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Comparison of economic performance of solar and diesel energy generation as standby choice for industries using thermal power

Due to rapid depletion of fossil fuels and environmental risk, several non-conventional sources of energy like water, wind, geo-thermal, nuclear and solar photovoltaic, have been taken into account for power generation. Solar energy is finite energy resources to meet up long term global energy crisis. In the last decade the demand of power in India has increased manifold, therefore government has announced the National Solar Mission of generating 100 GW of solar power up to 2022. Around 60% of the total National Solar Mission target is allotted to the national/international large-scale solar power developers/investors. Environmental friendly, reduced installation cost, improved power quality, abundant availability of source makes photovoltaic based distributed generation as one of the most popular alternative source of energy production.

Many industries operate 24 hours in a day, practically every day of the year. They expect full reliability and availability from their power systems, with very low tolerance for outages or shortfalls. Such industries operate at a 70% to 90% annual load factor relative to their peak load, but peak loads can occur at any time of day in any season. Due to their inherent variability, most renewable technologies, like photovoltaic panels (PV) and wind, can only address a small fraction of the energy needs, and are not reliable enough for off-grid power so we propose a hybrid grid system for the same.

This report analyzes the key barriers and bottlenecks faced by solar power and diesel power developers in achieving the target and their growth and propose an automated method to do the economic calculation of solar power plant at any location. We compare this with diesel plant economics to find the best possible power generation solution for situations. They could be singly used or in a hybrid system.

1.0 Introduction

Solar energy is available in abundance in most parts of the world and is the most readily available free source of energy. Solar energy happens to be the most appropriate green energy and is quite environmental friendly. The amount of solar energy incident on the earth's surface is approximately 1.5×1018 kW hr./year, which is about 10,000 times the current annual energy consumption of the entire world. India receives solar energy around 5–7 kW hr./m^2 for 300 – 330 days in a year. This energy is sufficient to set up a 20 MW solar power plants per square kilometer land area. The utility electricity sector in India has one national grid with an installed capacity of 331.11 GW as on 31 October 2017. India is the world's third largest producer and fourth largest consumer of electricity. Electricity is very important for any country for urbanization, industrialization, economic growth and improvement of living standard of society. Presently, India has installed capacity of 331.11 GW out of which 66.6% is from thermal, 13.6% from hydro, 2.1% from nuclear and about 17.7% from renewable energy sources.

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TABLE 1: YEARLY GROSS ELECTRICITY GENERATION BY (MWH)\

		2015	2018	
1.	Total generation	276.783 GW	331.11GW	↑
2.	Thermal	69.6%	66.6%	↓
3.	Hydro	15.2%	13.6%	↓
4.	Nuclear	2.1%	2.1%	⊘
5.	Renerable resources	13.2%	17.7%	↑

SECTOR	MW	PERCENTAGE
State	81102	24.6
Central	103033	31.3
Private	145163	44.1

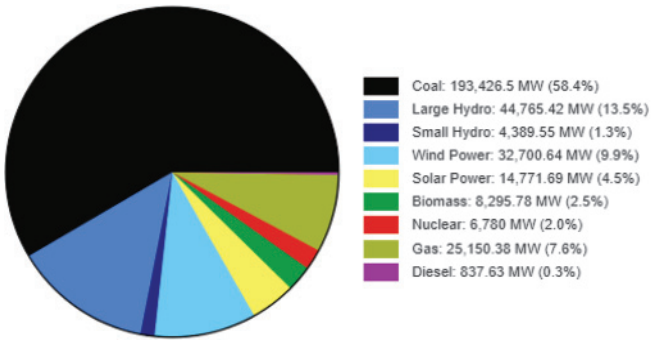

Fig.1: Pie chart wise distribution according to their source

We have observed a huge change in just recent years in the sector of power generation. Here we compare the power generation scenario of 2015 to 2018.

A. Indian Government incentives nd support

The template is used to format your paper and style the text. All margins, column widths, The Government of India is providing Rs.15,050 cr. subsidy to promote solar capacity addition in the country. This capital subsidy will be provided for solar projects in many cities and towns. Solar power projects with investment of about Rs.90,000 cr. would be developed using bundling method with thermal power. Further, investment will come from large public sector undertakings (PSU) and independent power producers (IPPs). Many states governments have also come out with state solar policies to promote solar energy technology.

Here we can see that due to government policies, sponsorship and developing technology in SPV-solar photovoltaic energy generation, the cost of generating energy from conventional sources has decreased a lot. We can see negativity in the growth rate of conventional sources which is good for environment and economy.

Government rules and regulation

Target

As per MNRE there is a target to harness 5336 MW of solar power through grid connected projects and through rooftop in the state.

