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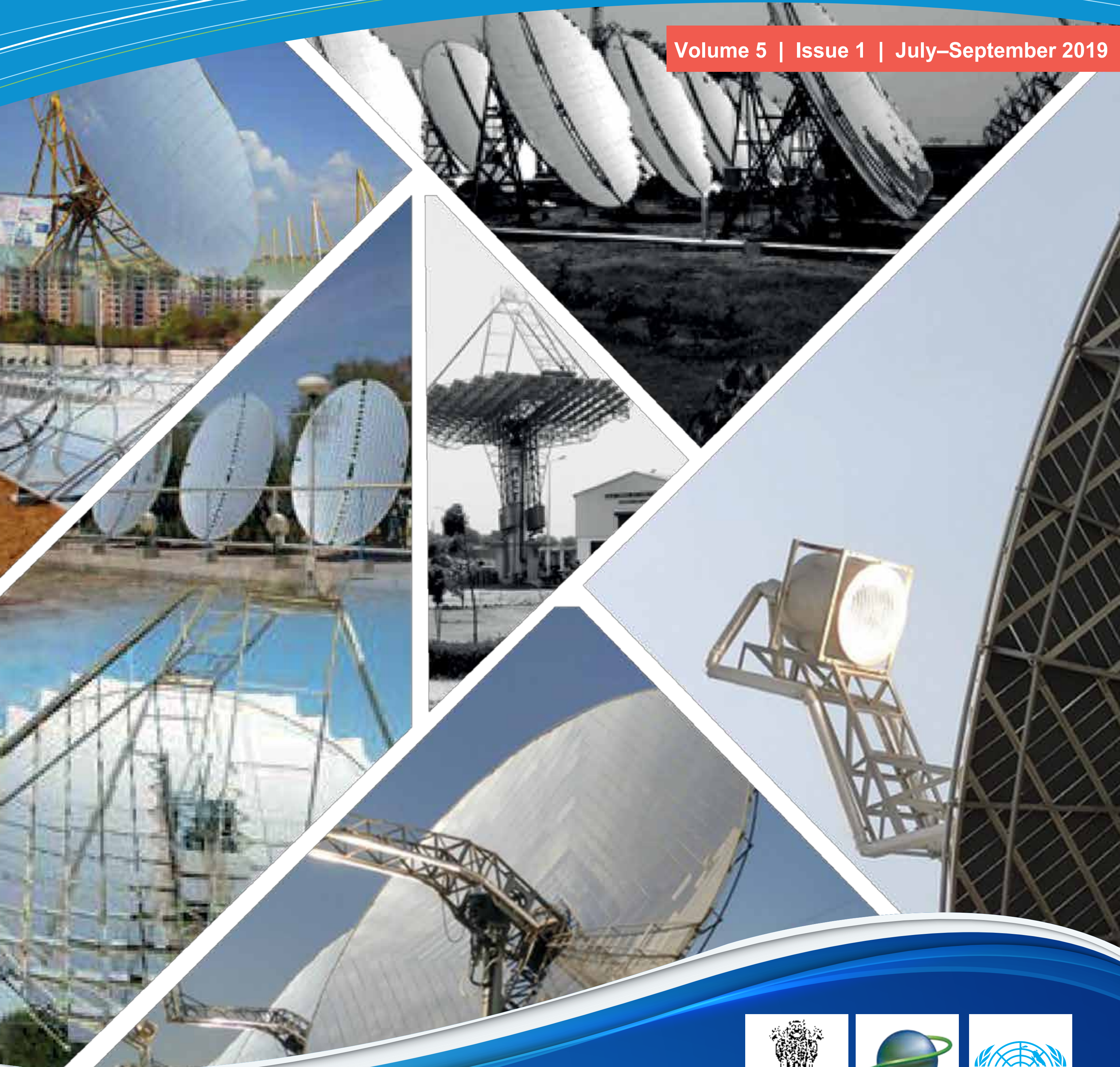

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PROMOTING BUSINESS MODELS FOR INCREASING PENETRATION AND SCALING UP OF SOLAR ENERGY

