish: least applied systems for power generation**
  - **Solar Power Tower (SPT): cost reduction potential**

Introduction

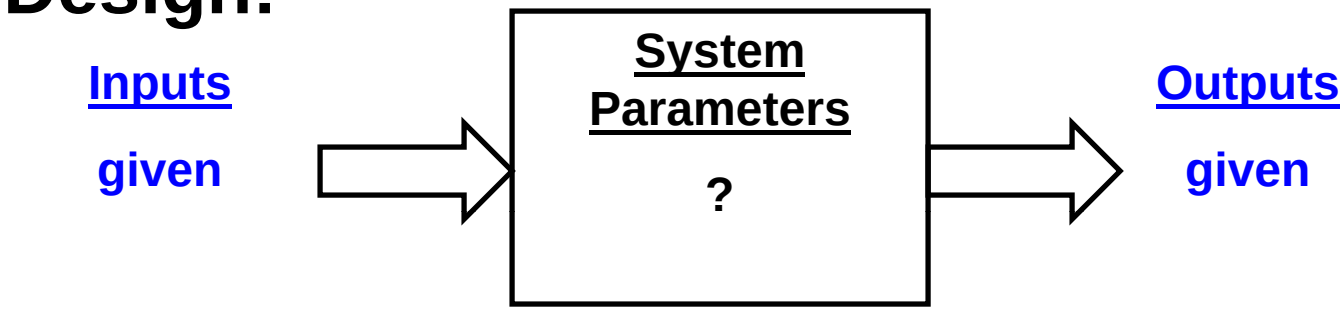
- Power Generating Cycles
  - Steam Rankine Cycle
    - most widely used in the CSP plants
  - Organic Rankine Cycle (ORC)
    - modular CSP plants
    - one plant in MWe range: working fluid is n-pentane
- Conceptual design of a CSP plant
  - Important to screen numerous design alternatives
  - Type and size of solar field
  - Power generating cycle and the working fluid
  - Sizing of the power block

Need of a Simulator

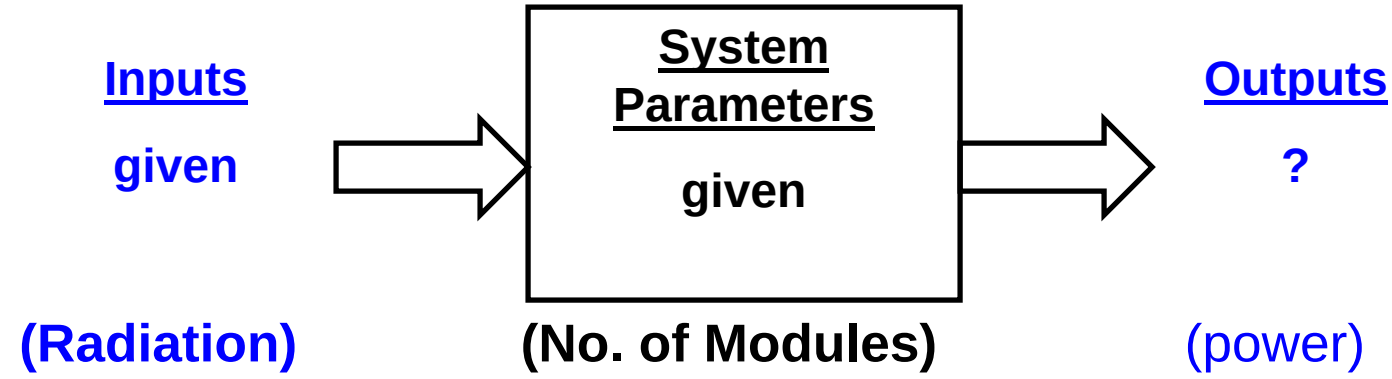
- Finalization of plant configuration
  - Evaluate different solar collector technology
  - Evaluate different power generating cycle configurations and parameters
  - Equipment sizing
- Control strategy
  - Startup and shutdown
  - Auxiliary Boiler Firing
- Concept of innovative CSP configurations
- Total number of equations significantly high
- Number of recursive dependencies between various equipments
- Typical operation year with 8760 calculation

