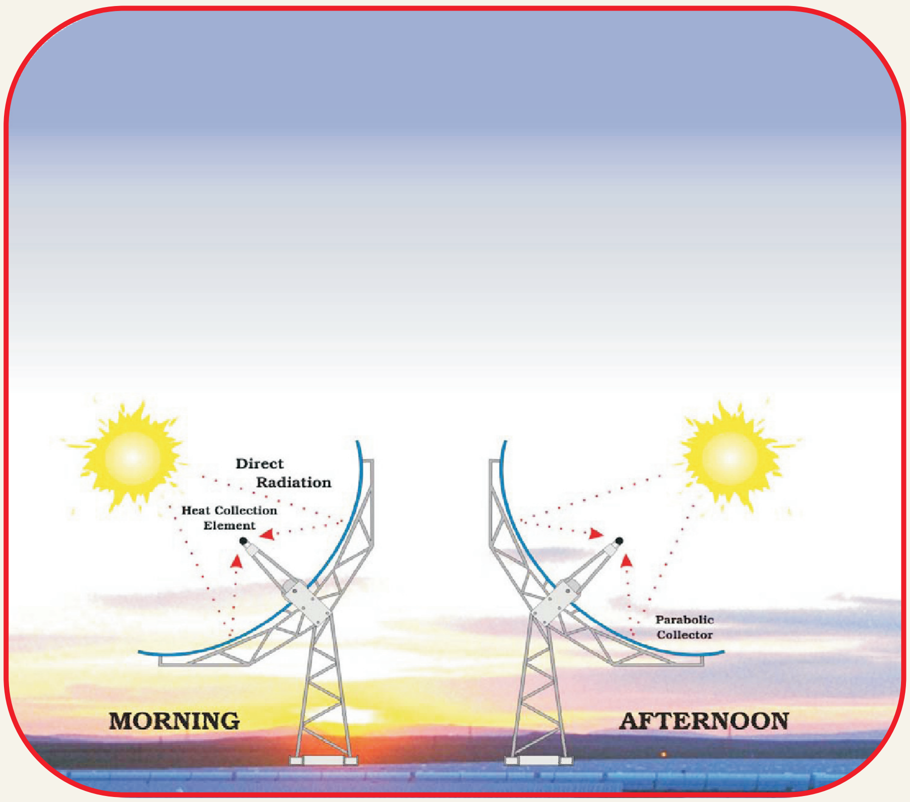
REPORT OF SUB-GROUP II & III
on
INTEGRATION OF SOLAR SYSTEMS WITH THERMAL/ HYDRO POWER STATIONS



CENTRAL ELECTRICITY AUTHORITY
New Delhi – 110066

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REPORT OF SUB-GROUP –II & III ON " INTEGRATION OF SOLAR SYSTEMS WITH THERMAL/HYDRO POWER STATIONS"

1 Background

1.1 A Task Force was set up by the Ministry of New & Renewable Energy (MNRE) under the chairmanship of Chairperson CEA, vide O.M. No. 32/61/2009-10/PVSE dated 28th May 2009, to examine technical issues relating to feasibility of integrating solar power plants with thermal/hydro-electric power plants and connectivity of solar roof top systems with grid. Composition of the Task Force is given at enclosed Annexure-I.

The first meeting of the Task Force was held in CEA office on 18th June, 2009. During the meeting three sub-groups were formed as follows:-

Sub-group – I	Grid interactive rooftop solar PV systems
Sub-group – II	Integration of solar systems with thermal power stations
Sub-group –III	Integration of solar systems with hydro power stations

This report covers the salient issues relevant for installation of solar power plants in existing thermal and hydro power stations as referred to Sub-Group-II and III. Report of Sub-Group-I on "Grid interactive rooftop solar PV systems" has been issued separately.

1.2 The **Terms of Reference** of the sub-group –II and III are as follows:-

i) To examine feasibility of integrating solar based plants with Thermal (Coal and gas)/Hydro-electric power plants including issues relating to availability of land and effect of fugitive ash in coal based plants.

ii) To suggest the feasible options for type of solar plants (PV solar cells, solar thermal plants) for installation at thermal/hydro-electric power plants.

iii) To examine the feasibility of hybrid solar power systems in thermal power plants including use of secondary fuel firing or heat storage devices during the period when solar power is not available.

iv) To suggest scheme for connecting solar based plants with the station electric supply system for thermal/hydro electric power plants.

v) To suggest arrangements for metering and accounting for energy supplied by the solar based plants.

vi) To suggest modalities of implementation for solar based plants at thermal/hydro electric power plants including preparation of project report

1.3 The composition of the sub-groups is given below:

Sub-group-II

i) Shri S. Seshadri, Member (Thermal), CEA - Chairman
ii) Dr. Ashvini Kumar, Director, MNRE
iii) Shri Lalit Kapur, Director, MOEF
iv) Shri A.K Gupta,. G.M, NTPC
v) Shri R.K. Sikri, GM, NTPC
vi) Shri Vishnu Gupta, G.M(I/C), BHEL
vii) Shri M. M Vijayvergia Executive Director RRECL
viii) Shri N.M. Mathur, Chief Engineer, RRVUNL
ix) Sh. Sanjay Sharma, Director, CEA – Member-Secretary

Sub-group –III

i) Shri Suresh Chander, Chief Engineer (TE&TD), CEA - Chairman
ii) Dr. Ashvini Kumar, Director, MNRE.
iii) Dr. S. Bhowmik Addl. Director, MOE&F
iv) Shri Vishnu Gupta, G.M (I/C), BHEL
v) Sh. M.K. Raina, ED(T&RE), NHPC
vi) Shri Ashok Thapar Director BBMB
vii) Shri Moti Lal Director , Hydro, CEA – Member-Secretary

1.4 Deliberations of Sub-groups –II & III

i) The sub-groups had three meetings on 16th July 2009, 6th August 2009 and 25th September 2009. Presentations on solar technologies were made by various Indian suppliers developing solar technologies in the second meeting of the sub-group on 6th August ’09. In the third meeting held on 25th September ’09, presentations were made by NTPC on the feasibility studies made for installation of a solar plant at their Anta Combined Cycle Gas Turbine station. Visit was also made to Bhakra hydro stations on 21.08.2009 for study of potential for installation of solar power plant.

ii) This report of the sub-group –II & III has been prepared based on the deliberations held in the meetings of the sub-group and various presentations made.

2 About Solar Irradiation

2.1 Extraterrestrial solar irradiation follows in a direct line from the sun to the earth. Upon entering the earth's atmosphere, global irradiation is divided into two components – direct normal component and diffused component. The solar irradiation diffused by air, water molecules and dust within the atmosphere is known as diffused component. The direct normal irradiation component represents that portion of solar radiation reaching the surface of the earth that has not been scattered or absorbed by the atmosphere. The Direct Normal Irradiation (DNI) is the integral value of direct normal irradiance over a certain time interval and its unit is J/m^2 or kWh/m^2.

Concentrating Solar Power (CSP) or solar thermal technologies can only use the direct irradiation. The second part, the diffused irradiation cannot be converted into beam radiation and is thus not useful for CSP. Generally sites with annual sum of DNI larger than 1800 kWh/m^2 are considered as potential sites for CSP. The solar photo-voltaic (SPV) technologies, however, utilize both direct and diffused irradiation for electricity generation.

The DNI available at a certain site may be interpreted as “fuel-resource” for a CSP plant and the annual sum of DNI as well as the seasonal and daily distribution is very important for solar field layout and plant performance. However, irradiance measurements are not common for meteorological stations today and particularly long term measurements from the past are hardly available. The main problem with DNI data from any source is the accuracy, which is hard to determine. The validation can only be done by a cross check of the data from different sources. Some sources from where DNI data can be accessed are given below:

i) DLR has developed methods to derive DNI data from satellite measurements. These services are offered under the name SOLEMI (http://www.solemi.de/) at a cost.

ii) NASA Website (http://eosweb.larc.NASA.gov/sse/) where data tables for a certain location and plots for a whole region are available free of charge. The main differences between this NASA data and the DLR satellite data are the different temporal and spatial resolution. The NASA data contains only mean daily values for each month whereas the DLR satellite data contains mean values for every hour of each year. The NASA satellite data is derived from a pixel size of 30km×30km whereas the DLR satellite data is derived from a pixel size of 3km×4km.

iii) The third source of irradiation data is a software tool called METEONORM 6.0 (http://www.meteonorm.com/) which provides a method for the calculation of solar radiation on arbitrarily orientated surfaces and other meteorological data at any desired location with hourly resolution.

iv) The National Renewable Energy Laboratory (NREL), Golden Colorado, USA has prepared a DNI map of Asia with a 40km resolution for SWERA (http://swera.unep.net). This map does not provide specific information but it may be used for further investigation of potential CSP sites in India.

2.2 A few solar maps are appended at **Appendix- I** for reference. These include global solar map of India for global radiations (source: TERI) and DNI maps for Asia and North-west India by NREL.

3 Solar Generation Technologies

3.1 Solar power generation technologies can be broadly classified into two broad types as under:-

i) Solar Photovoltaic technologies
ii) Concentrated Solar Power (CSP) technologies

3.2 The **Solar Photovoltaic technologies** convert sunlight falling on to a photovoltaic (PV) cell directly into D.C. electricity which is then converted into AC by inverters. This technology has several variants based on the type of photovoltaic materials used. Tracking and concentrating systems are also used to focus sunlight on to the PV modules to improve the system efficacy and enhance generation. Application of PV systems is generally limited to rooftops on residential and commercial buildings, though utility scale plants are also possible.

