OPERATIONAL ISSUES AND INNOVATIVE APPROACH FOR PERFORMANCE IMPROVEMENT AT NTPC UNCHAHAR SOLAR PV PLANT

Ravi Prakash Singh
AGM (O&M – Opn. & Commg.)
NTPC Unchahar

Amit K Gautam
Sr. Manager (O&M – Opn. & Commg.)
NTPC Unchahar

1. INTRODUCTION

India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/sq.m. which is comparable with radiation received in the tropical and subtropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year. Solar power in India is a fast-growing industry and as of 30 September 2016, the country's solar grid had a cumulative capacity of 8,626 megawatts (MW).

India is ranked number one in solar electricity production per watt installed, with an insolation of 1700 to 1900 kilowatt hours per kilowatt peak (kWh/KWp). In line with this NTPC has set a target to have an installed power generating capacity of 1,28,000 MW by the year 2032. The capacity will have a diversified fuel mix comprising 56% Coal, 16% Gas, 11% Nuclear and 17% Renewable Energy Sources (RES) including hydro. By 2032, non-fossil fuel based generation capacity shall make up nearly 28% of NTPC's portfolio. As on today, the installed capacity of NTPC is 47,228 MW through its 18 coal based, 7 gas based, 9 joint ventures, 1 hydro and 9 solar PV power projects.

2. BRIEF DESCRIPTION OF SOLAR PV TECHNOLOGY

Solar power plant is based on the conversion of sunlight into electricity, either directly (PV), or indirectly (CSP) also called solar thermal. Photo Voltaic (PV) converts light into electric current using the photoelectric effect. Out of these two technologies the solar PV is more popular because these plants are very easy to operate as these plants have no moving parts. Photovoltaic (PV) solar cells directly convert sunlight into electricity, using the photovoltaic effect. The process works even on cloudy or rainy days, though with reduced the production and conversion efficiency.

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load

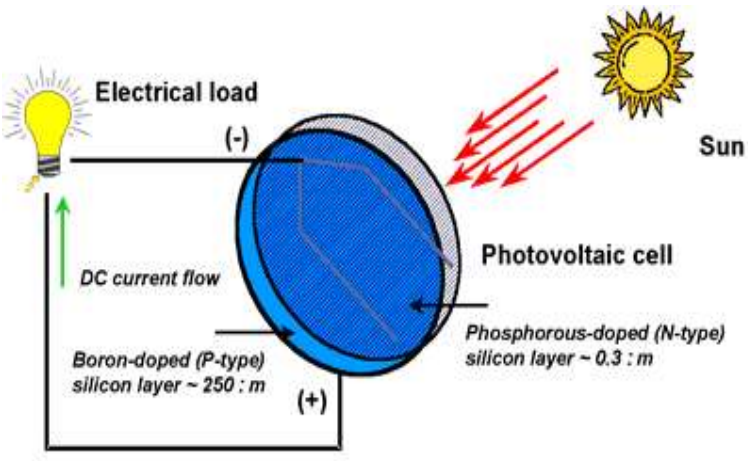


Figure 1. Diagram of a Photovoltaic Cell

3. 10 MWp SOLAR PV PLANT AT UNCHAHAR

A 10 MWp capacity Solar PV (Mono-crystalline Silicone) plant is operative in the vicinity of Feroze Gandhi Unchahar Thermal Power Project (FGUTPP) of NTPC Limited.

3.1 Salient features of Unchahar Solar PV Plant

Installed Capacity: 10 MWp	*Land Area: 43.9 Acres*	*No of Modules: 42,240*	*No of Structures: 1760*
Each Module Rating:240 Wp	*Annual Generation: 14.85 MU*		*Date of first Synchronization/COD : 31-Mar-14*

This Clean Development Mechanism (CDM) project has been registered with United Nations Framework Convention on Climate Change (UNFCCC). This will enable NTPC Unchahar to get carbon credits for solar power generated (13,895 metric tons CO_2 equivalent per annum).