Design and Simulation

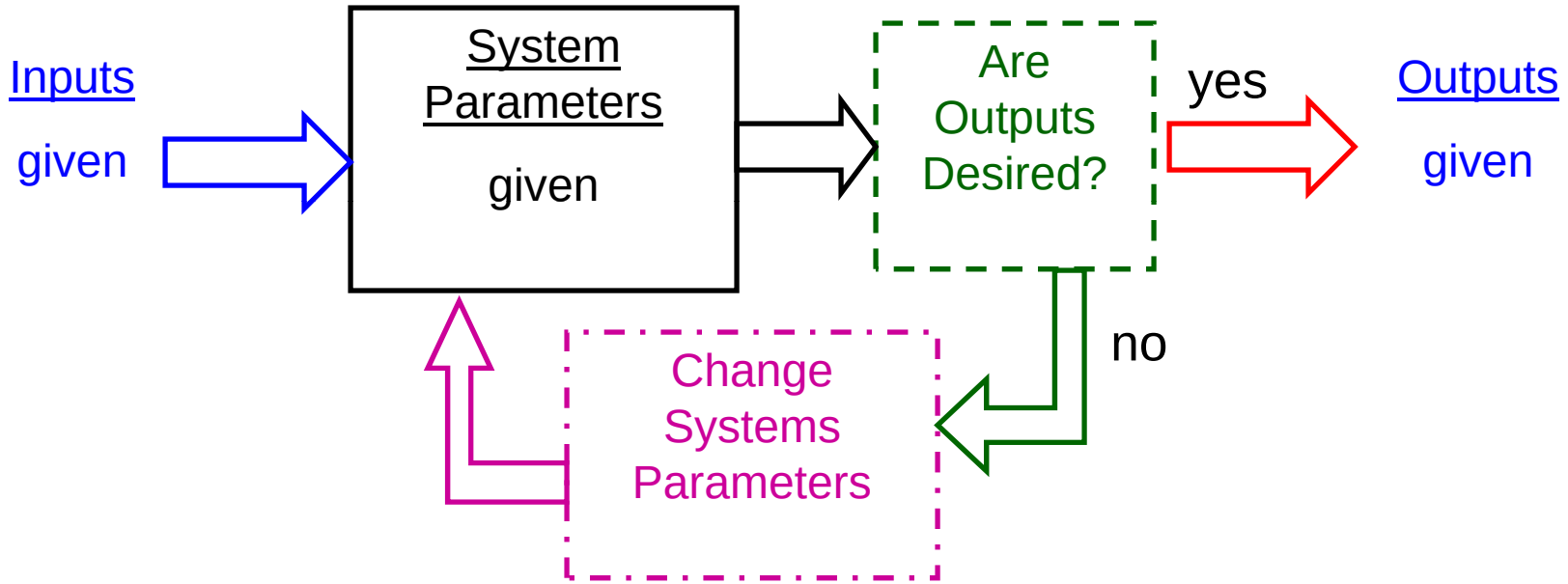
Design:



Simulation:

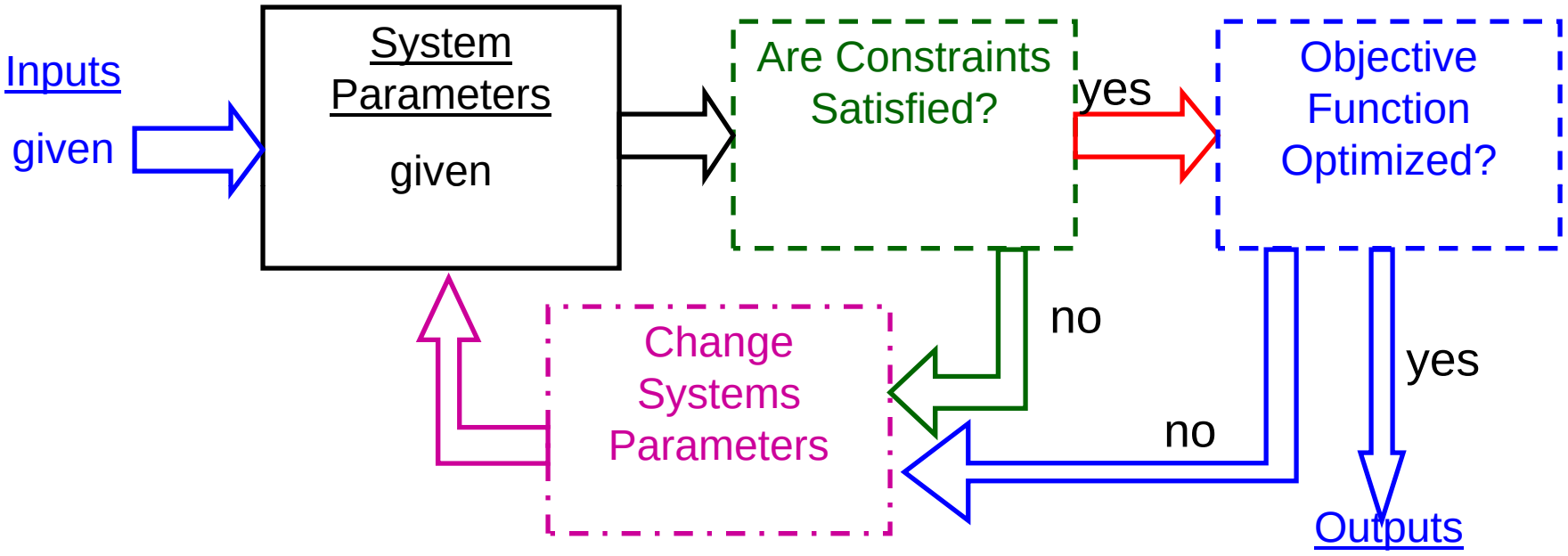


Simulation Aided Design



Design of a System or a Process may be done by Repeated Simulation.

Simulation Aided Optimization



A System or a Process may be Optimized subject to Certain Constraints by Repeated Simulation.

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**
  - **Cost of energy**

Features

- Graphical user interface for data input and output
- Equipment model library with database as well as manual entry of the parameters
- Model library for 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 as MS Excel file

Solar Thermal Simulator

- **How Simulator is useful**
  - **Preliminary sizing and cost estimation**
  - **Heat and mass balance design**
  - **Parametric studies**
  - **Performance evaluation of a small subset of a complete plant or a complete plant**
  - **Optimization of plant configuration through multiple simulations**
  - **Devise the overall control strategy**

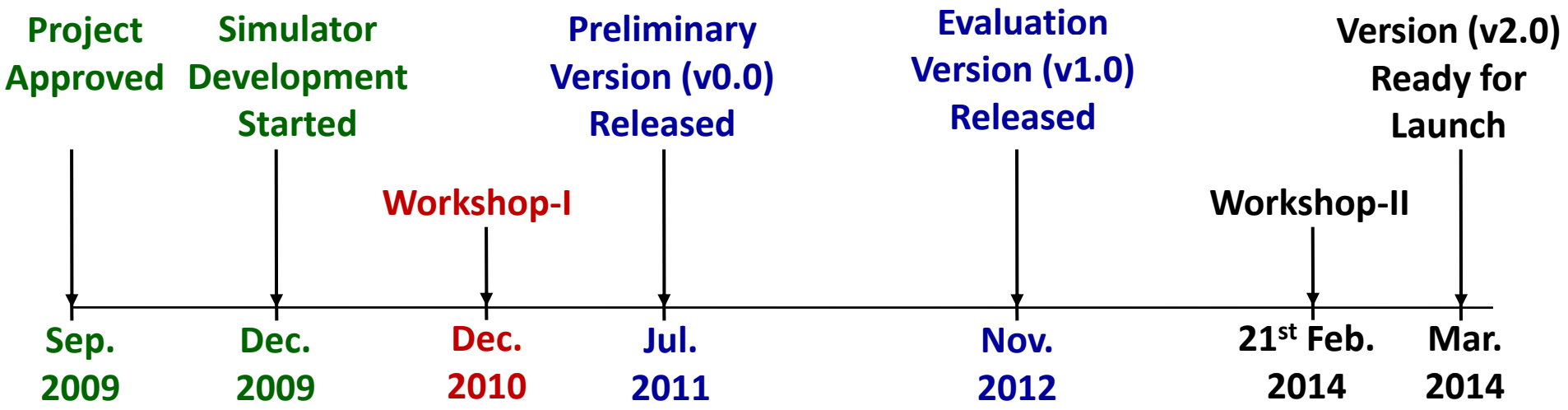
Solar Thermal Simulator

- **Who can use**
  - **Solar equipment suppliers**
  - **EPC contractors**
  - **Investors and others involved in engineering and analysis of solar thermal systems**
- **Simulator can also be used for**
  - **Solar thermal process heat application**
  - **Conventional power plant with steam Rankine cycle**