The Solar Photovoltaic (SPV) technologies have been covered in detail in Report of Sub-Group-I on "Grid interactive rooftop solar PV systems".

3.3 In **Concentrated Solar Power (CSP)** plants, also known as Solar Thermal plants, solar energy is focused through various types of mirrors to heat a working fluid and produce steam (directly or indirectly through an intermediate heating fluid). Steam is then used to rotate a turbine or power an engine to drive a generator and produce electricity as in a conventional power block. CSP technology are better suited for utility scale power plants as compared to SPV technologies.

These technologies are of following four types, characterised by the type of mirror used to collect solar energy. A brief description of these technologies is given below and their comparison is drawn in Table-I.

Parabolic trough is well established and most proven CSP technology and commercial plants upto 80 MW size are in operation.

Parabolic trough shaped mirrors collect and reflect the solar energy onto receiver tubes positioned along the focal line of parabolic mirrors. Troughs are made to rotate on a north-south axis to track the sun from east to west. Heat transfer fluid (synthetic oil), suitable for temperatures upto 400 deg C, flowing through these receiver tubes is used to generate steam through steam generators and drive turbine to generate electricity.

Solar Towers deploy numerous large number of flat sun tracking mirrors, known as heliostats, to focus sunlight onto a fixed receiver mounted on a tower. The heliostats tack the sun on two axes. The central receiver can achieve very high concentrations of solar irradiation thus resulting in extremely high temperature for the operating fluid. Most of the concepts for solar tower utilize a Rankine cycle as power conversion process. Heat of the absorber coolant is transferred in separate heat exchangers to a water/steam cycle as in conventional steam power plants. Direct steam generation, without any intermediate fluid, is also possible. Steam parameters upto 100 bars and 560 deg C are achievable. Brayton cycle is the focus of development to increase efficiency levels.

Spain has several solar tower systems operating or under construction. Maximum size in operation is 20 MW. Most of the realized pilot and demo solar tower facilities have thermal storage facility incorporated to improve the dispatchability of the plant. Nevertheless these storage solutions have the drawback of higher initial investment costs and higher land requirements.

Linear Fresnel Reflectors technology uses a reflector made of several slices of mirrors with small curvature approximating a parabola. Mirrors are mounted on trackers and configured to reflect sunlight onto a receiver tube fixed in space above these mirrors. These Fresnel reflectors offer direct steam generation and thus omit intermediate high transfer fluid.

These systems have lower investment costs and also lower optical performance as compared to parabolic trough collectors. This technology is in developmental stage and some small experimental systems have been realised.

Solar Dish The parabolic shaped dish tracks the sun, through a two axis movement, continuously to gather the solar energy and point focuses the same onto a thermal receiver (mounted at the focal point) to heat up the fluid. Heat from the thermal receiver is used to produce electricity through Stirling Engine.

Dish technology is modular and produces relatively small amount of electricity compared to other CSP technologies – typically in the range of 10 to 25 kW which results in high capital costs. Distributed dish concept with common power conversion unit was also adopted in eighties but is not the focus of development any more due to heat loss during heat transportation over long distances.

TABLE-I : COMPARISON OF CSP TECHNPLOGIES

Parameter	Solar Thermal (CSP) Technologies			
	Parabolic Trough	Solar Tower	Fresnel Reflector (CFLR)	Solar Dish
Site Solar Characteristics/ Solar radiation required	Generally sites with annual sum of DNI larger than 1800 kWh/m²			
Land Requirement	Typically 5-7 acres/MW			
Typical shape of solar plant	Rectangle	Sector of a circle/ Rectangle	Rectangle	Rectangle
Water Requirement	Typically $4m^3$/MWhr			No water requirement
Maximum Temperature	400 deg C	270 deg C Possible upto 560 deg C	400 deg C	800 deg C
Efficiency	~ 14%	~17% Possible upto 22%	-	~ 22-24%
Typical CUF	Typically 22-25%			
Plant cost		Lower than parabolic trough	Lower than parabolic trough	Very High
Largest plant size	80 MW	20 MW	5 MW	
Development Status	Most proven	Mature	Demonstration	Demonstration
Plants installed	-9 SEGS plants (14 MW to 80 MW) in California built from 1985 to 1991 – Total capacity : 354 MW - Nevada Solar One (64 MW) started in 2007	-Planta Solar 10 and Planta Solar 20 are in operation with capacities of 11 and 20 MW in Seille Spain -Sierra Sun Tower USA 5 MW - Solar Two plant (10 MWe) with molten salt storage-demo plant	- 9MWth used for FW heating in 2000 MW coal fired Liddell Power plant (Australia) - Two small capacity experimental plants in Spain in 2007 - 1.4 MWe at Murcia, Spain in 2009	Small operational plants with unit size of 10-25 kW
Technology Providers	Sener Solar Millenium Abengoa ACS-Cobra Acciona Solel	Abengoa eSolar Sener BrightSource Torresol Solarreserve	Austra MAN Ferrostaal	Stirling Energy Systems

4 Solar options for Power Stations

Technology Options

4.1 From the discussions in the foregoing para, it may be seen that the options for solar generation at any power station would depend upon the following:

i) Adequate solar irradiation
ii) Availability of land
iii) Availability of water (for solar thermal)

4.2 As mentioned above, adequate direct normal component of solar irradiation is necessary for solar thermal plants. Normally a solar irradiation (DNI) of 1800 kWh/m^2 is considered necessary for solar thermal plants. Solar PV plants can, however, utilize global radiations including diffused components. Thus solar irradiations available at a location is the prime consideration for selection of technology.

4.3 About 5-7 acres/MW land is required for solar thermal plants. Thus availability of large tract of continuous flat land would be required if solar thermal is to be considered. When land is available in several scattered patches, rather than a contiguous piece, then Solar photovoltaic plants could be considered. Following considerations should also be kept in view regarding land:

i) Land should be flat with 1-3% gradient or less.
ii) North- south orientation is preferred.
iii) Aspect ratio of land should be commensurate with the technology

Economy of solar thermal improves with scale of plant. For sites suitable for higher size solar thermal plants, presently parabolic trough technology is the most proven and widely deployed technology. For this technology, 50 MW plant would be ideal from techno-economics point of view though lower sizes (10-20 MW) can be considered depending on availability of land. NTPC have prepared feasibility report for a 15 MW plant at Anta CCGT plant based on parabolic trough technology.

For solar tower technology, maximum 20 MW plant is operational. This technology is available in 2.5 MW modules also. Fresnel reflector and dish technologies are at demonstration stage and, if considered, can be deployed for still lower sizes.

4.4 Solar thermal plants require water for cooling tower blowdown and DM make up. Usually water requirement is 4 M^3/MWh. Additionally, some water is also required for washing of mirror panels and requirement varies with location depending on dust levels.

4.5 In hydro stations large tract of continuous land are generally not available. Also the hydro stations have no facilities for supplying warm up steam etc to solar thermal power plant. Thus solar PV systems may be the only choice for hydro stations. Details of solar PV technology are covered in the Report of Sub-Group-I on “Grid interactive rooftop solar PV systems”.

4.6 Solar thermal plants are sometimes provided with heat storage systems to improve the despatchability. For this purpose, additional solar field is provided to cater for storage which can then be used for generation during off-sun hours; else storage systems can only facilitate shifting solar generation from on-sun to off-sun period for peaking purposes etc. Providing additional solar field for storage systems is not only expensive; it would also require additional land for the storage system itself and also for additional solar field. Storage systems constitute major cost of the solar thermal plants, accounting for almost 70-80 % of the total plant costs.

In the context of power stations, storage systems are obviously not necessary. The limited objective of keeping the solar power generation equipment in hot condition can be met by supplying steam to the solar power plant from the auxiliary steam supply of the thermal station.

4.7 Hybrid plant operation has also been adopted to increase capacity utilization of solar plant even without storage systems. The solar thermal plants in California employ gas fired boilers to supplement power generation during off-sun hours. Such an arrangement appears to have been provided as a means to improve quantum and reliability of power supply to the grid as these are large solar plants. One solar tower based system has been commissioned in Kibbutz Samar in Israel which has 30 different heliostats tracking the sun and directing solar energy to the top of a 30m tall tower. The tower also houses a micro-turbine that can be run on solar thermal, as well as bio-diesel, natural gas or biogas, particularly when the sun goes down.

Possible areas of installation of solar plants

4.8 The choice of areas for solar plants in existing Thermal Power Stations could be:-

- Open land areas not intended for any future expansion
- Abandoned ash ponds in coal fired stations
- Areas in existing green belt subject to MOE&F approval
- Roof top of turbine hall (for PV systems)
- Roof top in administrative building, guest houses, and large buildings (for PV systems)

4.9 The land chosen should be away from high dust areas like coal and ash handling plants and their fugitive emissions. In case of abandoned ash pond lands, suitable surface improvement may be required to prevent ash carry over and deposition on solar field. Washing arrangement for solar field would have to be provided commensurate with the expected dust levels in the vicinity.

4.10 Land availability would vary at each plant. Land availability at two thermal plants is indicated below as an example:

- 1000x700 M^2 at Anta CCGT plant of NTPC
- Two plots of 1200 mtrX200 mtr and 600 mtrX 200 mtr at Suratgarh Thermal power plant of RRVUNL.