Land allotment

Government land, if available, permission for use will be given for 30 years or the project life whichever is less. Land to be allocated and transferred to WBGEDCL, which will then lease the land to the developers. For projects on private land developer to arrange the entire required quantum of land through direct purchase/suitable agreement with the land owner. Projects may not require conversion of private/a gricultural land to non-agriculture purposes subject to necessary government orders passed for these purposes. The allotment of land, if any, shall stand cancelled if the power project is not started within the time frame in accordance with the time limits as stipulated in the implementation agreement

Table 2: Generation and growth in conventional generation in the country during 2012-17

Year	Energy generation from conventional sources (Billion unit)	% of growth
2012-13	912.056	4.01
2013-14	967.150	6.04
2014-15	1048.673	8.43
2015-16	1107.822	5.64
2016-17	1160.141	4.72

Incentives

Exemption of demand cut to the extent of 50% of the installed capacity assigned for captive use purpose will be allowed subject to the Regulations of the Commission.

The host and obligated distribution utilities shall provide revolving Letter of Credit from a nationalized bank as a payment security mechanism for all RE projects. Developer/ Government acquiring land to provide an amount not exceeding one per cent (1%) of the project cost for the rehabilitation and resettlement of the persons displaced from the project area. In case of RE project construction in very remote areas, some infrastructural support including approach roads to the project site may be provided at government cost.

Sale of power and tariff

All the electricity generated from the renewable energy projects established within the state of West Bengal are to be preferably sold to the distribution licensees within the state of West Bengal. All transactions between WBSETC/ distribution licensee and the developer involving wheeling or sale of power will be settled on a monthly basis as per PPA and transmission service agreement executed. Power evacuation and grid interfacing. The inter-connection point of the renewable energy generation facility with the transmission and distribution system will be as per regulations of the commission. WBSEDCL and the distribution licensee to jointly create evacuation infrastructure for RE projects i.e. pooling stations. The evacuation infrastructure cost beyond the inter-connection point to be borne by the licensees which is to be recovered from consumers as per suitable pricing framework developed by WBERC. Interfacing equipment and associated switchgear as well as their maintenance to be undertaken by developers at their own cost.

B. Solar power generation

Sunlight based radiation touches base on the outside of the earth at a most extreme power thickness of roughly 1 kilowatt for every meter 2 (kW/m^2). The real usable radiation part fluctuates relying upon land area. Overcast spread, long stretches of daylight every day, and so on in actuality, the sun based motion thickness differs somewhere in the range of 250 and 2500 kilowatt hours for each meter square every year. As may be normal the complete sunlight based radiation is most noteworthy at the equator, particularly in bright, desert regions.

We intend to build the daylight falling span and power caught by the PV-board by making it move reasonably as indicated by sun's position and assessing the required battery bank limit required for the plant amid days of autonomy.

The areas with easier grid access are utilizing grid connectivity, the places where utility power is scant or too expensive to bring, have no choice but to carry out their own

generation. This is known as off-grid electricity. We are studying to design and compare a compatible and cheap off grid system having these benefits –

- Combining various generating options available - hybrid power generation
- Desire for independence from the unreliable, fault prone and interrupted grid connection
- Available storage and back-up options
- No overhead wires - no transmission loss

C. Key considerations for developing solar power plant projects

- Technical considerations and project management
- Grid connectivity and choosing a project area
- Design options and financial feasibility of project
- Structural considerations and maintenance and operation

D. Solar photovoltaic method

Sun powered photovoltaic innovation (SPV) empowers direct change of sun light into power. Photovoltaic cells are utilized to change over light into power. Various solar cells combined make a solar photovoltaic module.

- The electrical output of a PV module is rated in terms of peak watt
- A combination of few solar modules makes a solar array. Solar modules made of solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery
- An inverter is required to convert a direct current (DC) into an alternating current (AC). These systems can be grid connected or off grid power for remote

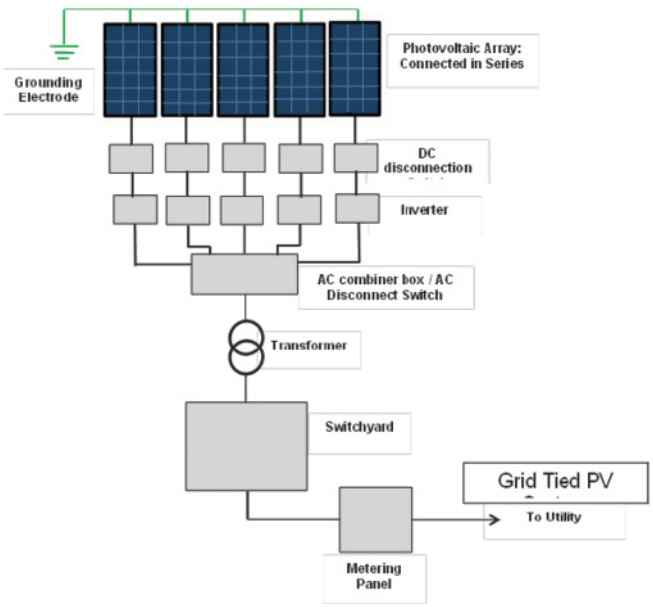

Fig.2: Block diagram showing interconnection of components of solar PV plant

In order to capture maximum solar energy falling over the earth's surface we will primarily focus on two types of installations to capture solar energy:

a. Grid connection
b. Roof-top solar system

Grid connected solar power plant comprises the main equipment and components listed below:

a. Solar PV modules
b. Central inverters
c. Module mounting system
d. Grid connect equipment monitoring system
e. SCADA and cables connectors

Solar rooftop system is an arrangement of interconnected components installed on the roof of a building or work-shed with the purpose of converting sunlight into electricity. The installed solar panels absorb and covert solar energy directly into electricity. The DC electric current generated is converted into AC with the inverter (Fig.3).

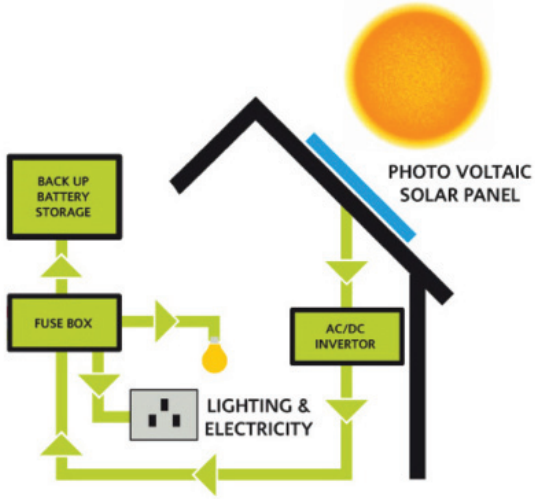

Fig.3: Block diagram showing interconnection of components

E. Dalmia solar power plant – Medinipur

The OCL India Limited is a leading cement producer in eastern India with a capacity of 4.0 million TPA. 1.35 million tonnes per annum (MTPA) clinker grinding and cement manufacturing plant in the name of OCL Bengal Cement Works at Kulapachuria village, Paschim Medinipur, West Bengal. Solar power plant installations are made to fulfill the energy requirement of the plant. They are currently using live-grid connection on government provided lines and not battery storage or backup method is employed (Figs.4 to 7).

Plant capacity 5 MW

(5.5 Megawatt DC) to (5.0 Megawatt AC)

The energy obtained from the plant is measured kWh and the loss observed above is due to conversion of DC currents to AC currents that has to be supplied over the grid.

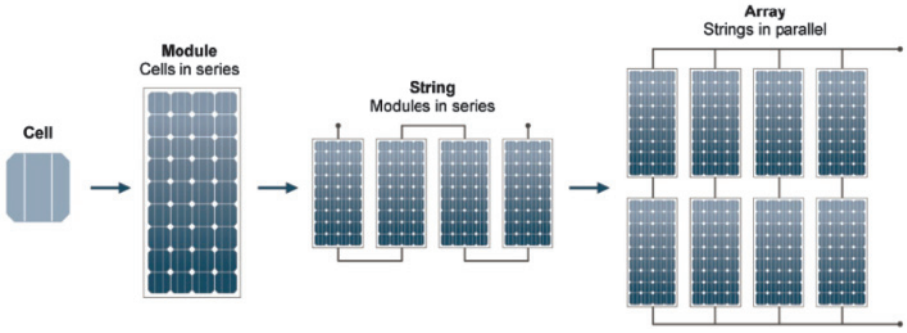

Fig.4: Arrangement of PV panel at Dalmia solar power plant

by the help of "Y" type connector two tables having 20 modules in series each are connected to each other in parallel connection forming array

- Module used has a life of 25 years and the maintenances for the whole system along with its cleaning is done once per month
- In total the plant has 444 tables and the angles which they are fixed with the horizontal level is 28*

Fig.5: Paranometer used at Dalmia solar power plant

Fig.6: Overall Inverter connection at Dalmia solar power plant

Solar panel used is polycrystalline type and has its cost around INR12000

The selection was based on several economical and geographical parameters, also keeping in mind the required efficiency of the panel for 5 MW plant. Polycrystalline panel was selected due to its easy availability, cheap cost, 15% efficiency rate and temperature near this region stays within a non-harming zone.

