EAI
catalyzing cleantech in India

Diesel to Solar

Motives and Means

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1. Executive Summary

Solar power has emerged as a viable alternative to diesel power generation for industrial and commercial units that run diesel gensets to meet their power needs. This whitepaper from EAI discusses both the technical aspects of substituting diesel with solar power and the financial benefits from doing so. This whitepaper does not discuss substituting heat energy generated through diesel with solar thermal energy.

The interest in substituting diesel with solar has been spurred by

1. Burgeoning power deficit (**9-10%** of peak demand in 2012 – 8.9% in the North and 18.0% in the South)
2. Rapid escalation in cost of diesel (**46%** since 2010)
3. Steep decline in cost of solar power (**40%** reduction in module prices in 2011-12)
4. Favourable policies encouraging the use of solar power (capital subsidies, soft loans, etc.)

While solar power can provide significant savings when substituting diesel, there are several factors that should be carefully considered to derive optimum returns from the investment in the solar PV plant, such as

1. The nature of loads that can be supported by solar power (heavy starting currents could be an issue)
2. Choice of solar technology that is appropriate to the site and the region
3. PV plant configurations that best serve your needs (with or without batteries, etc.)
4. Issues in integrating solar energy with diesel power (generator capacity and its ability to handle reverse current)
5. Economics of solar PV under different scenarios (IRR of **16.7%** even with conservative assumptions)

These factors will be examined in detail in the following pages, helping you formulate and implement a solar strategy that provides economical and reliable solar power for years to come.

2. Diesel in India

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 34.44 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.

> EAI estimates that India has as much as 13.5 GW installed capacity of diesel based captive power generating plants.

2.1. The cost of diesel

In addition to the environmental cost, diesel also imposes a financial cost to the

1. Consumer – Ever increasing price of diesel
2. Government – Subsidy on diesel and a heavy oil import bill

The deregulation of the diesel price by the government has resulted in a steep increase in the cost of diesel. The price of bulk diesel has been completely deregulated and stands at around Rs. 60 while the retail price of diesel is heading towards complete deregulation with increases of 50 ps every few months.

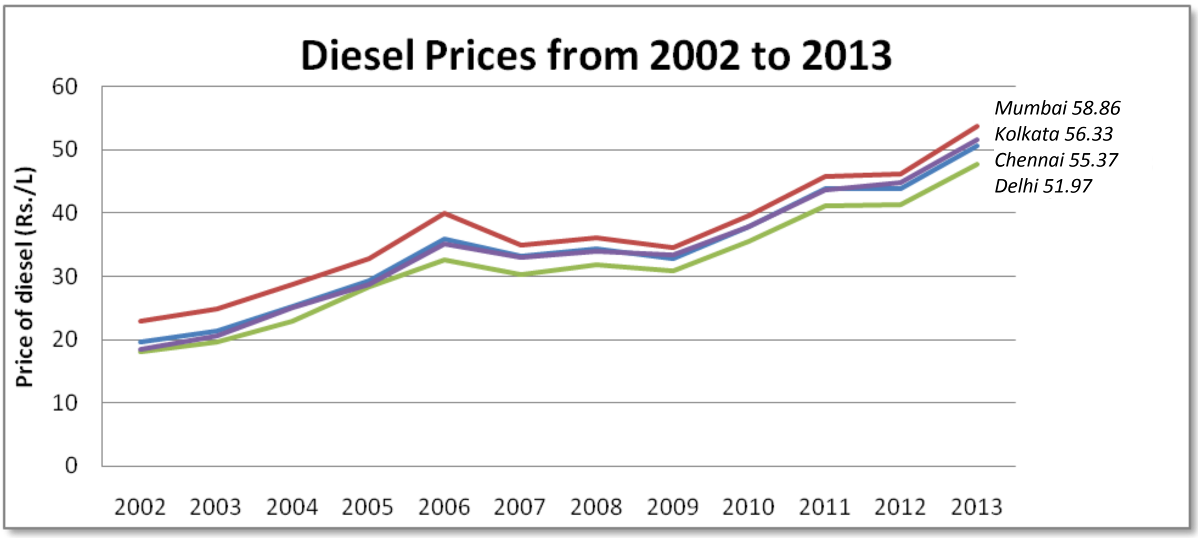

Figure 1: Increase in retail price of diesel

The levelised cost of diesel power (including genset maintenance cost) is about Rs. 16/kWh and could be as high as Rs. 40/kWh in some applications such as rural telecom towers.

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.

Takeaways

- Cost of diesel power (including genset maintenance) varies from Rs. 16/kWh to as high as Rs. 40/kWh
- Transportation, storage, and other costs associated with acquiring and using the fuel can push the per unit cost even higher
- The deregulation in price of diesel coupled with the depreciation in the value of the rupee continue to put upward pressure on the cost of diesel

3. Solar as a source of power

Solar PV systems directly convert the energy of the sun into electricity. India is ideally placed to exploit this energy source with most regions receiving 4-7 kWh/m^2/day of solar radiation depending on location. With 300 sunny days and 3,000 hours of sunshine in a year India receives the equivalent of 5,000 trillion kWh. The map below[1] shows irradiation levels in different parts of the country.