NTPC have assessed the solar capacity of 15 MW at Anta CCGT plant in 70 hectare plot. Per MW area requirement is high because of gas pipeline passing through the plant which cannot be relocated. It is estimated that about 15 MW capacity can be installed in 36 hectare area available at Suratgarh TPP.

Integration with Thermal Stations on steam side

4.11 Solar thermal plants generate steam from solar heat and thus conceptually it should be feasible to utilize the solar heat (steam) in existing thermal cycles of the coal or gas based stations to achieve fuel savings and reduced CO_2 emissions. This type of integration can result in a) elimination of power conversion equipment (steam turbine generator etc) for the solar plant thus reducing the cost of solar thermal plants and b) increase the efficiency of solar thermal plant due to higher efficiency of higher size steam-turbine generator.

4.12 Some plants of Integrated Solar Combined Cycle Systems (ISCCS) i.e. a combination of solar field and fossil fuel fired combined cycle power plants, are under construction but none is under operation. These include:

i) 30 MWe parabolic trough field (130000 m^2 collector area) integrated into a146 MWe CCPP at Kuraymat, Egypt.

ii) 20 MWe parabolic trough field (183000 m^2 collector area) integrated into a 472 MWe CCPP at Ain-Beni-Mathar, Morocco.

iii) 25 MWe parabolic trough field (180000 m^2 collector area) integrated into a 150 MWe CCPP at Hassi-R'mel, Algeria..

It is also feasible to integrate solar thermal with coal fired power plants. One example of this integration, also the only one, is Fresnel reflector technology based 9MW solar thermal plant integrated with 2000 MW Liddle coal fired plant in Australia.

4.13 The possible areas of integration with thermal stations on steam side can be identified as

i) Using solar steam for feed water heating

ii) Mixing solar steam with main steam inside boiler/HRSG or in pipe en-route to turbine.

iii) Injecting solar steam directly in turbine at some intermediate stage.

iv) Separate back pressure turbine for solar steam and exhaust to existing plant condenser.

Using solar steam for Feed Water (FW) heating may appear to be least cumbersome as solar steam would not be fed to the turbine. However, in coal fired plants, feed water heating is done partially in the regenerative cycle and then the FW is fed to the economizer. Replacing or supplementing regenerative cycle feed water heating with solar heating would involve taking the existing FW heaters out by closing their extractions and the adverse thermodynamic impact on the turbine cycle heat rate would have to studied. Further, even physically installing the solar steam based FW heaters in the turbine hall area and routing solar steam pipes to the turbine hall from the solar field may pose severe space constraints in view of compact and optimized turbine hall layout. Also the additional pressure drops in FW circuit may necessitate installation of additional FW pumps or augmenting boiler feed pumps which may not be possible.

Heating FW after the regenerative cycle so as to have higher than design FW temperature at entry to boiler thus reducing the economizer duty may also not serve much purpose as in existing boilers it will only increase the flue gas exit temperature thus increasing the flue gas losses and not leading to any fuel savings. Besides, the physical constraints of installing solar FW heaters and problem of meeting additional pressure drop in FW circuit would remain. Similar issues are likely in using solar steam for FW heating in CCGT stations.

Mixing solar steam to Main Steam would require special mixing arrangement due to difference in temperature of solar steam and Main steam. Also variation in solar irradiation over the day and during various seasons may involve large variations in the solar steam quantity and parameters thus leading to changes in aggregate steam quality to the turbine. Fluctuating steam flow to the turbine and large variation in steam parameters may involve stress implications on the Steam Turbine and will have to be examined in consultation with turbine manufacturer.

Injecting solar steam in turbine intermediate stages is virtually ruled out in existing turbines as the turbines have very little flow margins available, primarily for operational degradations.

4.14 The feasibility of integrating solar power plant with existing station on the steam side were also examined in the Feasibility study for solar plant at Anta CCGT station got conducted by NTPC through Evonic, Germany. The salient extracts of possible integrating options examined and findings are given at **Appendix-II**. As may be seen, integration options involved:-

- Issues of mismatch of steam parameters of solar and conventional power station steam, (especially under fluctuation of flow and parameters of solar steam due to fluctuation in solar conditions) and sub-optimal steam use
- Margins available in existing equipment to accommodate additional steam flow from solar field
- Concerns about impact on existing performance of the stations

It was finally decided to go for standalone 15 MW solar thermal plant.

4.15 Thus, integration on the steam side to the existing station is expected to be too cumbersome. This may also disturb the existing cycle and involve issues of performance reliability of the existing station. Thus, the solar plants in existing TPS may be considered as a stand alone plant without any inter-connection to the steam side of the station.

However, integrated solar plants with gas plants could be considered for new stations depending on site specific factors for which site specific techno-economics and feasibility studies would be required. It may not be advisable to integrate solar plant with new coal based plants since turbine-generators in coal based plants are of standard rating and there would be no increase in the power output by solar thermal energy.

It may be mentioned here that a 140 MW Integrated Solar Combined Cycle Power Power Plant with solar component of 35 MW and gas turbine component of 105 MW was conceived at Mathania, Rajasthan. CEA had given its techno-economic clearance to the plant in the year 1999. However, the plant could not materialize due to high prices of Naphtha, non-availability of gas and some other reasons. Details of this plant are given in enclosed **Appendix – III**.

Sharing of Existing Facilities

4.16 Even for a standalone solar thermal plant, the existing station facilities would require to be shared with the solar power plant and it needs to be ensured that appropriate provisions exist for the same in the existing station systems. Typical station facilities required to be shared in case of solar thermal plants are as under:-

- DM Water
- Circulating water make up
- Auxiliary steam
- Auxiliary electricity supply
- Fire fighting system

i) Solar thermal plants need DM water for the power cycle initial filling as well as cycle make up. The typical make up quantity can be taken similar to the conventional power cycle at about 3% of the cycle flow. In addition, if the solar field washing is also required to be done by DM water, the water requirement for same would also have to be considered. Frequency of washing, quality and quantity of water for washing would have to be ascertained from suppliers of solar field.

ii) In all probabilities, separate cooling tower would have to be installed for solar thermal power plant. However, the circulating water requirement would have to be met from the existing station CW system.

iii) The solar thermal plant may need auxiliary steam supply for initial warm up of the power plant island so as to enable faster start up of solar plant.

iv) The existing fire fighting system would required to be extended to cover the solar thermal plant also.

v) The issue related to auxiliary supply is discussed subsequently.

Electrical Interconnection between Solar Thermal and conventional Stations

4.17 Following options are available for integration of solar thermal power with electrical system of existing plant.

- Solar power connected to Generator bus of existing plant (Option-I)
- Solar power connected to plant 6.6kV unit/ station bus (Option-II)
- Solar power evacuation to grid through new switchyard bay (Option-III)

The site specific interconnection scheme may be required depending on the techno-economics of various options.

i) <u>Solar power connected to Generator bus of existing plant (Option-I)</u>

Generator voltage of solar thermal plant is likely to differ from that of existing plant. Either solar generator is required to be customized as per existing generator bus voltage level or is to be stepped up by a transformer. Further, size of existing generator-transformer may not have adequate margin to take up solar power also. In addition, following issues will also need to be considered, if this option is to be deployed:

a) Feasibility of connection to generator bus from point of view of availability of space.
b) Operation of solar plant in the event of tripping of existing unit

The scheme is shown in Exihibit-I.