4. OPERATIONAL ISSUES AND CORRECTIVE ACTIONS

Various problems faced during initial phase and corrective actions taken to overcome these problems are listed below:

4.1 Failure of one 220 kV CT

Total 03 no. of CTs are installed in 220 kV switchyard for Solar Plant. In Feb 2015, Y-phase CT failed due to blasting, causing tripping of one 220 kV bus which leads to tripping of one 210 MW unit and associated transmission lines.

Corrective Actions:-

All the 03 no. CTs were replaced by OEM in March 2015. On 14th Dec, 2015 "Tan-δ" testing was done to check the healthiness of all newly installed CTs. R-phase CT's "Tan-δ" value was found deteriorated the same was again replaced by OEM on 19th Dec 2015.

4.2 Failure of 33 kV PT

Total 57 no. PTs are installed in 33 kV switchgear for measurement and Total 14 no. 33 kV PTs failed due to blasting in a few months of installation. In all blasted PTs damage occurred in secondary winding only. A continuous humming sound was also observed from some of the PTs.

Pic 1-. Blasted PTs

Various studies were conducted and it was observed that CTs are failing due to *"Ferro-resonance"* phenomenon. Ferro-resonance or nonlinear resonance is a type of resonance in electric circuits which occurs when a circuit containing a nonlinear inductance is fed from a source that has series capacitance, and the circuit is subjected to a disturbance such as opening of a switch. It can cause over-voltages and over-currents in an electrical power system and can pose a risk to transmission and distribution equipment and to operational personnel

Ferro-resonance is a resonance situation with nonlinear inductance, so the inductive reactance not only depends on frequency, but also on the magnetic flux density of an iron core coil (e.g. transformer iron core). The inductive reactance is represented by the saturation curve of a magnetic iron core.

Theoretically, this non-linear inductance could be represented by two inductive reactance, according to the situation on the saturation curve.

- Linear zone $\Rightarrow X_{L-linear} = \omega L_{linear}$ *Equation* (1)
- Saturation zone $\Rightarrow X_{L-sat} = \omega L_{sat}$ *Equation* (2)

Ferro-resonance can cause dangerous over-voltages and over-currents in three-phase core-type transformers. The largest values of the over-voltages and over-currents caused by Ferro-resonance occur when the transformer is at no load. The over-voltages and over-currents caused by ferro-resonance due to unsymmetrical switching are found to be larger than those obtained when all transformer phases are connected to supply.

Corrective Actions:-
As per recommendations to overcome to *"Ferro-resonance"* problem:

a) A resistance was required to be conned in the series of PT with increase in ratings to take care of harmonics also.
b) The safety margin was to be increased from 1.2 to 1.9%.

4.3 Frequent tripping of 33 kV overhead transmission line

The 33 kV transmission line was frequently tripping due to movement of birds especially in evening hours. It was observed that the minimum distance between conductors and pole (ground) was 320 mm as per design (for 33 kV systems) in 2-pole and 4-pole structures. But, due to heavy movement of large size birds, especially in evening hours, frequent tripping of transmission line due to earth fault observed.

Corrective Actions:
A "C" clamp of 125 mm length has been fitted in pin insulators base causing an increase in distance between conductor and ground from 320 mm to 445 mm. After this modification, no tripping observed in transmission line due to earth fault.

The transmission line jumpers were also insulated to improve the reliability of the transmission line.

4.4 Frequent ground fault in MC-04 connectors in rainy seasons

Initially, during rainy season frequent ground fault observed in various modules due to shorting in MC-4 connectors.

Corrective Actions:
It was observed that the fault was due to filling of water inside "C" sections of module mounting structures (Figure 2), especially in rainy seasons. The location of these MC-04 connectors was shifted from bottom to top position (Figure 2). Frequent ground fault problem resolved after this action.

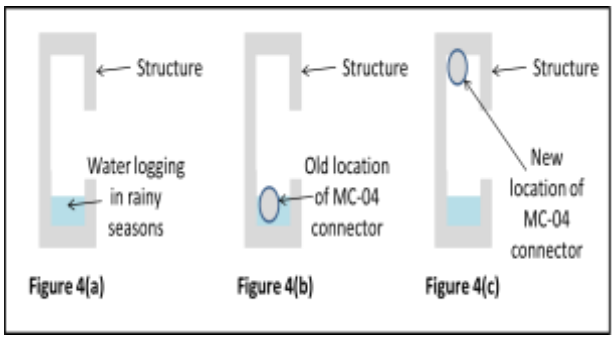


Figure 2. Location shifting of MC-04 connector

4.6 Solar plant generation forecasting

Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Third Amendment) Regulations, 2015, came into force with effect from 1st November 2015. After implementation of this regulation, day ahead forecasting of solar plant generation is to be done. The solar plant generation should remain under ±15% of day ahead forecast.