MNRE-GEF-UNIDO Project

PERFORMANCE IMPROVEMENT OF 125 MW CSP SOLAR THERMAL POWER PLANT OF RELIANCE POWER, DHURSAR, RAJASTHAN, INDIA

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Background

Rajasthan Sun Technique Energy Pvt. Ltd. (RSTEPL), a subsidiary of Reliance Power Limited, had installed a 125 MW CSP solar thermal power plant at Dhursar, Rajasthan, India based on the CLFR technology (Figure 1). This plant has been in commercial operation since November 2014. M/s AREVA Solar, a French Company was the CLFR technology provider of this plant. It worked as an EPC contractor of solar field under Reliance Infrastructure Limited. Reliance Infrastructure Limited, in turn, was an EPC contractor of RSTEPL for the project. Solar fields with 35 solar steam generators (SSGs) are designed to generate direct superheated steam. This SSG configuration is different from the configuration of AREVA's Kimberlina Solar Thermal Power Plant located in Bakersfield, CA, USA.

After erection, testing, commissioning and commercial operation, the plant faced technical and operational challenges related to LFR components and control systems for smooth operations and target energy generation. After the exit of M/s AREVA from this project and from CSP business globally, it was a big concern and challenge for RSTEPL to operate the plant and produce the desired load and PLF. Reliance Power took it as a challenge and converted it into an opportunity by understanding and analysing the basics of the technology and operation. Reliance Power engaged various consultants but did not realize the expected improvement in generation. Then Empereal-KGDS Renewable Energy Pvt. Ltd. was engaged as a third-party technology consultant to improve the performance and achieve reliable operation.

This solar thermal plant has a total mirror area of 1, 400, 000 m^2 and consists of 35 SSGs. Each SSG is 540 m long and has 33 mirrors, each having a width of 2.25 m. The receiver is 30 m above the plane of the mirrors. Nine receiver tubes are in the cavity. Eight tubes, called economizer-cum-evaporator tubes, travel from one end of the receiver to the other. The fluid carried by these eight tubes passes through a header at the end of the receiver and travels back the entire length of the receiver through a central tube called the superheater tube. In this once-through

Figure 1: A view of the Reliance 125 MW solar thermal power plant in Dhursar, Rajasthan, India

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boiler, water enters at one end at around 70–150°C. The design outlet condition out of the superheater tube is superheated steam at 390°C and 90 bar pressure. The turbine requires 568 tonne/h of steam of this quality to produce 125 MW.

Original control logic used by OEM distributes flow through each of the eight economizer tubes in the receiver by measuring the temperature at five different points along its length. Five RTDs were installed in each tube, resulting in a total of 40 RTDs for eight tubes. There were also eight RTDs for the superheater tube. There was no direct measurement of flow through individual tubes. Instead, it was calculated as a function of the total mass flow rate and control valve opening position of each tube. Wherever temperature rise is higher than a certain value, the automated valve controls will send more flow through that tube. The control logic was exercised every 15 or 30s. The intention was to distribute the flow rate according to the heat flux falling on that tube.

When even 1 out of 40 RTDs failed or had an error (it is difficult to conclude from the data whether there is definitely an error), over-heating or under-heating was possible. This, in turn, would result in the tubes bending due to thermal elongation. Complete control failure was a possibility, resulting in shutting down of the plant.

The feedback loop of global mass flow control to maintain exit temperature was based on thermal calculations and hence could be performed once steady state was achieved. This resulted in failure of control system to respond effectively and in right direction during transient weather or operating conditions. It was also required to optimize the initial filling of boiler during start-up to achieve quick superheat without causing starvation, tube expansion and possible tube bending.

Figure 2: *Reliance CLFR plant during operation at Dhursar*

Major performance improvement by an advanced control system

Reliance engaged Empereal-KGDS with the task of devising methods to produce 125 MW of power (Figure 2). This article describes how the control logic of the plant was completely re-engineered in order to bring about a design power output of 125 MW and in a stable manner. A well-coordinated detailed analysis, empirical database, development and implementation by the Reliance team and Empereal-KGDS team resulted in a substantial improvement in plant performance.

After a year-long analysis and field exploration, Empereal-KGDS arrived at a set of controls and operation philosophy for achieving required steam parameters for turbine throughout the day to capture available solar energy. There were also other responsibilities, such as avoiding RTD failures and the overheating and bending of absorber tubes.