Table layered formation is used and each table consists of 40 same polycrystalline modules

- 20 modules are connected next to next in series and then

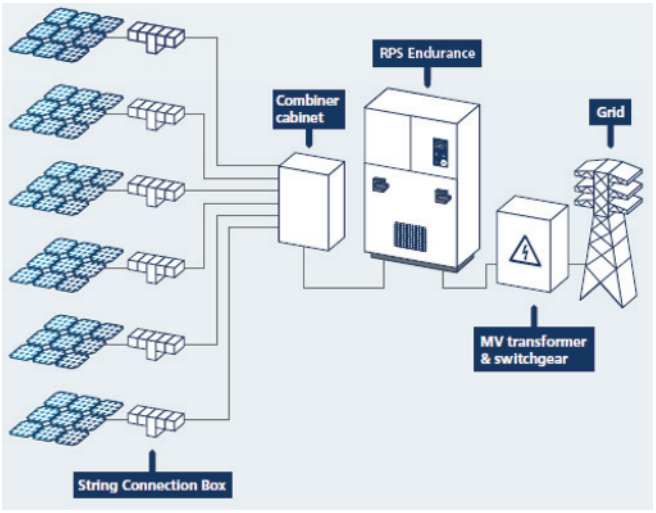

Fig.7: Overall Inverter connection at Dalmia solar power plant

- "Paranometer" is used to measure weather condition, module temperature, wind direction and its speed
- The connection between the panels and from main source to inverters are made from wire cables of capacity of 300 amps
- Solar PV panel used here is from Japan – "Harensolar" – HR 310P

1. Cell technology type: polycrystalline
2. Frame: anodized aluminum alloy, silver
3. Weight: 55 lbs.
4. Product warranty: 10 years material workmanship
5. Performance guarantee: 25 years power output
6. Fire safety classification: Class C

- Technical specifications of PV panel – HR310P

1. Peak power (Pmax) – 310 W
2. Production distribution of Pmax – 0/+5
3. Voltage @ Pmax (Vmpp) – 36.82 V
4. Current @ Pmax (Impp) – 8.42 A
5. Open circuit voltage (Voc) – 45.05 V
6. Short circuit current (Isc) – 9.10 A maximum series fuse – 15A

- Presently there are no cleaners installed in the plant and around 10 people are employed to clean the panels throughout the year in a continuous process
- Present electricity that is being supplied by the West Bengal government costs around Rs.9 per/unit and the solar power plant installed produces about 25000-27000 units of electricity per day throughout the year

There is no battery backup to store power hence the energy that is produced in excess is supplied over the same grid that is provided by the government to them without any track over it.

- Inverters are used for DC voltage to AC voltage conversion. According to output voltage form they could be rectangle, trapezoid or sine shaped. The most expensive, yet, the best quality inverters have output voltage in sine wave.

Inverters connecting a PV system and the public grid are purposefully designed to allow energy transfers to and from the public grid. Central inverters are used in large applications. Many times they can be connected according to the "master-slave" criteria, when the succeeding inverter switches on only in case of enough solar radiation availability or in case of main inverter malfunction.

- Main features of RPS endurance system installed at Dalmia solar plant

1. 500 kW AC rated power at 50°C ambient temperature
2. 15% overload capacity at reduced ambient temperature
3. Active components including power electronics, controls and sensors
4. High reliability due to robust air cooling technology
5. Very compact dimensions allow for easy transportation and installation

F. Diesel power plant

The rapid pace of growth of the Indian economy has been accompanied by a tremendous need for energy which has not been matched by an increase in power generation from state run utilities. The resulting power deficit has triggered the need for captive generation plants at many industrial and commercial units, many of which run on diesel. As of March 2013, India has 314.44 GW of installed captive power generation (renewable and non-renewable) capacity, representing over 15% of the total installed electricity capacity in India. Diesel represents about 40% of the installed captive capacity.

In addition, the recent weakening of the rupee puts further pressure on the price of diesel. To this can be added location and enterprise specific overheads such as the cost of

- Transporting the fuel
- Storing the fuel (and associated loss due to evaporation)
- Security to prevent pilferage
- Uncertainty over delivery of diesel (with corresponding adjustment of operations)

Diesel generated power is one of the most popular solutions to the power deficit in India but the rising cost of diesel coupled with environmental considerations has set the stage for solar power to shoulder greater loads in India's energy intensive enterprises. EAI estimates that the diesel power generating segment will drive the adoption of solar power in industries.

The interest in substituting diesel with solar has been spurred by

- Rapid escalation in cost of diesel (36% since 2014)
- Steep decline in cost of solar power (30% reduction in module prices in 2017-18)
- Favourable policies encouraging the use of solar power (capital subsidies)

G. Site Selection of diesel power plant

Ideal choice for the diesel electric power plants is as near the load centre as possible in order to avoid transmission costs and losses. The factors to be considered for site selection of diesel power plants are:

- Availability of water supply
- Availability of fuel
- Availability of transportation facilities distance from populated area
- Availability of land at reasonable rate and of high bearing capacity to withstand the load of the plant and also vibrations transmitted to the foundation from compressors and diesel engines.