The very basic compliance requires accurate forecasting of Solar Power Generation. But, initially, there was a huge difference in actual generation and the forecasted one. It was observed that the day ahead prediction is accurate only for 30% cases.

Corrective Actions:
For day ahead forecasting we were taking data from actual generation of present day and we are also considering Block-wise actual generation of the present day, Modules tilt angle, Generating capacity (strings outages – if any), Average solar insolation of the day, Weather conditions e.g. sunny, foggy, rainy. After taking these parameters into account we were able to predict more accurately and our accuracy percentage is more than 80%.

5. INNOVATIVE APPROACH FOR PERFORMANCE IMPROVEMENT

5.1 Polarity reversal operation

Solar cells can be electrically connected in series (voltage add) or in parallel (current add) to give any desired voltage and current (or power). Photovoltaic cells are typically sold in modules (or panels) of 12, 24, 36, 48, 60 volts with power outputs of 50 to 200+ watts. These are then combined into arrays to give the desired power or watts.

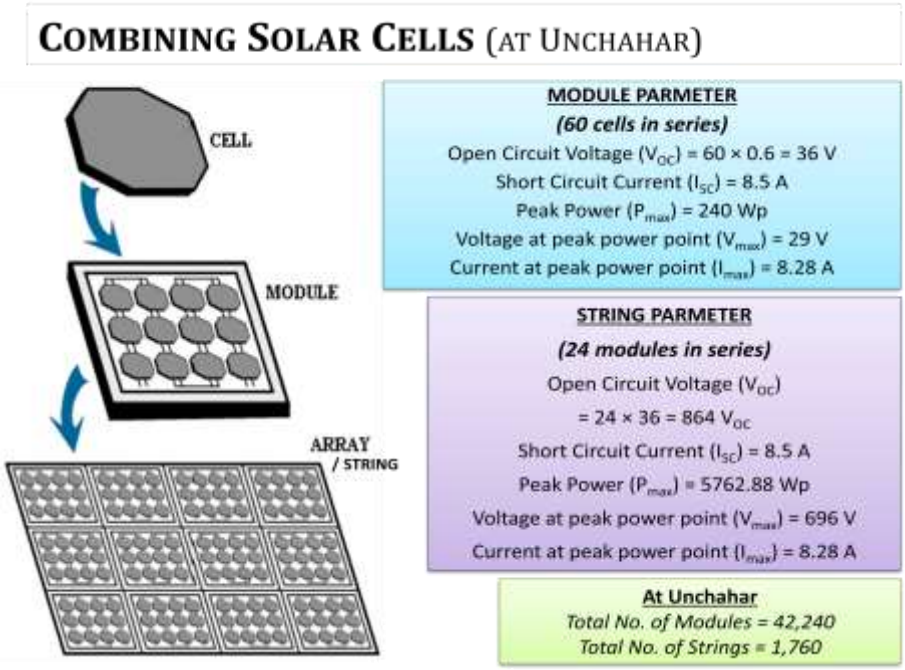


Figure-3 Combination of Solar Cell

In monsoon season all the modules and junction boxes were exposed to high moisture. It was observed that inverter efficiency reduced to 5-6%. On testing the modules it was observed that its open circuit voltage reduced from 36 V to 1-11 V DC and its short circuit current reduced from 8.2 A to 5.5-6.0 A, causing huge performance deterioration of the plant.

The matter was immediately discussed BHEL engineering group. They have adviced to convert “low voltage” modules to “high voltage” module and vice versa by doing “polarity reversal operation” as shown in Figure-4.