Solar Thermal Simulator

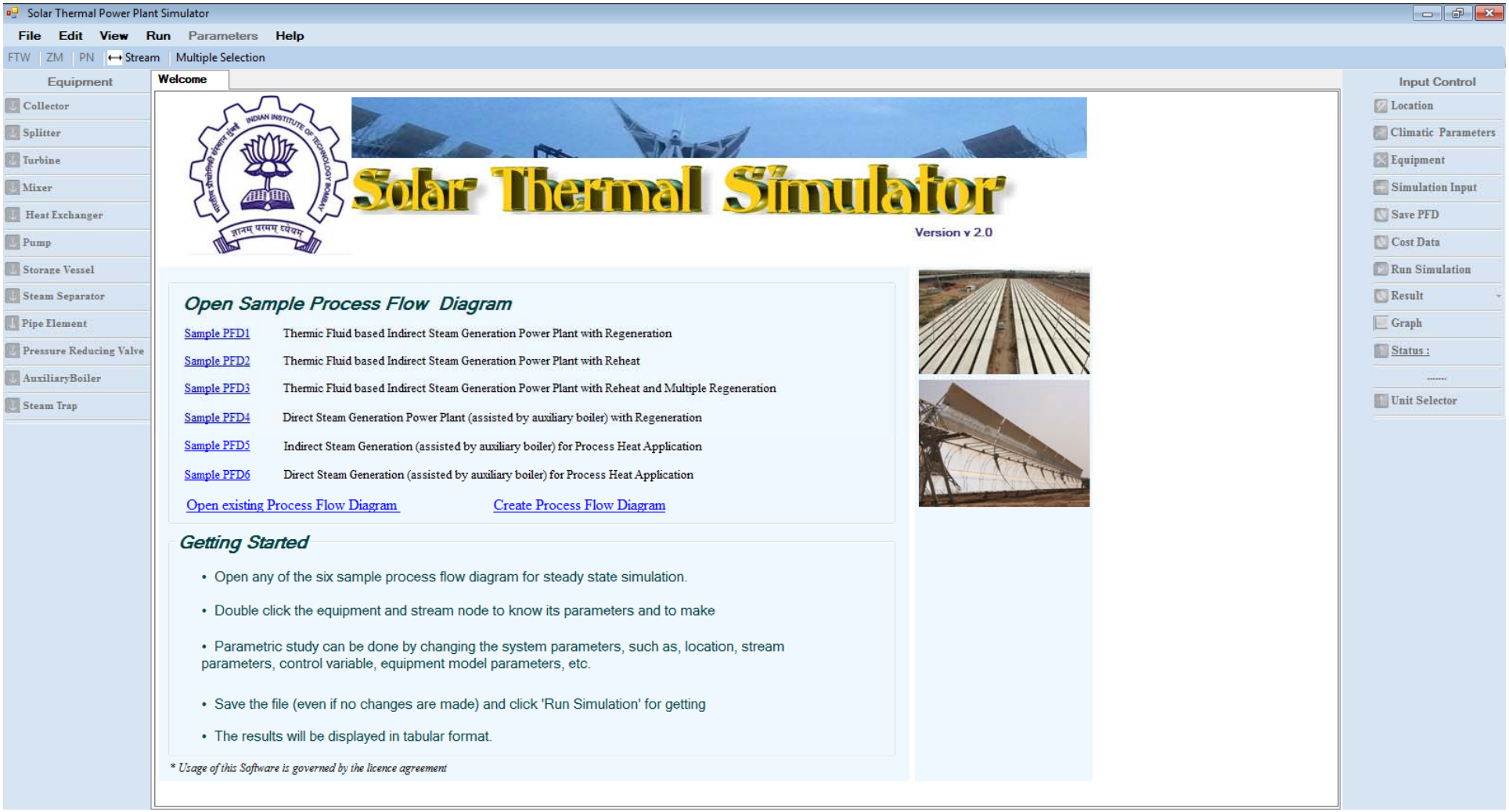
- **Limitations of current version**
  - **Equipment library**
    - **Solar collector: PTC, LFR and Paraboloid dish**
      - **Heliostat and Flat plate collector: next version**
    - **Storage Vessel: well-mixed tank, sensible heat storage**
    - **Data defined models**
  - **Working fluid library: Water/Steam, TherminolVP-1, NitrateSalt, HitecXL, DowthermQ, DowthermRP, Caloria**
  - **Basic cost analysis**