H. Mechanical components of diesel power plant (Fig.8)

1. Mechanical components
- Air intake system
- Fuel supply system
- Exhaust system
- Prime-mover
- Lubricating system

2. Electrical components
- Alternator
- Exciter
- Control room
- Transformers and switchgear

3. Fuel system
- Storage tank and strainers and filters
- All day fuel tank fuel transfer pump

4. Air intake system
- Filters and pipes

5. Exhaust system

- Exhaust pipe and silencer

6. Cooling system

- Water source
- Raw water pump
- Cooling tower

7. Lubricating system

- Lubricant
- (Oil) Tank and oil pump
- Oil filter and oil cooler

8. Prime mover

- Diesel engine and engine start system

9. Fuel supply system

It consists of storage tank, strainers, fuel transfer pump, all day fuel tank, filters and fuel injection pump.

Fuel is stored in a storage tank from which it is pumped through strainer by a transfer pump to a smaller all day tank at daily or short intervals. From this tank, fuel oil is passed through filters to further remove suspended impurities.

The clean oil is injected into the engine by fuel injection pump.

10. Air intake and exhaust system

It supplies necessary air to the engine for fuel combustion. It consists of pipes for the supply of fresh air to the engine manifold. Filters are provided to remove dust particles from air which may act as abrasive in the engine cylinder.

Leads the engine exhaust gas outside the building and discharges it into atmosphere. A silencer is incorporated to reduce the noise level.

11. Lubrication system

It comprises lubricating oil tank, pump, filter and oil cooler. It minimizes wear of rubbing surfaces of the engine.

Lubricating oil is drawn from the lubricating oil tank by the pump and is passed through filters to remove impurities. Oil coolers keep the temperature of the oil low.

- Types of engines

TABLE 3: TYPES OF ENGINES

Two stroke engine	Four stroke engine
The cycle of operation is completed in two strokes.	The cycle of operation is completed in four strokes.
Simple construction.	Complicated construction.
High working efficiency.	Low working efficiency.
Produce more noise.	Produce less noise.
They consume more lubricating oil.	They consume less lubricating oil.
These engines required less space.	These engines required more space.

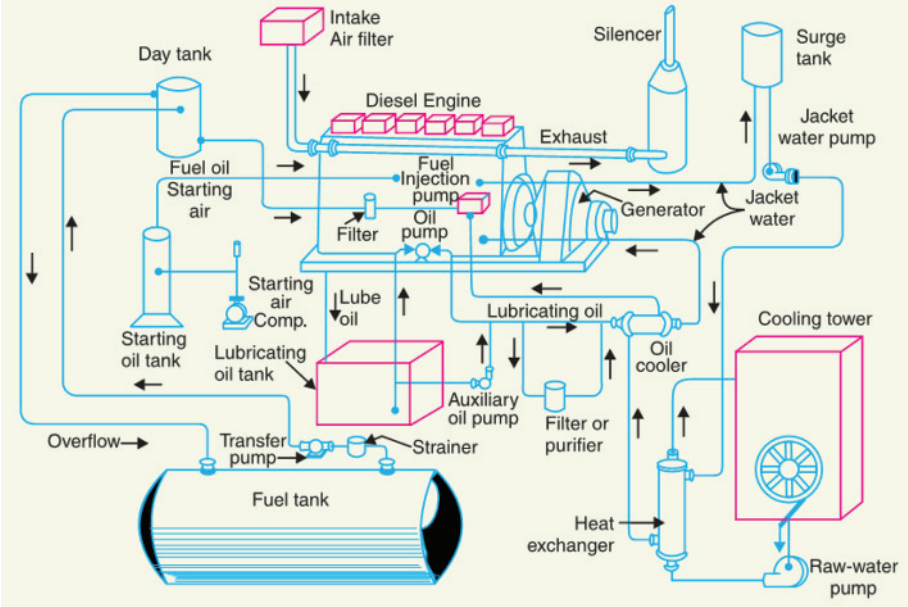

Fig.8: Main components of diesel power plant

I. ADVANTAGES AND DISADVANTAGES OF DIESEL POWER PLANT

- Advantages of diesel power plant
- It can be located near load center. Plant layout is simple.
- The plant can be quickly started and can pick up load in very short time
- There is no stand by losses. The plant is smaller in size than steam power plant for the same capacity
- Less civil engineering work is required. There is no ash handling problem.
- Thermal efficiency of diesel is quite higher than of coal. It requires less operating staff
- Disadvantages of diesel power plant
- The plant cannot work under overload condition for longer times
- Lubrication cost is high. The capacity of the plant is limited.
- High operating cost and noise problem
- Cost of fuel is high and also varies from time to time
- Life is small due to high maintenances
- Environmental effects of fuel
- Thermal plants are considered as the main source of atmospheric pollutants due to their massive emission of sulphur dioxide