The polarity of some selected sample modules was reversed and these modules were tested after 20 days of the activity. It was observed that those modules whose open circuit voltage were in the range of 2-10 V DC has boosted up and reached to 30 V DC. After achieving this result, the polarity of all 42,240 modules have been reversed and enhanced the plant

Table-1 Polarity reversal details
(10 MWp Solar PV Plant at NTPC Unchahar)

SMU No.	Voltage Range (date) - faulty	Voltage Range (date) - rectified	Voltage Range (date) - rectified
4A3	13-28 (18.09.16)	22-30 (26.09.16)	29-32 (22.10.16)
4B2	02-28 (16.09.16)	11-30 (22.10.16)	22-34 (02.11.16)
5A1	02-29 (15.09.16)	29-31 (25.09.16)	29-32 (26.10.16)
5A3	02-28 (14.09.16)	29-31 (22.09.16)	29-31 (04.11.16)
5A5	06-29 (16.09.16)	17-29 (22.10.16)	29-33 (03.11.16)
6A1	11-27 (16.09.16)	29-32 (22.10.16)	31-33 (01.11.16)

performance.

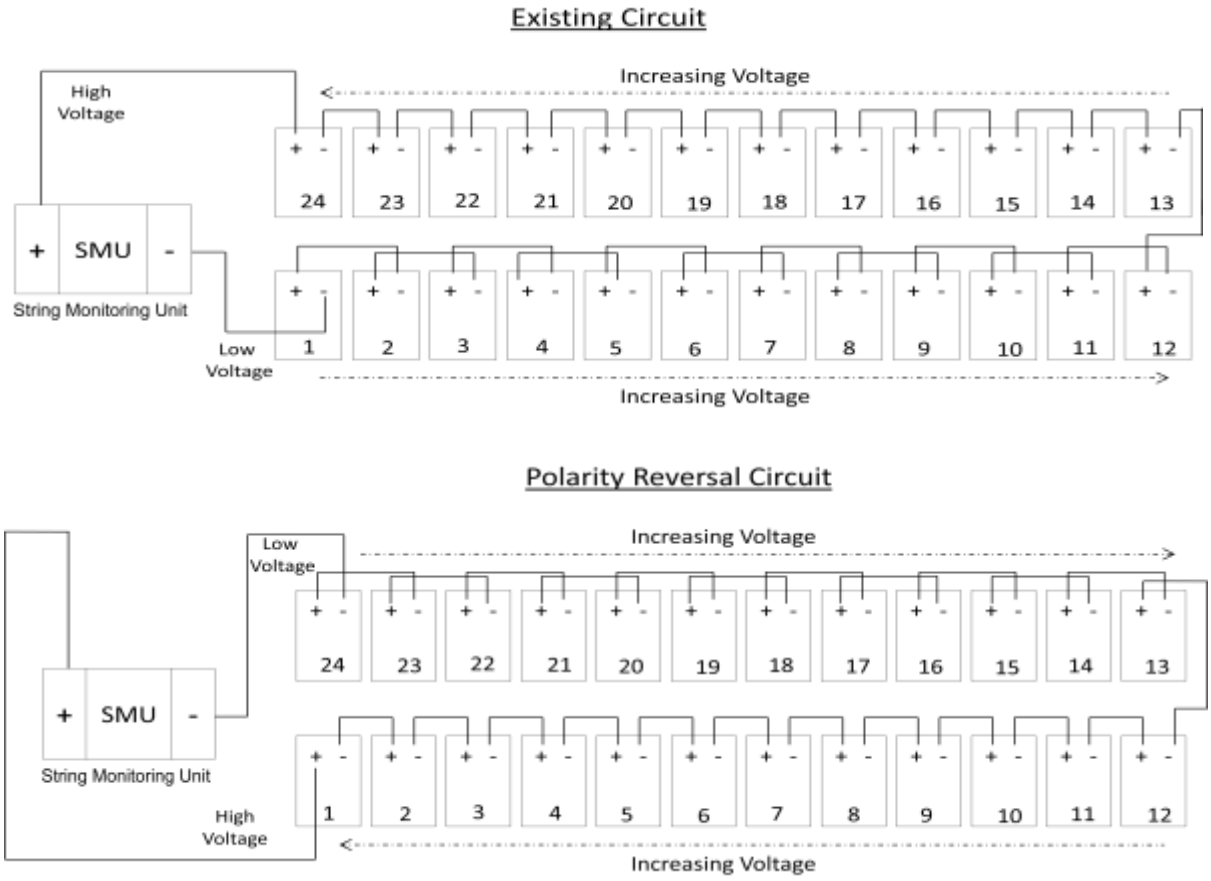


Figure-4 Polarity Reversal Operation

5.2 Increase in module washing frequency

The solar module surface contamination is multi-factorial process. The local environment comprises site-specific factors influenced by the nature of prevailing human, industrial, agricultural activities, road transportation, built environment characteristics, natural vegetation types and weather conditions. These effects are significantly more difficult to define losses in energy production. (Fig 5)

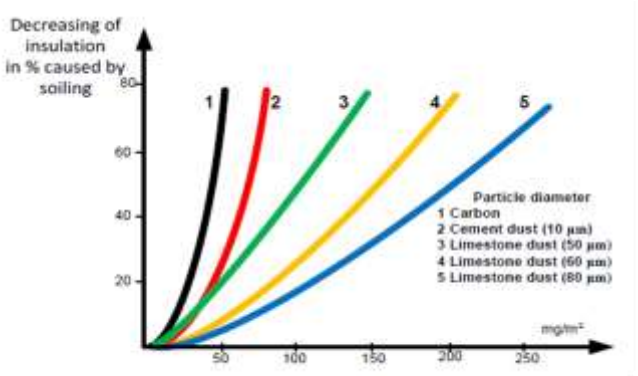
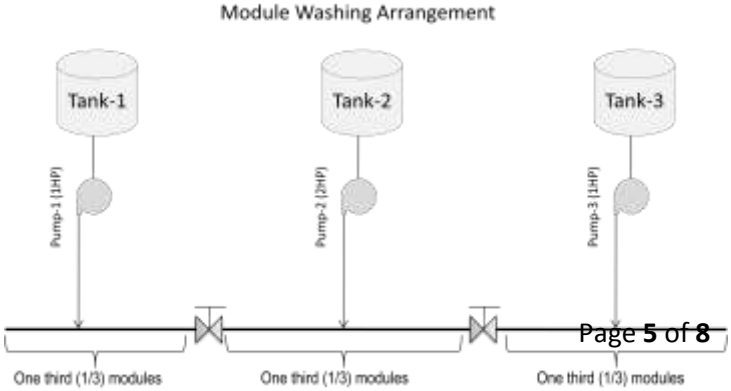


Fig 5: Effect of different particle pollutants to the energy loss

There are 42,240 modules spread in around 43 acre land. As per initial design these modules were required to clean in every 10 days with mopping. As the plant is located along railway track, hence it was attracting lot of dust and dirt. The designed cleaning