Evolution of Simulator



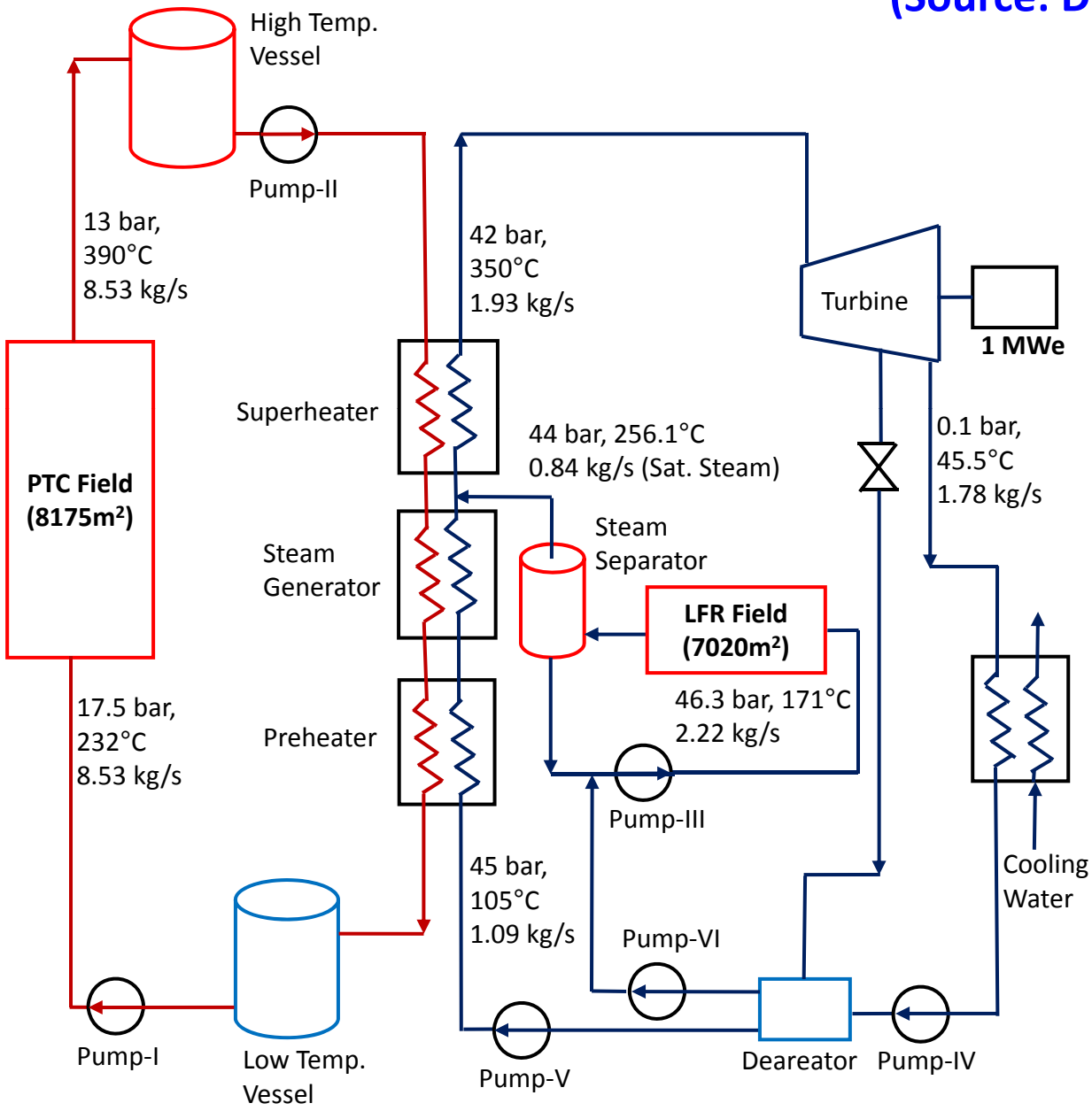
- **Preliminary Version v0.0**
  - **Downloaded by 250 institutes, 450 industry and other organizations across 24 countries**
- **Evaluation Version v1.0**
  - **Evaluation License for evaluation and testing of the version to Fichtner India Pvt. Ltd.**
  - **Tata Power as a consortium member**
- **Workshop-I**
  - **About 50 participants from different industries**