TABLE 4: ENVIRONMENTAL EFFECTS OF FUEL

Pollutant	Natural gas–g/Kg	Diesel–g/Kg
CO	31.80	80.047
NO_x	2.4×10^{-7}	0.001
CO_2	2712.6	3168.5
SO_2	-	10.04

Table 5: Fixed cost for installing diesel power plant

	Nomenclature	Qty.	Value (In Rs.)
1	Control panel with voltmeter, ammeter and wattmeter etc.	1	8,000/-
2	Arc welding Transformers with cables	1	9,000/-
3	Safety valve, air and drain cocks complete with 1 HP motor and starter	1	5,000/-
4	Misc. fixed assets (furniture, office and safety equipments)	1	20,000/-
5	Cost of tools, dies and fixtures	1	12,000/-
6	Electrification and installation charges @15% on the cost of plant and machinery	1	8000/-
7	Alternator	1	10,00,000
8	IC Engine	1	70,66,000
9	Coupler and control panel	1	10,000
10	Fuel tank nuts and bolts etc.	1	50,000
	Total fixed capital		80,88,000/-

- These gases lead to several environmental issues
  1. Respiratory effect
  2. Climate change
  3. Acidification

J. Estimation of diesel and solar power plant cost to compare NPV

- Modelling the diesel generator plant
- Initial capital costs(ICC)
  1. Engineering
  2. Procurement
  3. Construction
- Fixed operation and maintenance cost consists of operational personnel salaries, insurances, property taxes
- Variable operation and maintenance cost consists of start-up cost and scheduled maintenance, fuel cost and transmission cost
- Financial aspect - Method to be followed for calculation
- Fixed capital
  1. Land and building
- Built up area of 2000 sq.ft
  2. Plant and machinery
  i. Drills, control panel
  ii. Electrification charges
  iii. Furniture and equipment
- Economic view point over the Dalmia solar power plant

Total number of panels used in the plant will be 444×20, since there are 20 single PV polycrystalline modules on each table. Cost of every panel is around INR12000 and is installed in a rectangular field having an area of 13.2 hectare. Since a gap of 3m is provided between the bench structures which are 222 connected to each other, so due to resultant distance between all panels and width being close to 1m the required length will be around 1.4 times its width.

Now,

- Number of benches = 222 and distance required for its arrangement will be around = 1.4×222 = 310 and similarly for other side we have 178m. The required area will be – 310×178 = 13.5 acre
- Module and inverter cost

  Cost of each PV module = INR12000
- Total cost of 8880 modules used for 5MW plant = INR11 cr
- Cost of one inverter of required capacity = Additional cost of replacement of inverter parts or upgrade of inverter at 12-14 years should be considered.
- Thus the commission includes additional Rs.5 lakhs/MW for requisite replacement or upgrade. The Inverter cost is thereby set to Rs.55 lakhs/MW.
- Total cost of all 8 inverters = 55 L×8+5L×5=4.65 cr
- Design engineering and management cost

  Labour cost for design, engineering and project management Rs.300/hour
- Design, engineering and project management hours/kW-5h
- Total design, engineering project management cost = 5000 ×300×5 = 75 L
- Labour cost for installation - Rs.175/man-hour
- Installation man-hour required for per kW-12 h
- Total labour cost for installation of 5MW power plant - INR 1.05 cr
- Installation hardware cost

  Cost of assembly and hat panel along with ground electrodes will vary year to year according to the present market scenario cost of installation material per kW – INR 15000
- The required plant capacity is 5000 kW so the total cost spent on material for base and structure assembly will be 15000×5000 = 7.5 cr