The investigation concluded that using direct measurement of parameters and control based on those was an effective way for stable controls and plant operation. One objective was to minimize off-tracking, which is the act of not focusing primary reflectors in the cavity receiver under certain conditions. For example, off-tracking is used to avoid economizer tube overheating, a restriction imposed by tube metal temperature. Achieving a degree of superheat in steam as early as possible during morning start-up of SSG is very important for early synchronization and more generation of electrical energy. Reliance Power Limited team with its extensive technical and operational knowledge and experience provided suitable guidance for development of new control laws and logic as described next.

Various considerations driving the modified control

1. **Global mass flow control**

   The outlet temperature of each SSG is controlled using input flow rate control and thermal tracking control. Higher outlet temperature can be achieved with lower input flow rate. But, lowering the flow rate to less than the optimum flow rate will cause higher off-tracking. Therefore, controlling the input feed water flow rate is optimized in line of available solar irradiance to get optimum flow of steam on desired parameters.

2. **Parallel flow distribution**

   Each of the eight parallel tubes in each of the 35 SSGs has non-uniform heat flux across the length.

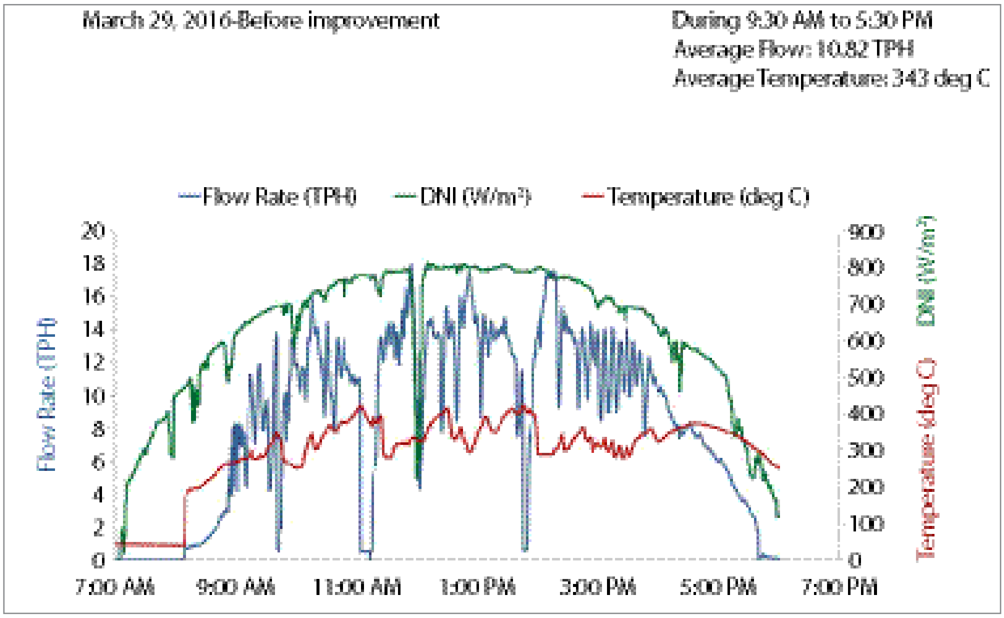

***Figure 3:** DNI, flow rate and superheated steam temperature in the SSG before modification on 29 March 2016*

The global feed water flow has to be distributed according to the total heat flux in each tube, which is termed as tube balancing. In the previous control logic, tube balancing was based on the metal temperature feedback using RTDs and valve position control. Tube balancing was found to work better in some SSGs where RTDs showed good values. There were 32 RTDs used for tube balancing, out of which 24 RTDs were critical. If any of the consecutive RTDs in any tube failed (abnormal values) or if any RTD showed erroneous values and there was difficulty in judging the values, it would lead to improper tube balancing and reduced performance of the entire SSG. So an improvised method was developed to avoid RTD-based feedback and uniform tube balancing.

3. Start-up sequence algorithm with modification in inventory and tracking control

SSG start-up time depends upon the amount of inventory (amount of fluid mass inside the boiler tubes) and overall tracking percentage. The start-up time increases with higher inventory. But with reduced inventory, there would be a higher rate of increase in metal temperature and subsequent off-tracking, which result in further delay to achieve superheat. So an optimum level of inventory had to be provided to SSG based on the available DNI conditions for the proper start-up. The amount of inventory required depends upon target flow and time taken for the fluid to reach the farther end of the receiver. Proper inventory should prevent dry out conditions and heat transfer rate in the farthest end. 100% track power would be given from start-up with flow rate adjusted according to the DNI and sun angle. If tube expansion occurs due to low inventory, SSG is off-tracked and required inventory is established by the control.