User Interface: Main Window

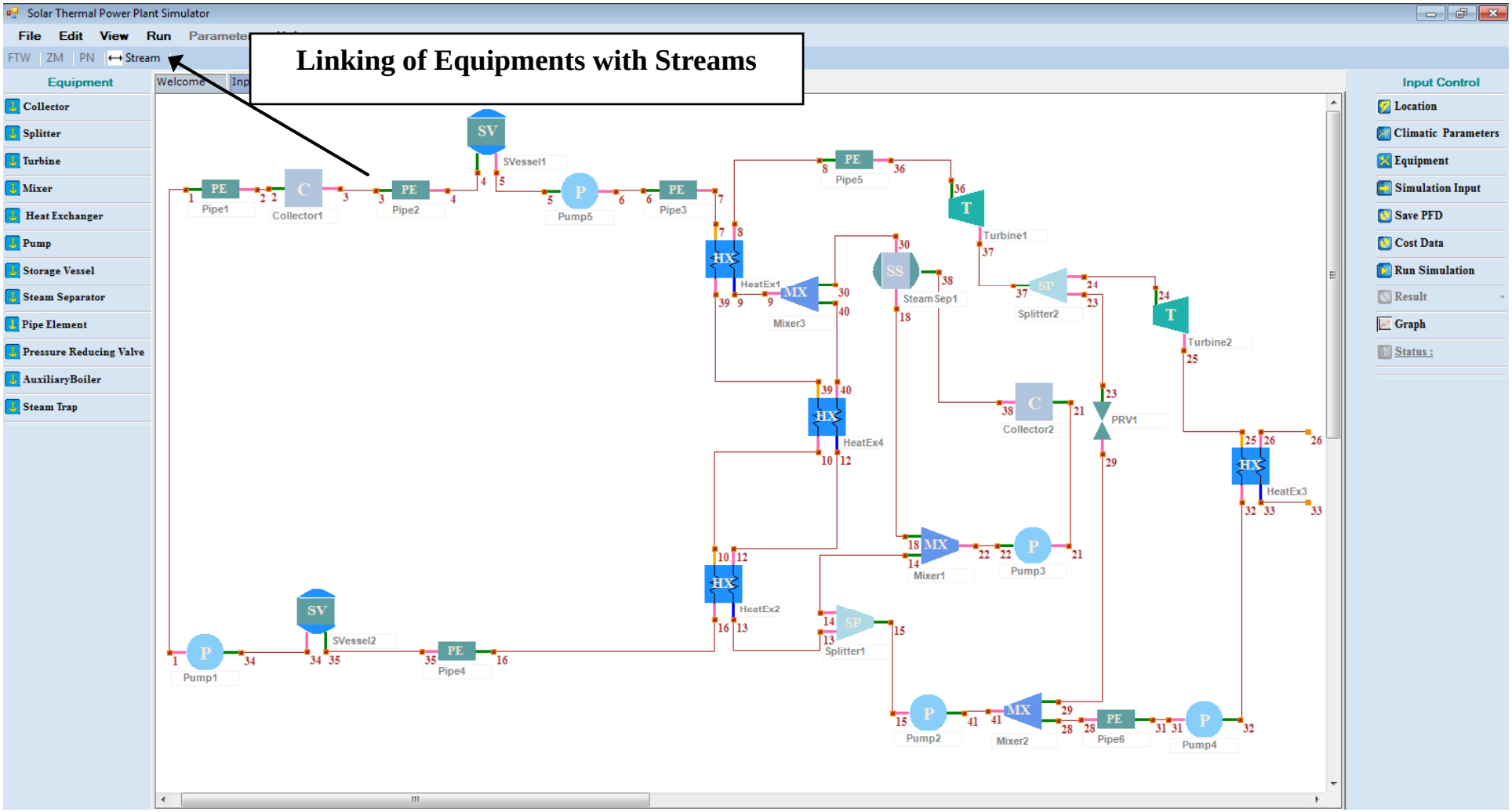


Process Description of 1 MWe