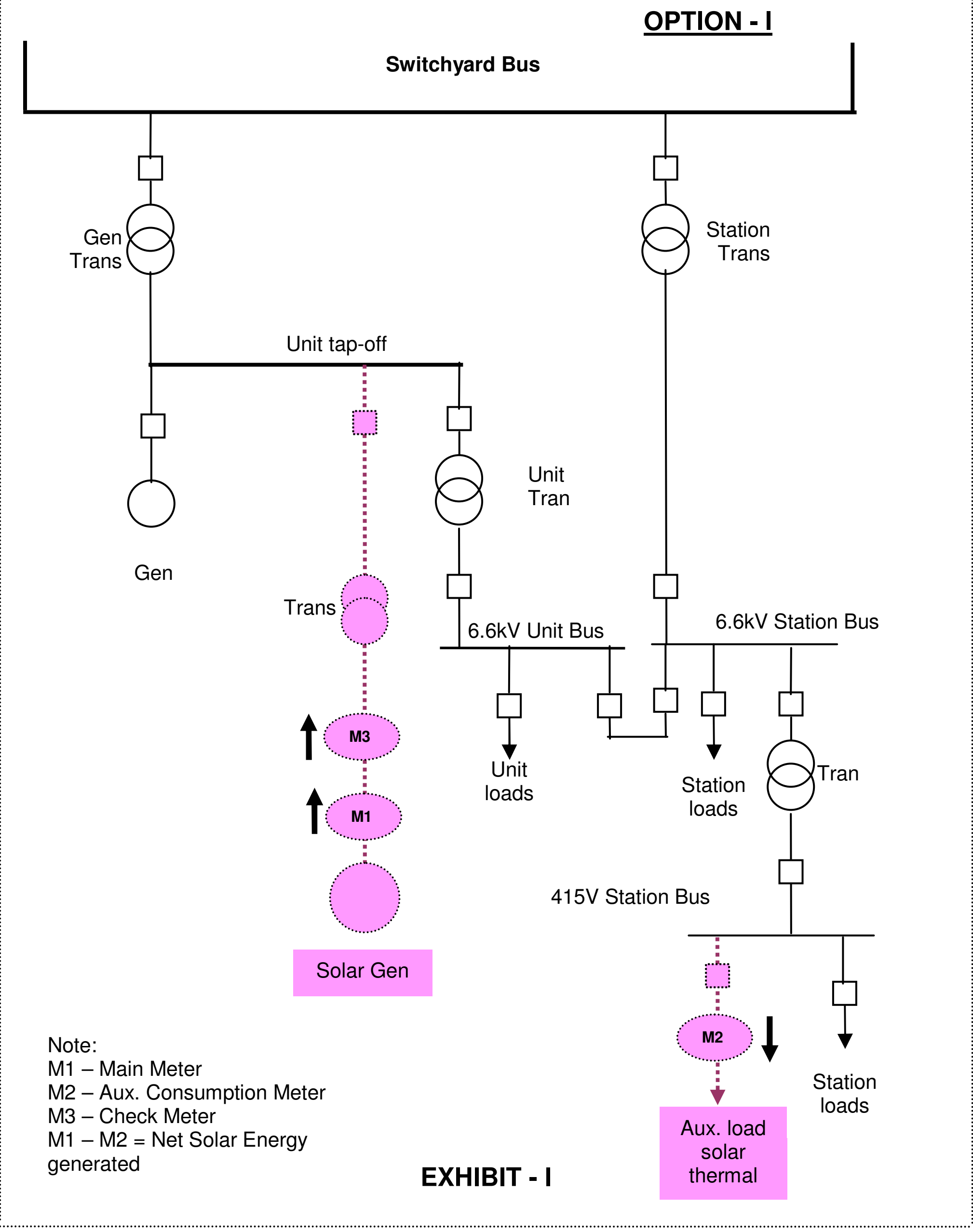


EXHIBIT - I

ii) Solar power connected to plant 11/ 6.6kV unit/ station bus (Option-II)

In this option, solar power will be used to meet part of the auxiliary power consumption of the existing plant. It is preferable to connect solar power to station bus so that it would be possible to evacuate solar power in the event of tripping of one of the units. An auxiliary transformer would be required to match the solar power with the voltage level of the unit/ station bus. The following aspects need to be studied before deciding for implementation of this option:

a) Solar power should be less than the load on unit/ station bus
b) With the addition of solar generation, the fault level of the existing switchgears will increase and the existing switchgear, bus duct etc. may or may not be adequate to meet the new fault level.
c) Feasibility of connection from point of view of availability of space
d) Changes required in present protection scheme, logic of operation etc.

The scheme is shown below

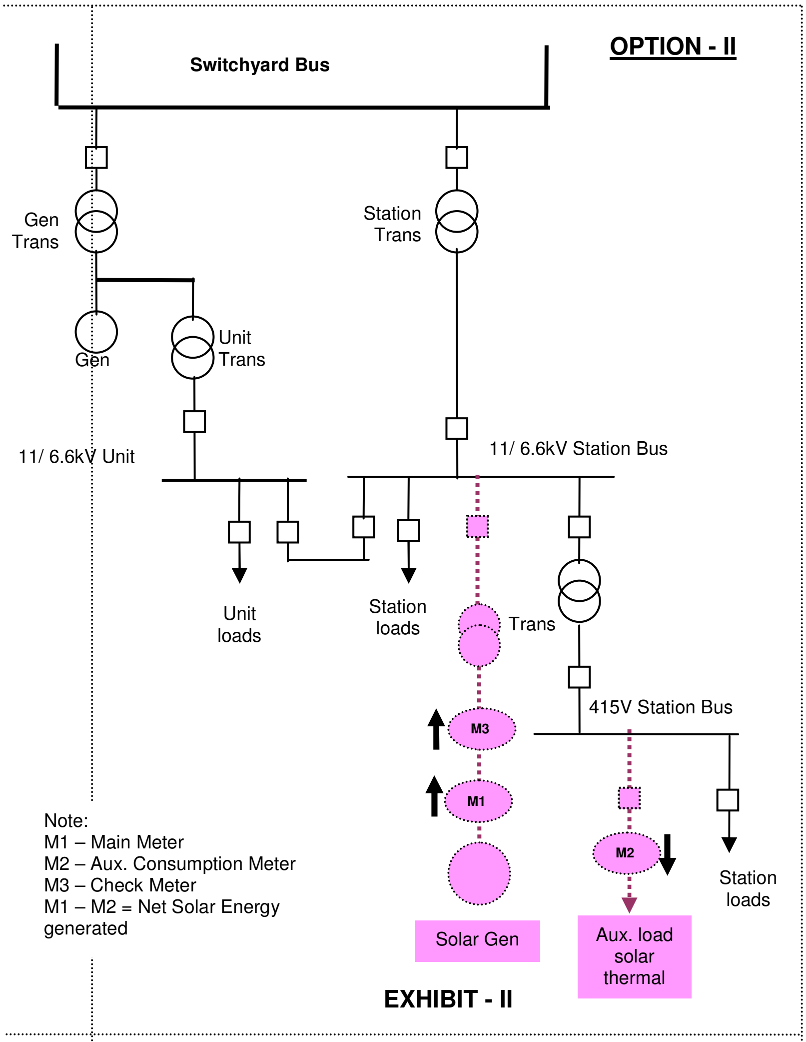


EXHIBIT - II

iii) Solar power evacuation to grid through additional switchyard bay (Option-III)

In this option, generated voltage by solar plant will be stepped up to switchyard voltage level through transformer and connected to the grid. No modification/ augmentation are envisaged in the electrical system of the plant. Since additional bay will have to be added, the availability of space in the existing switchyard need to be studied before deciding for implementation of this option.

The scheme is shown in Exihibit-III.