frequency and procedure was not adequate and module efficiency was continuously deteriorating. *Fig-6*

Module Washing Arrangements:
Module washing pumps with tanks are installed at 03 locations as shown in Figure 6.

Corrective Actions:
a) The module washing frequency was increased from 10 days to 04 days (without mopping).
b) The pressure was increased from 1.5-2.0 ksc to 5-6 ksc with desired modifications.

Advantages:
a) Module efficiency improved by 2%.
b) Water consumption reduced from 10-12 lit/module to 1.7 lit/module.
c) Module washing time reduced; hence 25% modules are being washed daily.
d) As mopping is not being done in new process, hence wear and tear reduced causing increase in module life.

5.3 Trials of rain gun and cylindrical nozzle for automated washing

Module washing is very time consuming and labour intensive job. To overcome this situation two types of systems are under trial run:

5.3.1 Rain Gun Nozzle System

Rain gun sprinkler irrigation nozzle system (Pic 2) is under trial run in association with an irrigation company (Jain Irrigations). This arrangement requires a 04 wheel trolley (fabrication cost INR 3000) fitted with nozzles Two types of nozzles are available in the market, one is with “Horizontal Flap” and another is with “Vertical Flap” (each nozzle cost INR 6500). In this arrangement the nozzles are fitted on trolley. Hence, cost of one arrangement is around INR 10,000. A water supply hose is connected in the nozzle. The trolley in run on the pathways between each row and spray water on the modules for washing. The washing pattern depends on the type of nozzle.