Solar Thermal Power Plant

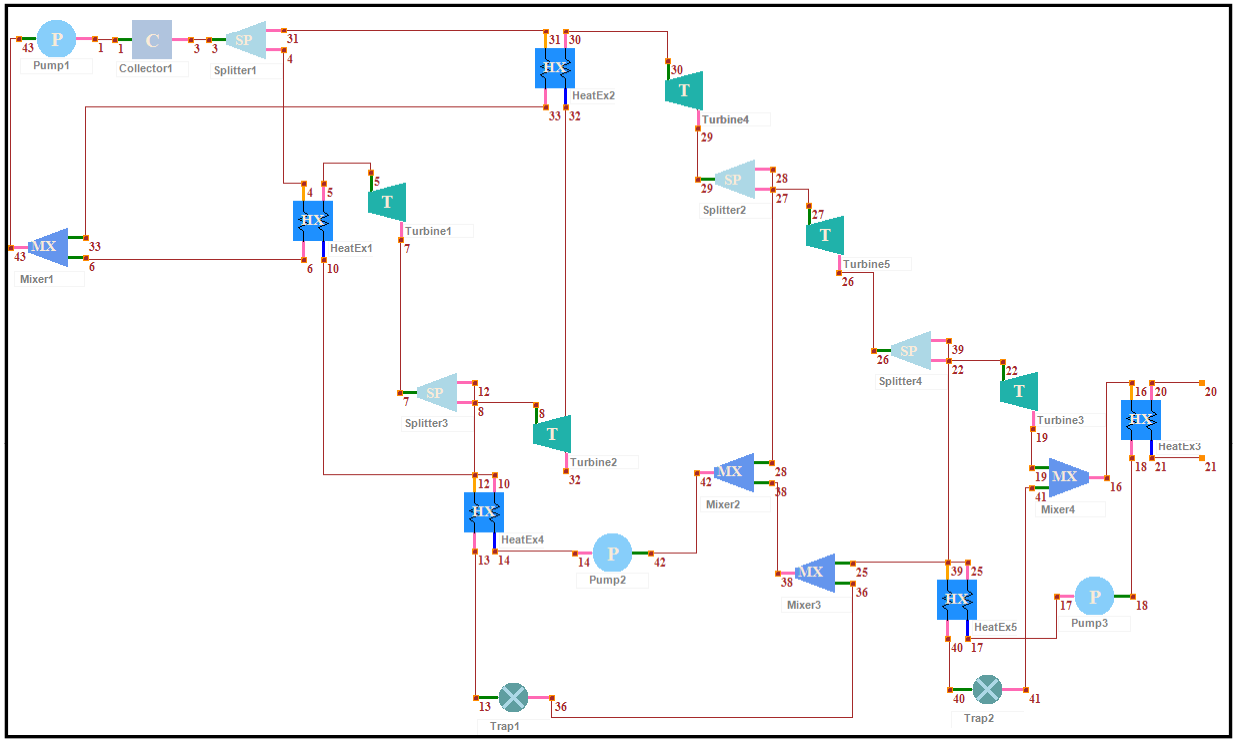
(Source: Desai et al. 2013)