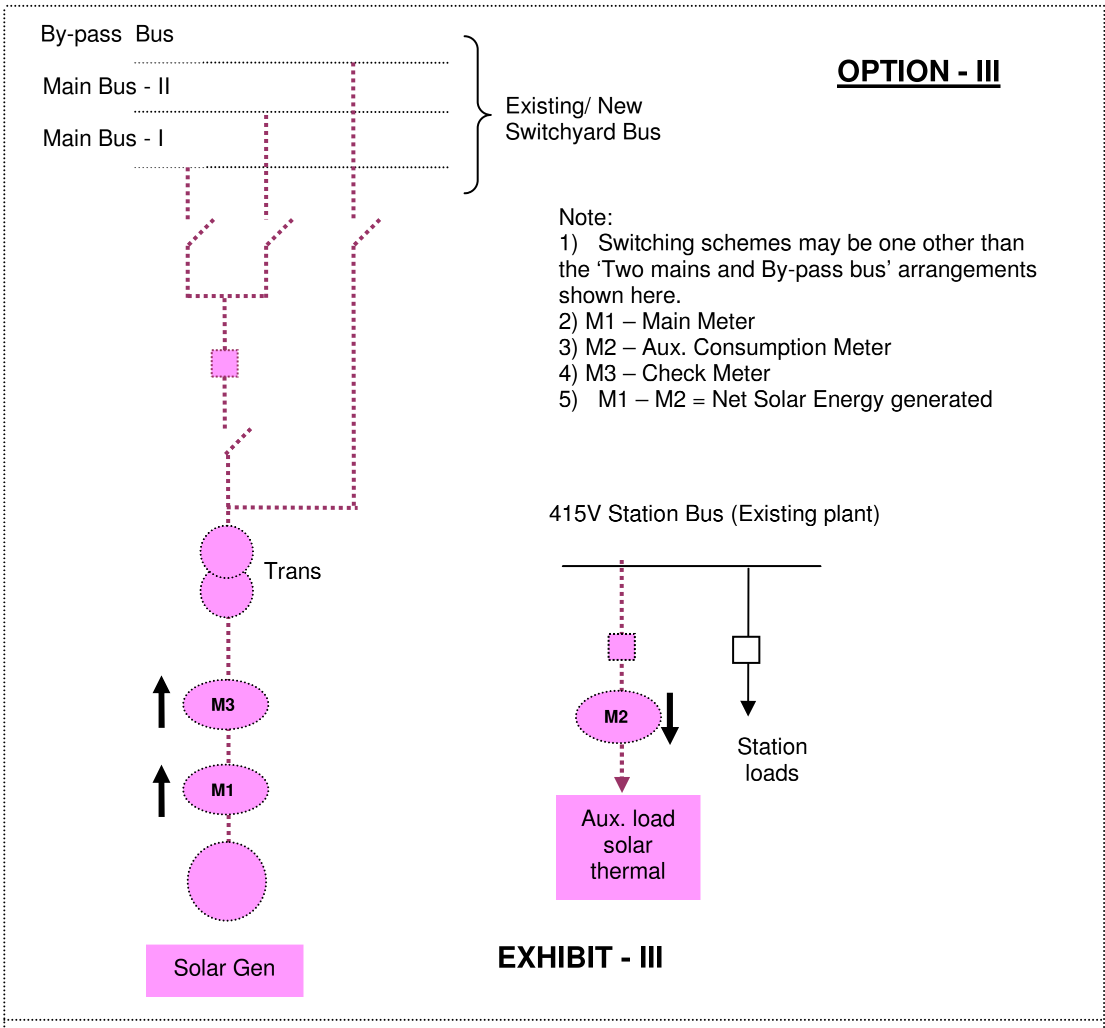


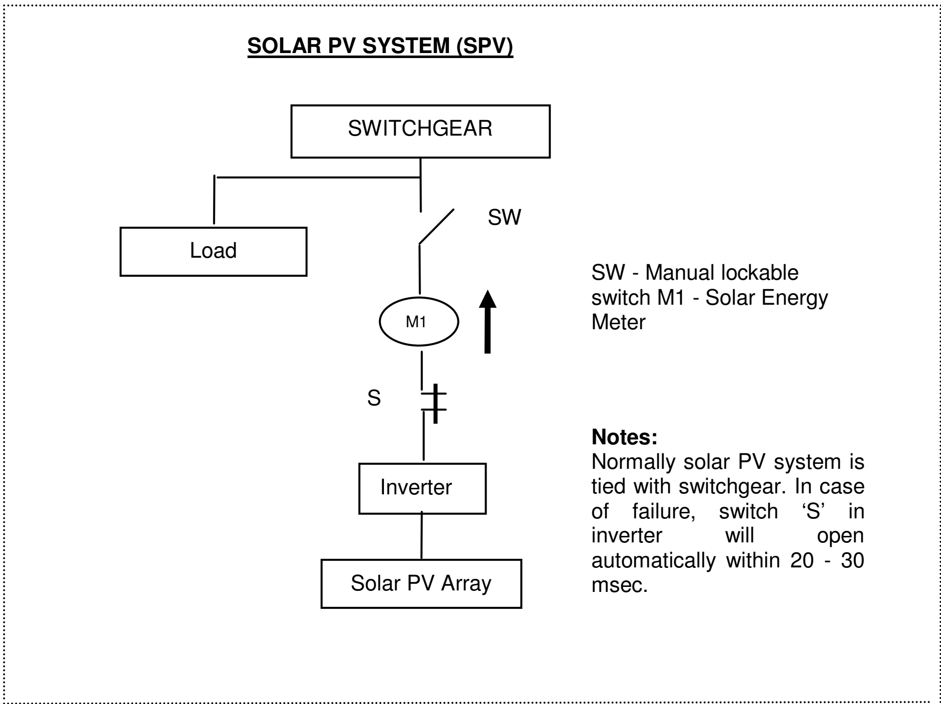
EXHIBIT - III

Auxiliary Power requirement of Solar Thermal Plant

4.18 Solar thermal plant requires auxiliary power of about 8% when solar plant is in operation and about 1% during off sun hours. Besides, solar thermal plant will daily require start up power. It is preferred to tap off feeder from existing station switchgear for auxiliary power/start up power requirement of solar plant at required voltage level.

Electrical Interconnection between Solar PV system and conventional Stations

4.19 Generally, in an existing plant vacant space is available in scattered areas and also on the roof-top of buildings. In case the space available is shadow free, independent Solar Photovoltaic system may be installed to generate electricity and power may be fed into the respective switchgear nearby at 3 ph 415V or higher voltage levels. SPV output of the inverter shall be synchronized automatically to the exact AC voltage and frequency of the system. Typical schematic diagram is illustrated the sketch below:



Following suggested criteria shall be considered for selection of voltage level of Solar PV system:

i. Up to 10kW solar PV system : 1 phase, 240V supply
ii. Above 10kW and upto 100kW solar PV system,: 3 phase, 415V supply
iii. Above 100kW and upto 1.5MW: 6.6/ 11kV level.
iv. Above 1.5MW and upto 5 MW: 11/ 33/ 66kV level or as per the site condition

For further details regarding connectivity of solar PV systems, Report of Sub-Group-I on “Grid interactive rooftop solar PV systems” “may be referred.

Metering

4.20 As shown in the Exihibits I-III above, three nos. meters shall be provided – two (one main meter and one check meter) for metering solar energy generated and another for auxiliary power consumed by the solar thermal plant. Tariff for solar generation shall be provided for the net energy generated after deducting auxiliary power consumed. Meters shall interface type complying with the requirements of CEA Regulations on “Installation and Operation of Meters“.

5 Solar Power Plants in Hydro Power Stations

5.1 The sub-group made a visit to Bhakra hydro stations to ascertain the feasibility of installing solar plants. It is seen that areas around the dam have a hilly terrain with dense vegetation. Such topography is not considered suitable for installing solar power plants. The spillway slope could have been considered but is facing north and thus not suitable. However depending on suitable direction, such areas could be possible choice for installing solar plants.

5.2 Roof tops in Ganguwal and Kotla power houses and fore-bay areas measuring about 2580 m^2 were found suitable for solar PV systems. These areas can support solar PV of about 150 kW capacity. In addition rooftop of Nangal Dam workshop Building and vacant land near guest house were also identified for solar PV systems. The dimensions/area available and possible solar plant capacity are being worked out by BBMB. BBMB also proposed to install floating solar panels on the canal downstream of the Kotla and Ganguwal power houses. Specific studies may be required to examine the feasibility of floating systems.

5.3 From the visit it is seen that large tract of continuous land are generally not available in hydro stations; also the hydro stations have no facilities for supplying warm up steam etc to solar thermal power plant. Thus solar PV systems may only be considered for hydro stations. The possible areas of installation could be power house roof tops, fore-bays, colony roof tops, open grounds etc. Floating solar PV panels if found feasible can also be considered in canals or dam areas.

5.4 For such solar PV systems in Hydro stations, Report of Sub-Group-I on “Grid interactive rooftop solar PV systems” may be referred to.

6 Tariff Projections – CERC Regulations

6.1 CERC has notified Central Electricity Regulatory Commission (Terms and Conditions for Tariff determination from Renewable Energy Sources) Regulations, 2009 and also issued orders for the generic tariffs for the financial year 2009-10 for renewable energy sources including solar PV and solar thermal based power projects. As per these orders, generic levellised tariff has been worked out as under by CERC:

Figs (Rs./kWh)

Parameter	Solar PV	Solar Thermal
Levelised Tariff	18.44	13.45

Parametric Assumptions for the above levelised tariff are given in **Appendix-IV**.

7 Conclusion

7.1 The options for solar generation at any power station would depend upon the following:

i) Adequate solar irradiation
ii) Availability of land
iii) Availability of water (for solar thermal)

7.2 Adequate direct normal component of solar irradiation is necessary for solar thermal plants. Normally a solar irradiation (DNI) of 1800 kWh/m^2 is considered necessary for solar thermal plants. Solar PV plants can, however, utilize global radiations including diffused component. Thus solar irradiations available at a location is the prime consideration for selection of technology.

About 5-7 acres/MW land is required for solar thermal plants. Thus availability of large tract of continuous flat land would be required if solar thermal is to be considered. Further in case solar thermal plant is envisaged, water availability of approx. 4 m^3/MWh has to be ensured.

7.3 When continuous tract of land are not available to suit solar thermal plants, and land is available in several scattered patches, then Solar photovoltaic plants could be considered. For hydro stations solar PV systems would only be feasible. As a rule of thumb these plants require about 20 m^2 for each kW of installed capacity and assessment of feasible capacity can be made based on total land/rooftop areas available.

7.4 In case of solar power plant in coal based stations, location should be away from high dust areas like vicinity of coal and ash handling plants. Also washing requirements of solar field/solar panels would have to be ascertained from the suppliers.

7.5 Integration of solar thermal plants on the steam side to the existing station is a cumbersome proposition. Thus, the solar plants in existing TPS may be considered as a stand alone plant without any inter-connection to the steam side of the station. However, integrated solar plants with conventional gas based plants could be considered for new stations depending on site specific factors for which site specific techno-economics and feasibility studies would be required.

7.6 Various options available for integration of solar thermal power with electrical system of existing gas based plant have been discussed in the report and as brought out, electrical integration with the option of additional switch yard bay comes out to be the most suitable amongst all the options. However, site specific studies are required regarding the interconnection before finalizing the scheme.

7.7 Considering the high tariff of solar power, two meters (one main and one check meter) may be provided for solar electricity generated. Suitable metering arrangements would also be required for measurement of auxiliary power consumption of the solar thermal plant from the existing station electric supply.

7.8 All thermal and hydro generating utilities should explore the potential of installing solar plants in vacant land of their existing stations. Detailed Project Report for the specific project would be required to be developed by a consultant to study the feasibility of the solar power plant, technology to be employed, generation projections, cost estimates etc. A brief summary of Feasibility Study for Solar Thermal Plant in NTPC -Anta CCGT station is enclosed at Appendix-II for reference.