Pic 2- Rain Gun Nozzle

On testing both types of nozzle it was observed that as the trolley is moving in horizontal path, hence the vertical nozzle is covering more area. Now, the vertical nozzle is being used for further testing.

Advantages:

a) Manpower reduced from 08 to 04 as only one man is sufficient to move the trolley.
b) The washing time will also reduce as these nozzles covers more area.

5.3.2 Cylindrical Nozzle System

In this type of arrangement one fixed cylindrical irrigation nozzle (Pic-3) is fitted at the centre of the table in such a way that only one nozzle can wash the whole table. The cost of one such nozzle is INR 10,250 and there are total 1760 tables. The initial cost of this arrangement shall be INR 1,80,40,000. This arrangement also requires high water pressure for effective washing. Due to high

initial investment this system is not being adopted for NTPC Unchahar.

Pic 3- Cylindrical Nozzle

Advantages:

a) This system does not require any manpower. We are only requiring switching on the pump for washing the modules.

5.4 Weed or vegetation management

Weed or vegetation management is particularly important for ground-mounted solar systems. Tall weeds growing around the installation can create shading, which can negatively impact system production. It can also cause hot spot heating — if a part of the solar cell is shaded, the cell can heat up to such extreme temperatures that a module can burn out causing permanent damage. Regular grass cutting is essential on solar plants to prevent shading. Moreover, grass cutting keep the perimeter of the solar plant looking neat and tidy and less prone to the danger of reptiles.

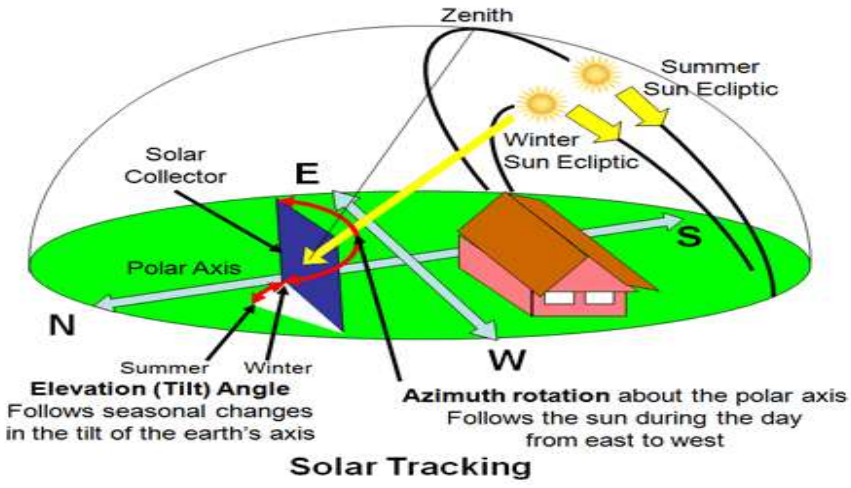
There are several weed control methods used for PV ground-mount systems; mowing, spraying herbicide, grazing sheep/goats, and covering the area with weed control sheets, for example. Controlling weeds incurs additional operation and maintenance (O&M) expenses for PV system and the long-term costs and benefits need to be carefully examined.

At NTPC Unchahar this problem becomes more severe during monsoon seasons. To get rid of tedious grass-mowing tasks following steps were taken.

a) A grass cutting machine was purchased (cost INR 30,000/-). This machine is cutting grass in 10 rows per day. The consumption of petrol is 2.5 lit for 10 rows.
b) Unchahar Solar PV Plant is spread in 43 acre of land. During this monsoon season, the whole land was treated with a chemical called “GLYPHOSATE” (mixed with urea). This treatment controlled the vegetation in this area for 4 months. The cost of this chemical treatment is INR 100 for one acre.