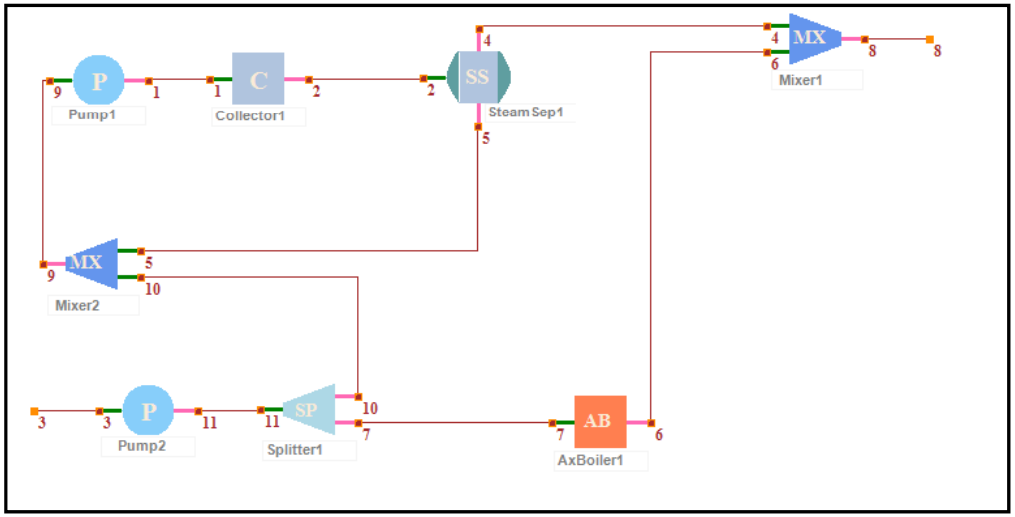
Solar Thermal Simulator Model



Generation of user defined PFD using Simulator



Typical 50 MWe Solar Thermal Power Plant



Direct Steam Generation Process Heat Application

Comparison of different widely used simulators with Solar Thermal Simulator of IIT Bombay

(Source: Desai and Bandyopadhyay 2012)

		System Advisor Model (SAM)	TRNSYS	THERMOFLEX	Solar Thermal Power Plant Simulator
1	**Developed By**	National Renewable Energy Laboratory	University of Wisconsin	Thermoflow, Inc.	Indian Institute of Technology Bombay
2	**Renewable Energy System**	Generic, includes different renewable systems other than solar thermal (e.g. Photovoltaic, Geothermal Power, Small Scale Wind)	Generic, includes different renewable systems other than solar thermal (e.g. Photovoltaic, Geothermal Power, Wind)	Generic, Focus on Solar Thermal System only	Generic, Focus on Solar Thermal System only
3	**Concentrating Solar Power**	Includes following systems: PTC, SPT, LFR, Dish Stirling	Includes following system: PTC, LFR, SPT	Includes following system: PTC, LFR	Current version includes: PTC, LFR, Paraboloid Dish
4	**Power Block**	Fixed configurations	Simulation of any configuration is possible	Simulation of any configuration is possible	Simulation of any configuration is possible
5	**Simulation of User Defined PFDs**	NO	YES	YES	YES
6	**Cost Analysis**	YES	NO	YES	YES
7	**Results reporting through tables and graphs**	YES	YES	YES	YES
8	**Weather Data (Radiation, Amb. Temp. etc.)**	Manual, Library	Manual, Library	Manual, Library, Model for Radiation Data	Manual, Library, Model for Radiation Data

Concluding Remarks

- Developed from scratch
- Simulation of any plant configurations
- Simulator can be used for
  - Preliminary sizing and cost estimation
  - Heat and mass balance design
  - Evaluating different alternative designs
  - Parametric studies
  - Optimization of plant configuration through multiple simulations
  - Devise the overall control strategy
- Who can use
  - Solar equipment suppliers
  - EPC contractors
  - Investors and others involved in engineering and analysis of solar thermal

References

- Desai, N.B., Bandyopadhyay, S., 2012. Solar Thermal Power Plant Simulator. In: Proceedings of International Conference on Energy Security, Global Warming and Sustainable Climate (Solaris 2012), Varanasi, India.

- Desai, N.B., Bandyopadhyay, S., Nayak, J.K., Banerjee, R., Kedare, S.B., 2013. Simulation of 1 MWe Solar Thermal Power Plant. In: Proceedings of the ISES Solar World Congress, Cancun, Mexico.

Thank you