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Annexure-I composition of subgroup

भारत सरकार
नवीन और नवीकरणीय ऊर्जा मंत्रालय
Government of India
MINISTRY OF NEW AND RENEWABLE ENERGY
ब्लाक . 14, केन्द्रीय कार्यालय परिसर, लोदी रोड, नई दिल्ली-110003
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Fax · 011-2436
Telegram : RENEWA

सं. No. 32/61/2009-10/PVSE

दिनांक Dated 28th May,2009

To

Shri Rakesh Nath,
Central Electricity Authority
Sewa Bhawan,
R.K.Puram
New Delhi – 110 066

Office Memorandum

Subject: Task Force to examine technical issues related to feasibility of integrating solar Power plants with thermal / hydro-electric power plants and connectivity of solar roof top systems with grid

A National Solar Mission is being envisaged to ensure rapid and large scale diffusion of solar energy technologies in the country. Among various applications, grid interactive solar power generation will be one of the important application. In this context, certain technical issues relating to feasibility of integrating solar based plants with thermal/hydro electric power plants and connectivity of solar rooftop systems and other solar plants with grid need to be examined. Accordingly, it has been decided to constitute a Task Force comprising the following:-

Shri Rakesh Nath, Chairperson, Central Electricity Authority	Chairman
Joint Secretary (Thermal), Ministry of Power	Member
Dr. G K Pandey, Adviser, MOE&F	Member
Dr B Bhargava, Director (SPV) MNRE	Member
Director (Technical), NTPC	Member
Director (Technical), NHPC	Member
General Manager (PEM), BHEL	Member
Executive Director, CEL	Member
Chief Executive, RRECL	Member
Managing Director, RRUVNL	Member
Managing Director, GSECL	Member
Director, GEDA	Member
Chief Engineer KPCL	Member
Shri Suresh Chander, Chief Engineer (TE&TD),CEA	Member-Secretary

O/o Chairperson
Dy. No. 1757
Date 4/6/09
C.E.A.

2.0 Terms of reference of the Task Force will be as under :-

2.1 In regard to thermal/hydro electric plants:-

i. To examine feasibility of integrating solar based plants with Thermal (Coal and gas)/Hydro –electric power plants including issues relating to availability of land and effect of fugitive ash in coal based plants.
ii. To suggest the feasible options for type of solar plants (PV solar cells, solar thermal plants) for installation at thermal /hydro –electric power plants.
iii. To examine the feasibility of hybrid solar power systems in thermal power plants including use of secondary fuel firing or heat storage devices during the periods when solar power is not available.
iv. To suggest scheme for connecting solar based plants with the station electric supply system for thermal/hydro electric power plants.
v. To suggest arrangements for metering and accounting for energy supplied by the solar based plants.
vi. To suggest modalities of implementation for solar based plants at thermal/ hydro electric power plants including preparation of project report.

2.2 In regard to solar rooftop systems:

i. To suggest schemes for connecting solar rooftop systems with grid.
ii. To suggest arrangements for metering for accounting of energy supplied by the solar rooftops.

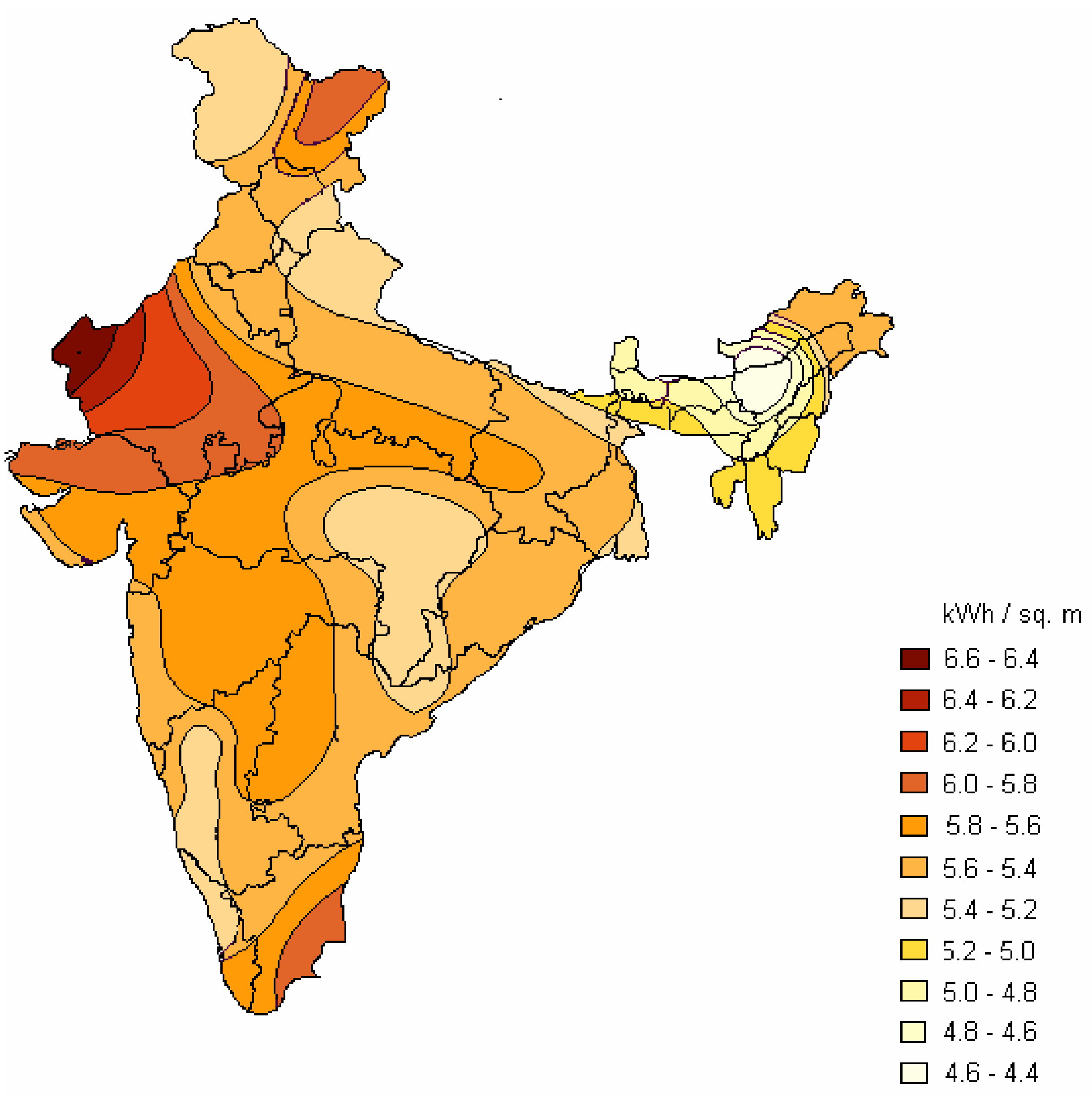
3.0 The Task Force will submit their report to the Ministry of new and Renewable Energy within three months.

4.0 Chairman may co-opt may other expert as considered necessary

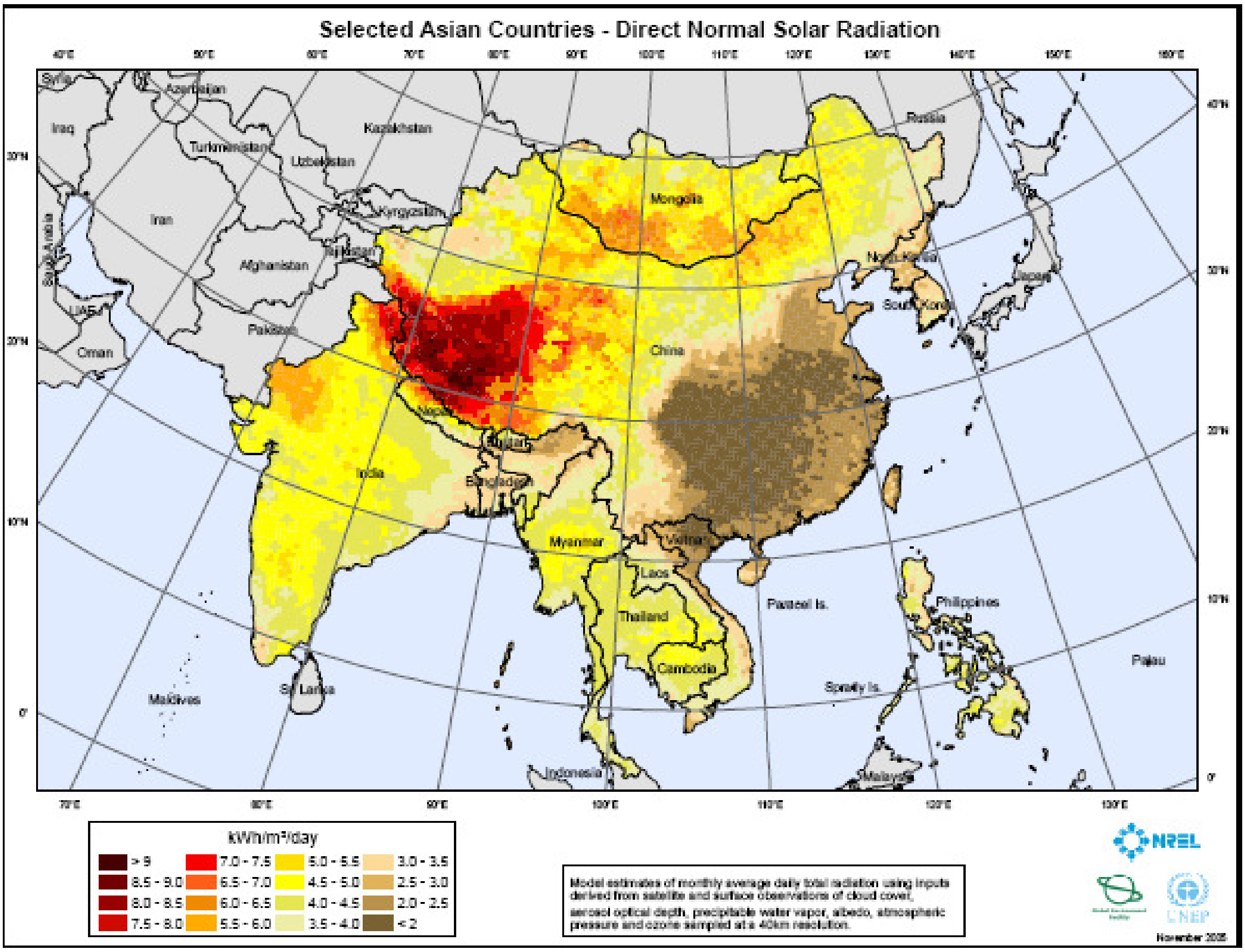
(B Bhargava)
Director
Telefax:24361891
Email: bhargava@nic.in.