5.5 Jack and gear arrangement for mechanical tracking

To get the most from solar panels, we need to point them in the direction that captures the most sun. To receive maximum intensity of sunrays the solar panel surface should be perpendicular to sunrays. Max performance is achieved when panels are perpendicular to the sun’s rays. Panels should be tracking the sun all the time, during day and during different seasons. (Pic 4)



Pic-4 Solar Tracking

Automatic solar tracking makes the system very costly. If the SPV panel is not tracking the sun then it should be inclined to an angle equal to the latitude of the location. Solar tracking allows to collect 30% extra energy with the

Tilt Position	Duration
10	Apr-Aug
25	March & Sept
40	Sept- Feb

same SPV panel. For NTPC Unchahar designed value of tilt angles is described in the table. Presently, tilt angle is being changed manually from 10° to 40° in the month of September and from 40° to 10° in the month of March. This is very labour intensive, time consuming and costly activity.

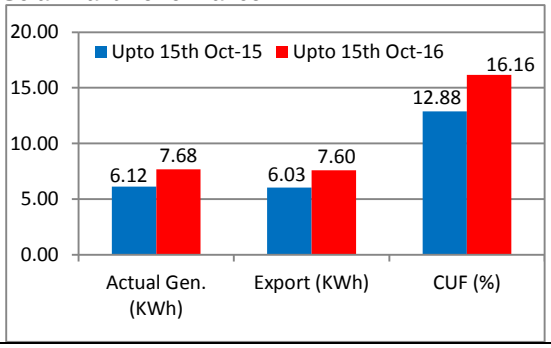
The cost of tilting one table is INR 125, there are total 1760 tables. So, the total tilting cost is INR 2,20,000. The tilting is being done twice every, so the annual cost is INR 4,40,000. The tilting activity takes 24-25 days every time. Hence, this activity affects generation of the solar plant for about 02 months. To overcome this problem initiative taken to install "Jacks & Gears" mechanism for mechanical tilting in place of manual tilting each module. This arrangement will give following advantages:

a) Reduction in seasonal tilting time leading less generation loss.
b) Fewer labours shall be required to operate the mechanism.
c) Less chances of accidents – increased safety.
d) No wear and tear to modules.

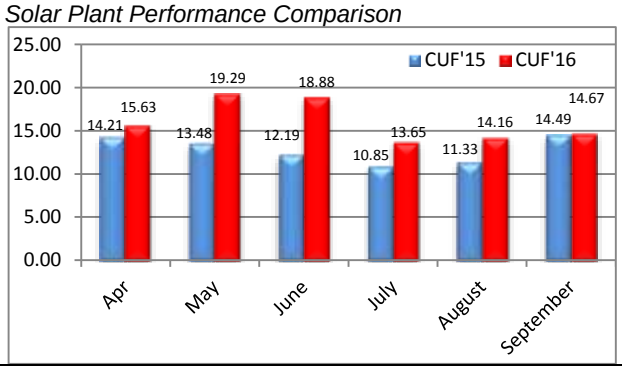
6. PERFORMANCE IMPROVEMENT

In future scenario NTPC have to play an important role in field of solar energy coupled with national energy requirement. By following and establishing best O&M practices in this field, we will have rich experiences over the period of time and will be able to provide reliable and indefinitely sustainable renewable energy at optimum cost, which will establish our leading place in this field. At Unchahar, we are making our continual efforts to make our plant a role model plant.

Solar Plant Performance



Solar Plant Performance Comparison



By our innovative approaches and best practices, our journey for performance improvement continues resulting in improvement in efficiency and capacity utilisation factor (CUF) increased from 12.88 to 16.16% (up to Oct-2016).

Main Author:-
Shri Ravi Prakash Singh is currently working as Senior Manager (Operations and Commissioning) at NTPC Unchahar. He has joined NTPC in 198 as an Executive Trainee. He has a vast experience in power plant operation, commissioning and consultancy. He has passed B. Tech. (Mechanical) from NIT Allahabad. He is a BEE Certified Energy Auditor.

Co-Author:-
Shri Amit K Gautam is currently working as Senior Manager (Operations and Commissioning) at NTPC Unchahar. He has joined NTPC in 2002 as an Executive Trainee. He has a vast experience in power plant operation (thermal as well as gas based combined cycle), commissioning of 10 MWp solar power plant and commissioning of 500 MW thermal power plant at NTPC Unchahar, He has passed B.Tech. (Electrical Engineering) from HBTI Kanpur. He is a BEE Certified Energy Auditor, IPMA Level D and MBA (Materials Management).