4. Thermal tracking control

In the previous thermal tracking control, there was very frequent off-tracking in order to comply with design temperature gradient of superheater tube. Continuous off-tracking of all the segments was observed frequently. With the present control, an overall tracking loss of less than 6% is achieved, which was earlier more than 17%.

Modified control logic implementation, testing and validation

To test the modified control system, one of the 35 SSGs was designated as prototype for testing. The first step was to install mass flow transmitters and differential pressure transmitters between the inlet and the outlet in each of the eight tubes. Mass flow transmitters were required to find out the correct amount of flow in eight tubes of the receiver and differential pressure sensors were to give the feedback for heat flux distribution in each tube so

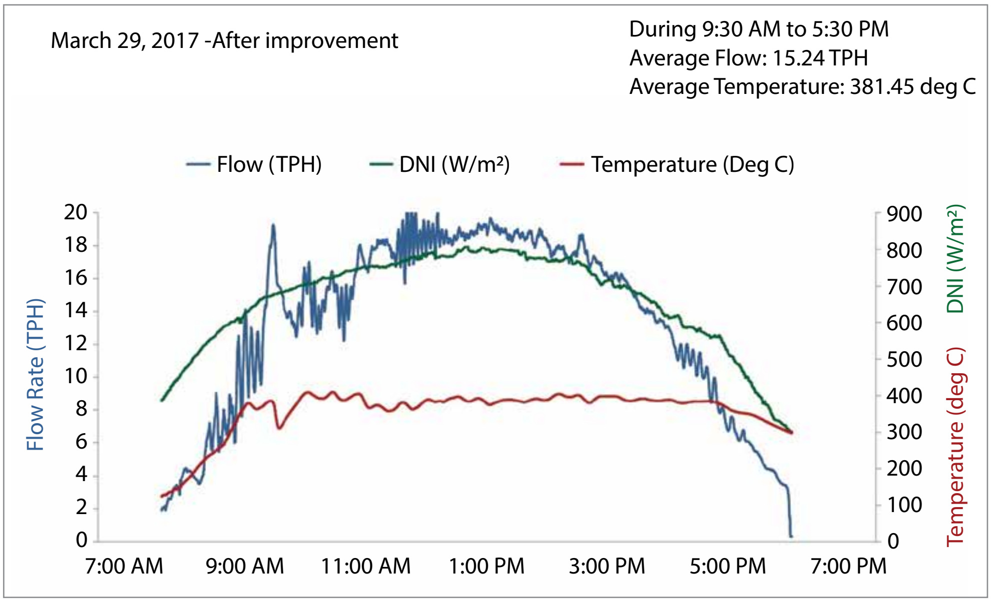

Figure 4: *DNI, flow rate and superheated steam temperature of the modified SSG on 29 March 2017, exactly one year later*

that perfect tube balancing could be performed. This avoided the major problem of RTD-based feedback and impact of RTD failures. The modified control algorithm worked well and the selected SSG showed significant and clear improvement in superheated steam production and also in the degree of superheat. Based on this encouraging result, it was decided by the leadership of the plant operation to modify all 35 SSGs. The resulting plant performance improvement was outstanding as shown in Figures 3 and 4.

One can observe that the two days selected for comparison were exactly one year apart, resulting in similar solar radiation levels. With the modified controls, the amount of steam produced is much higher and the degree of superheat is also higher. Also, the output steam temperature remains at a fairly constant level throughout the day.

After implementing the new control philosophy in all 35 SSGs, there has been a significant improvement in synchronization time and electricity production as shown in the table below.

	October 2016	October 2017
Synchronization time	10:37 AM	9:41 AM
De-synchronization time	5:15 PM	5:32 PM
% Increase in gross kWh/day	56.6%	
% Increase in net kWh/day	62.6%	

It took extensive scientific and technical analyses, discussions, understanding, as well as constructive and constant exchange of ideas between Reliance Power Limited and Empereal-KGDS, to produce these outstanding results. Design and execution of control system logic are very important to ensure successful performance and operation of an LFR based CSP plant.