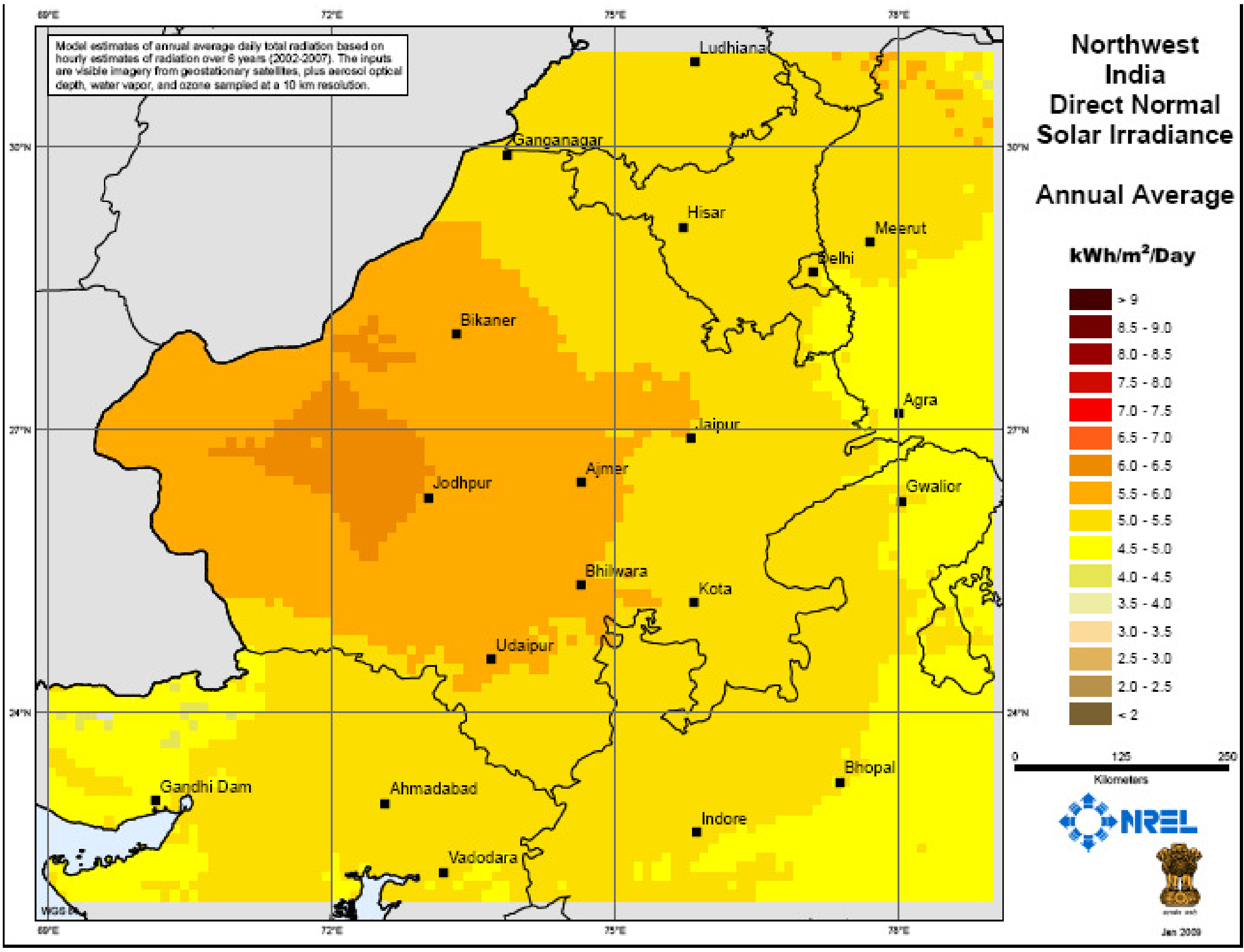
APPENDICES

Appendix-I Solar Maps



Global Solar Radiation Map of India
Source TERI


Selected Asian Countries - Direct Normal Solar Radiation
Syria
Azerbaijan
Iraq
Turkmenistan
Kazakhstan
Uzbekistan
Russia
Iran
Kyrgyzstan
Mongolia
Afghanistan
Tajikistan
North Korea
Japan
South Korea
Pakistan
Oman
UAE
Saudi Arabia
China
Nepal
Bhutan
India
Bangladesh
Myanmar
Vietnam
Laos
Thailand
Paracel Is.
Philippines
Cambodia
Spratly Is.
Palau
Maldives
Sri Lanka
Indonesia
Malaysia
kWh/m²/day
> 9
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2
Model estimates of monthly average daily total radiation using inputs derived from satellite and surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone sampled at a 40km resolution.
NREL
UNEP



DNI Map of North- west India

Appendix-II

Feasibility Study for Solar Thermal Plant in NTPC -Anta CCGT station

1. Anta Gas Power Plant is a Combined Cycle Power Plant (CCPP) owned and operated by NTPC, which consists of three gas turbines of 88.7 MW capacity each and a condensing steam turbine of 153.28 MW having a peak load capacity of 164.14 MW. Thus, the total installed capacity is 419.38 MW. Feasibility Study for installation of solar generation at Anta CCGT station has been done by NTPC. The study was done by Evonik Energy Services, Germany through KFW, Germany.

2. Anta site was chosen due to good solar irradiation. The direct normal irradiation (DNI) at Anta is 2090 kWh/m2 which is comparable with southern part of Spain where number of solar thermal plants are under construction.

3. Anta TPS has 175 acres of vacant land on which the proposed solar plant would be installed. Area available for solar field would be 1000 m x 700 m. The available land at Anta is considered suitable for supporting 15 MW solar power plant. More compact solar field is possible. However, this would require relocating the gas pipe line which is running in the centre of the plot and is not considered desirable by NTPC. Thus the solar field has been divided into two parts which appropriate clearance for the pipeline. The solar field would generate steam at 30 bar, 370 deg C.

4. Possibilities of connecting the solar plant to the existing CCGT station on the steam side were examined but not found feasible due to fluctuating steam output from the solar plant and large difference in the steam parameters from the solar field and CCGT station. Hence, standalone plant of 15 MW capacity is proposed. Such integration may, however, be possible in new CCGT stations where initial designs itself could incorporate the requirements of the solar integration

5. Parabolic trough technology has been chosen as several plants of this technology are operating in California for more than 20 years. Other technologies considered were Fresnel collector, solar tower and parabolic dish collectors which are stated to be in demonstration phase.

6. Net solar generation of 32163 MWh per year has been estimated considering 10% discount on DNI and plant availability of 96%. This works out to capacity utilization factor of 24.5%. The Auxiliary load for solar plant is estimated to be 1.7 MW when the plant is in service and 0.2 MW when the plant is not in service

7. The water requirements are estimated as under:-

   DM water consumption – 10,000 m^3 per year

CW water consumption – 183,000 m^3 per year
Total water consumption- 193,000 m^3 per yr

Thus the total water requirement works out to be about 6m^3/MWh. The water requirement would be met from existing plant. Also adequate provisions for cooling water system, raw water storage, DM water exist in the existing CCGT station.

8. Various options for integrating the solar plant with the existing pant on the electrical side were also considered. Options to connect the proposed solar plant to the existing generator bus ducts, 6.6 KV station supply and 220 KV Switchyard were studied. The brief findings in regard to interconnection options are as under:-

Option-I Interconnection to existing generator bus ducts

- The fault current rating of existing IPB is exceeded.
- Layout constraints for tap-off connection to new Solar Generator
- Load sharing between two generators of dissimilar ratings and circulating current through their grounding system is considered undesirable

Option-II Interconnection to 6.6 KV station supply

- The fault level with 10 MW solar generation increases to 22KA(rms), which is beyond the present capacity requiring complete replacement of complete HT switchgear.

Option-III Interconnection to 220 kV switchyard

- Addition of one no. 220 kV bay required along with equipments and protection.
- Modification of bus bar protection system required.
- Step up Transformer required GenV/220 kV (12.5 MVA)

Finally the option of **Interconnection to 220 kV switchyard was adopted.**

9. Operation and Financial parameters considered :–

Plant output	15 MW
Plant availability	96%
Total capital cost with IDC	Rs. 367.5 Crores
Cost per MW	Rs. 24.5 Crore
Debt : Equity ratio	70:30
Euro grant from KFW	5 million Euro
Interest rate on Kfw loan	3.5%

Interest rate on Rupee loan	12%
Repayment period Kfw loan	12 years and grace of 3 years
Foreign exchange variation	Not considered
O&M cost	Rs. 43.8 lakh per MW
O&M escalation factor	NIL
Contingency for solar panel cost	10%
Contingency for other plant cost	5%
Levelised cost of Generation	
Base case	Rs.8.47 per kWh
With 5 million Euro grant	Rs. 8.29 per kWh
With 5 million Euro grant + CDM Benefits	Rs. 8.29 per kWh
Base case + consultancy cost of 1 million Euro	Rs. 8.63 per kWh

10. The above study could serve as a typical reference/bench mark for guidance. However specific studies would be required for each site to establish the feasible solar field configurations, solar outputs, equipment efficiency and cost of generation.