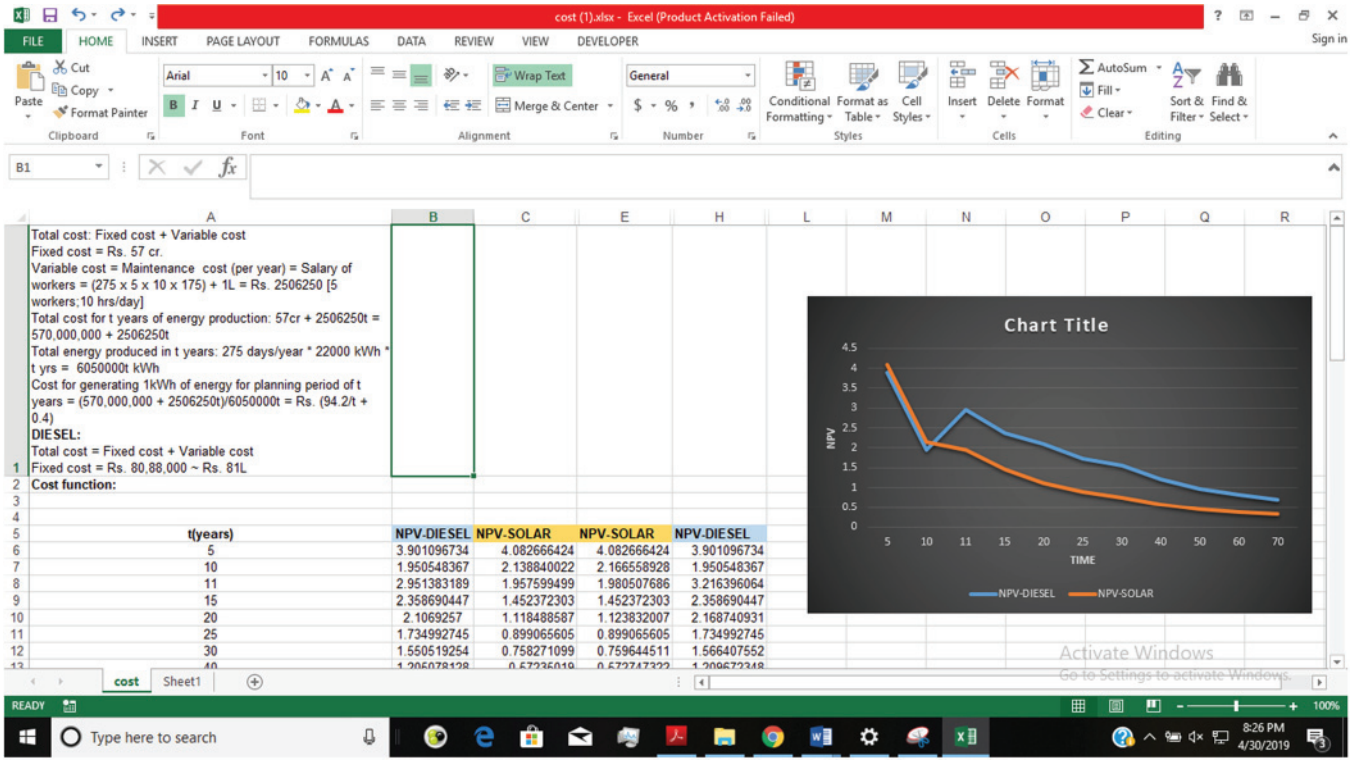

Fig.9: NPV calculation of solar and diesel power plant on Excel

Inverter sizing - size of the inverter used in PV power plant depends on the total peak watts requirement. The inverter must be large enough to handle the total peak watt requirement of the zone at any time. The Inverter size should be 25-30% bigger than the total wattage of the appliances and machines.

- Inverter size = 5 MW×1.3 = 6.5MW
- For Dalmia power plant, we will require 8 invertor having rating (500-850)
- Installation hardware cost
- Cost of assembly and hat panel along with ground electrodes will vary year to year according to the present market scenario cost of installation material per kW – INR 15000
- The required plant capacity is 5000 kW so the total cost spent on material for base and structure assembly will be 15000×5000 = 7.5 cr
- Cost on connection and electrical items
- Durable cables of capacity 300 Amps along with heavy electrical appliances are purchased, ex-transformer system, grid box, wire panel
- Cost for transformers, cables, fuse network boards = INR 5 cr
- Other heavy electrical item
- Cost of packaging and transportation during entire process of design and construction will be INR 2 cr
- Cost of operation and maintenance during the construction phase. The construction will start and modules will need protection from climate or tool damage, for the entire process all the expenses add up to INR 2 cr

K. Conclusion over result comparison of diesel and solar power plant NPV to decide on project selection

Solar

Total cost: Fixed cost + variable cost

Fixed cost = Rs. 57.7 cr.

Variable cost = Maintenance cost (per year) = Salary of workers = (275×5×10×175) + 1L = Rs. 2506250 [5 workers; 10 hrs./day]

Total cost for t years of energy production: 57cr + 2506250t = 570,000,000 + 2506250t

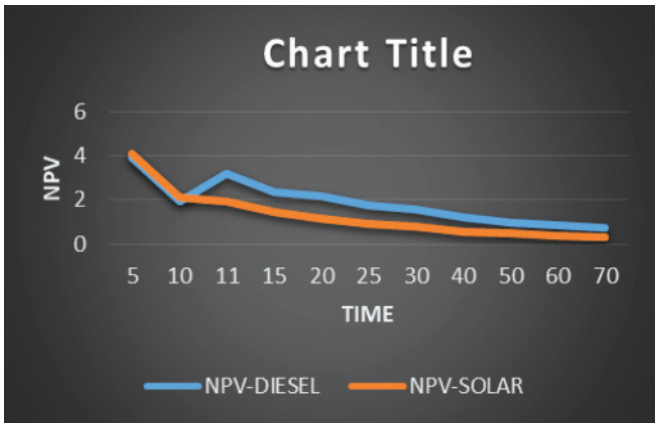

Fig.10: NPV graph of solar and diesel power plant on Excel

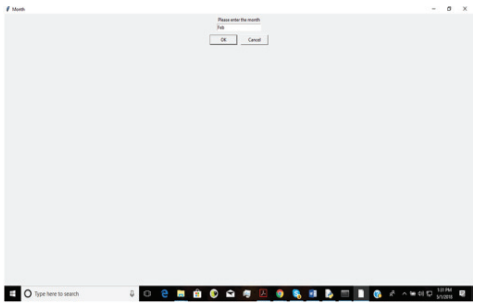

Fig.11: Required entry of the month and the time for required in GMT daylight

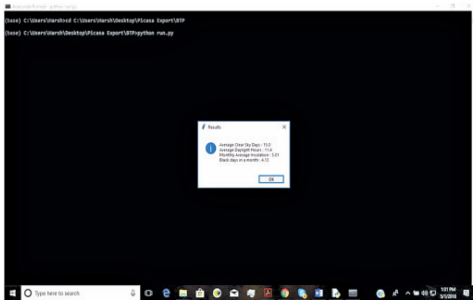

Fig.12: Results of solar geometry at IIT Kharagpur

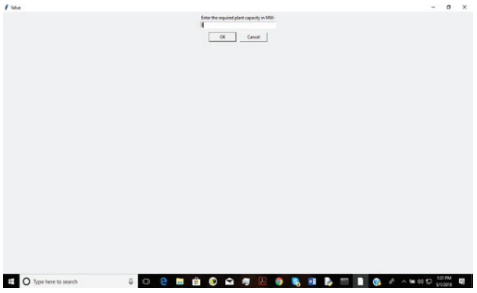

Fig.13: Enter desired solar power generation capacity of plant

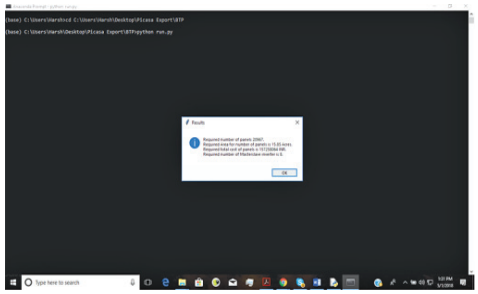

Fig.14: Results of economic study over any rated location wise solar power plant

The discounted rate for the calculation of NPV for both the industries was taken to be 10% and basic equation is used in Excel to calculate it over a period of time required to select which type of project to be proceeded with in the market.

At this rate the solar power plant has a better future for any project that has a life of over 11.33 years. Any project of less than this life duration should not go with the solar power plant unless and untill there goal is to focus more on the environment protection and usage of renewable source of energy.

Total energy produced in t years: 275 days/year * 22000 kWh * t yrs. = 6050000t kWh

Cost for generating 1kWh of energy for planning period of t years = (577,000,000 + 2506250t)/6050000t = Rs. (94.3/t + 0.4)

Diesel

Total cost = Fixed cost + variable cost

Fixed cost = Rs. 80,88,000 ~ Rs.81L

Variable cost = Fuel cost + salary of workers

Salary of workers: Rs. 40000 pm i.e. = Rs.360000 per year

Fuel cost: 18 hrs. * 3 nos. * 30 l/hr. * 65 Rs/l

{We will need 3 nos. of 400-500kVA rated generators which have a fuel consumption of around 30 l/hr.}

= Rs. 189000 per day i.e. 275 * 189000

= Rs. 28957500 per year.

Total variable cost per year = 360000 + 28957500

= Rs. 28993500

Total cost for *t* years of energy production:

= 8100000 + 28993500t

Cost for generating 1kWh of energy for planning period of t years = (8100000 + 28993500t)/6050000t = Rs. (1.4/t + 3.2)

When we use the above derived equation along with NPV function with few more mathematical formulas to automate the process and get the results over a vast time frame as per required for the given project.

L. GUI Interface on Python for the required data of PV Modules based on data from Dalmia Solar power plant and Nasa Corporation

This automated platform provides us with the estimate of cost and area required for desired panel in any area over which we have the NASA solar geometry data being used.

- Screenshots of GUI Interface on Python

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