Study of Integration of Solar Power Plant with Existing CCGT Station

11. The original aim of the Anta study was to assess the feasibility and economy of an extension by a solar collector field to increase generation capacity of the existing steam turbine at Anta. The peak load capacity of individual GT at Anta is 94.17 MW each and STG of 164.14 MW. Thus the existing steam turbine had margin available for taking solar steam and this originally led to the idea to analyze the extension of the CCPP by a solar collector field by integrating solar generated steam into the existing CCPP with the possibility of raising the output of the steam turbine.

12. Several potential integration concepts with variations were evaluated during the study. The integration options considered were:-

    12.1. To integrate the solar steam into the HP-drums of the existing HRSGs

    12.2. To integrate the solar steam between two super heaters of the existing HRSGs

    12.3. To integrate the solar steam of 370°C into the main steam (of 485°C) pipe via new mixing arrangement.

    12.4. To superheat the solar steam of 370°C in a separate fired superheater to bring it to 485°C before integrating it into the main steam (of 485°C) pipe.

12.5. Solar steam to be used in a new Back-pressure Turbine Generator and exhaust of the BPST to be mixed with LP steam at LPT inlet.

12.6. Solar steam to be used in a new Condensing Turbine Generator and exhaust of the CST to be connected to condenser of the existing power plant

13. The option to integrate the solar steam into the HP-drums could not be adopted due to the following reasons:-

- Solar steam would have required to be de-superheated to match the steam temperature inside drum thus leading to loss in efficiency
- Solar steam piping need to be connected to each of the three drums so that solar plant operates even when one of the gas turbine is working. This would have involved lot of complex pipe work
- Steam would be required to be injected in each drum in proportion of the gas turbine load needing complex control logics.
- Shut down of the entire plant for integration work would be required leading to loss in revenue.

14. The option to integrate the solar steam between two super heaters of the existing HRSGs was not considered in detail due to the fact that the super heaters of the HRSGs are difficult to access for modification, A major modification of 20 years old HRSGs was not considered desirable.

15. The option to integrate the solar steam of 370℃ into the main steam (of 485℃) pipe via new mixing arrangement was considered in detail. However it could not be adopted due to the following reasons:-

- It involved a temperature difference of around 100℃ between HP Main steam and Solar Steam and thus required special mixing arrangement.
- Stress implications on the Steam Turbine due to frequent changes in main steam temperature.
- Lower HP steam temperature at turbine inlet due to mixing of solar steam would lead to higher mass flow for the turbine. Thus the margin available in the turbine was getting further reduced.
- Due to implications on the turbine OEM consultation was felt necessary for this option

16. The option to superheat the solar steam of 370℃ in a separate fired superheater to bring it to 485℃ was considered in detail. However it could not be adopted due to the following reasons:-

- Superheating the solar steam at 370℃ in a separate fired superheater was required to bring it to 485℃ before integrating into the main steam (at 485℃) pipe.

- Separate fired superheater would have needed supplemental heating by gas-fired burners thus increasing gas consumption.
- Also the new gas fired superheater would have a low efficiency compared to the CCPP.
- Also it would have been difficult to separate the electrical output from the solar side and the conventional leading to possible problems with the regulators.

17. Using Solar steam in a new Back-pressure Turbine Generator with exhaust of the BPST to be mixed with LP steam at LPT inlet of existing steam turbine involved partially unloading the GTs as otherwise the max flow rate of LP turbine was getting exceeded.

18. Installing a new Condensing Turbine Generator for Solar steam and connecting exhaust of the CST to condenser of the existing power plant involved serious installation difficulties it required construction of new pedestal close to the existing STG which might have posed be a serious problem. Also it would not have ben possible to inject CST steam from the new condensing turbine into the existing condenser via a new opening in condenser neck.

19. Thus the integration options could not be considered and it was decided to install a stand alone solar power plant of 15 MW capacity.

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Appendix-III

Salient features of 140 MW Integrated Solar Combined Cycle Power Plant

1. A 140 MW Integrated Solar Combined Cycle Power Plant was proposed at Mathania Rajasthan. Salient details are given below:

Plant capacity	140 MW with solar component of 35 MW and non-solar component of 105 MW
Configuration	Solar + 2 nos. GTGs + 2 nos. HRSG +1 No. STG
Solar Plant Capacity	35 MW
Annual solar share	9% (operation without auxiliary firing at night) 6% (operation with auxilisry firing at night)
Solar field area	600,000 m^2
Solar technology	Parabolic trough
DNI (25 yr average) at site	2177 kWh/m^2
Solar heat input	94.5 MW
Feed water inlet temperature	245 deg C
Live steam pressure/ temperature	105 kg $/cm^2$, 370 deg C
Live steam flow	50 kg/S
Solar heat interconnection with CCGT cycle	The heat transfer fluid (HTF) is circulated through the solar field where it is heated. The solar heated HTF generates superheated steam in heat exchangers. The superheated steam is then fed to the high pressure (HP) casing of steam turbine. The spent steam is condensed in conventional steam condenser and returned to heat exchangers via condensate and feed water pumps. Provision also made for auxiliary firing in HRSG in the evening and night to make up for low or no insolation.

Assumptions for generic levelised tariff for solar power plants as per CERC

Form 1.1 Form Template for (Solar PV Power Projects) Parameters Assumptions

S. No.	Assumption Head	Sub-Head	Sub-Head (2)	Unit	Asumptions
1	Power Generation				
		Capacity			
			Installed Power Generation Capacity	MW	1
			Capacity Utilization Factor	%	19.0%
			Deration Factor	%	0.0%
			Useful Life	Years	25
2	Project Cost	Capital Cost/MW	Power Plant Cost	Rs Lacs/MW	1700
3	Financial Assumptions				
			Tariff Period	Years	25
		Debt: Equity			
			Debt	%	70%
			Equity	%	30%
			Total Debt Amount	Rs Lacs	1190
			Total Equity Amout	Rs Lacs	510
		Debt Component			
			Loan Amount	Rs Lacs	1190
			Moratorium Period	years	0
			Repayment Period(incld Moratorium)	years	10
			Interest Rate	%	14.29%
		Equity Component			
			Equity amount	Rs Lacs	510
			Return on Equity for first 10 years	% p.a	19.00%
			RoE Period	Year	10
			Return on Equity 11th year onwards	% p.a	24.00%
			Weighted average of ROE		22.00%
			Discount Rate		16.60%
4	Financial Assumptions				
		Fiscal Assumptions			
			Income Tax	%	33.99%
			MAT Rate (for first 10 years)	%	16.995%
			80 IA benefits	Yes/No	Yes
		Depreciation			
			Depreciation Rate for first 10 years	%	7.00%
			Depreciation Rate 11th year onwards	%	1.33%
			Years for 7% rate		10
5	Working Capital				
		For Fixed Charges			
		O&M Charges		Months	1
		Maintenance Spare	(% of O&M exepenses)		15%
		Receivables for Debtors		Months	2
		For Variable Charges			
		Interest On Working Capital		%	13.79%
7	Operation & Maintenance				
		power plant		Rs Lakh	9
		Total O & M Expenses Escalation		%	5.72%

Form 1.1 Form Template for (Solar Thermal Power Projects) Parameters Assumptions

S. No.	Assumption Head	Sub-Head	Sub-Head (2)	Unit	Auumptions
1	Power Generation				
		Capacity			
			Installed Power Generation Capacity	MW	1
			Capacity Utilization Factor	%	23.0%
			Auxiliary Consumption Factor	%	10.0%
			Useful Life	Years	25
2	Project Cost				
		Capital Cost/MW	Power Plant Cost	Rs Lacs/MW	1300
3	Sources of Fund				
			Tariff Period	Years	25
		Debt: Equity			
			Debt	%	70%
			Equity	%	30%
			Total Debt Amount	Rs Lacs	910
			Total Equity Amout	Rs Lacs	390
		Debt Component			
			Loan Amount	Rs Lacs	910
			Moratorium Period	years	0
			Repayment Period(incld Moratorium)	years	10
			Interest Rate	%	14.29%
		Equity Component			
			Equity amount	Rs Lacs	390
			Return on Equity for first 10 years	% p.a	19.00%
			RoE Period	Year	10
			Return on Equity 11th year onwards	% p.a	24.00%
			Weighted average of ROE		22.00%
			Discount Rate		16.60%
4	Financial Assumptions				
		Fiscal Assumptions			
			Income Tax	%	33.99%
			MAT Rate (for first 10 years)	%	16.995%
			80 IA benefits	Yes/No	Yes
		Depreciation			
			Depreciation Rate for first 10 years	%	7.00%
			Depreciation Rate 11th year onwards	%	1.33%
			Years for 7% rate		10
5	Working Capital				
		For Fixed Charges			
		O&M Charges		Months	1
		Maintenance Spare	(% of O&M exepenses)		15%
		Receivables for Debtors		Months	2
		For Variable Charges			
		Interest On Working Capital		%	13.79%
7	Operation & Maintenance				
		power plant		Rs Lakh	13
		Total O & M Expenses Escalation		%	5.72%