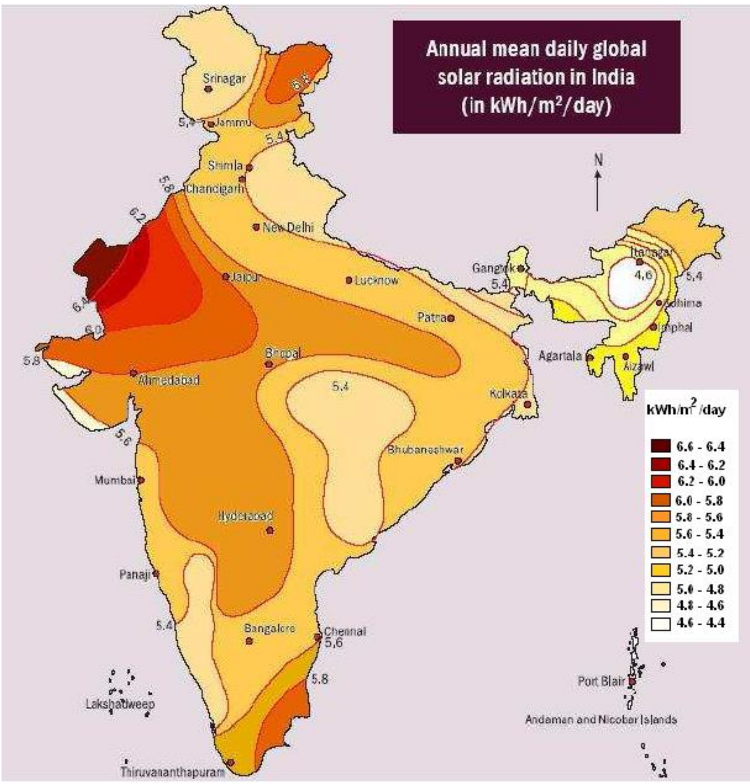

Figure 2: Solar irradiation levels by region

3.1. Components of a Solar PV plant

A typical solar PV system has the following components

a) Modules
b) Mounting structures
c) Inverters
d) Charge controllers
e) Batteries

3.1.1. Modules

Modules (more commonly known as solar panels) are groups of cells that convert light into electricity. There are two kinds of modules

[1] http://www.reeep.org/file_upload/5272_tmpphpJPhOrP.pdf

3.1.1.1. Crystalline silicon

Crystalline silicon (c-Si) solar modules are currently the most commonly used, primarily due to c-Si being stable and delivering efficiencies in the range of 13-19%.

3.1.1.2. Thin-film

Thin film modules are less efficient than c-Si based systems but enjoy a lower thermal coefficient making them more suitable for warmer areas.

> While they enjoyed a significant cost advantage a few years ago, thin film modules are now at par or in some cases even more expensive than crystalline modules. Their thermal coefficient of conversion, however, is lower than crystalline modules making them very suitable for more arid regions like Rajasthan.

Table 1: Comparison Crystalline Silicon vs. Thin Film[2]

Cell Technology	Crystalline Silicon	Thin Film
Module efficiency	13%-19%	4%- 12%
Temperature Coefficients	Higher	Lower (Lower is beneficial at high ambient temperatures)
Inverter Compatibility and Sizing	Industry Standard	System designer has to consider factors such as temperature coefficients, Voc-Vmp difference, isolation resistance due to temperature variances, humidity levels, etc.
Mounting systems	Industry standard	Special clips and structures may be needed. Significant savings in labour cost is witnessed in some cases
Required Area	Industry standard – 8 sq.m/kw	May require up to 50% more space for a given project size

3.1.1.3. Parameters to be considered when selecting Solar Modules

1. Cost
2. Solar panel quality
3. Tolerance
4. Temperature Co-efficient
5. Conversion Efficiency
6. Durability/Warranty
7. System Sizing
8. Certifications[3]

[2] http://www.civicsolar.com/resource/thin-film-vs-crystalline-silicon-pv-modules

a. Off Grid – Crystalline Silicon Solar Panels: IEC 61215/IS14286; Thin Film Terrestrial Solar Panels: IEC 61646
b. Grid Connected – Crystalline Silicon solar panels: IEC 61215 Edition II; Thin Film solar panels: IEC 61646

3.1.2. Mounting structures

Solar panels are mounted on iron fixtures so that they can withstand wind and weight of panels. The panels are mounted to face south in the Northern Hemisphere and north in the Southern Hemisphere for maximum power tracking. The tilt angle of panels is at an angle equal to latitude of that location and the tracking angle is set according to the angle ranges of the solar window.

L&T have utilised an East-West mounting arrangement for solar plants within the tropical zone that takes advantage of the panels' orientation to the sun as it moves between the tropics. L&T claims that the output from the plant is 9% higher (in peak summer) and on average 5% more than from the conventional south-facing installation.

3.1.3. Inverters

Solar panels generate direct current. An inverter converts the direct current into alternating current that can be fed into the facility's electric network. Inverters are a very important component of a solar PV system and are the only major component of a solar plant that is replaced during the lifetime of the plant.

3.1.3.1. Kinds of inverters[4]

a. **Micro inverters –** Can also be called "module" *inverters*. These inverters are typically attached directly to individual photovoltaic modules in order to extract the maximum power from each module.
b. **String Inverters –** Are designed to be wired to a single series string of 8-15 solar modules.
c. **Central Inverters –** A type of string inverter used in large scale applications. They offer easier installation and higher efficiency than smaller string inverters.

Inverters can further be classified as

a. Off Grid
b. Grid Tied
c. Hybrid

Off grid inverters are primarily used in small scale and remote installations where the grid is not present. Grid tied inverters work in conjunction with the utility grid with safety features that typically turnoff the solar system in the event of a power outage.

[3] http://www.sustainabilityoutlook.in/content/want-buy-solar-panel-%E2%80%93-key-things-be-considered#sthash.KNjaujKX.dpuf

[4] http://blog.syndicatedsolar.com/bid/52963/Different-Types-Of-Solar-Inverters

Hybrid inverters (also known as Bidirectional or magical inverters) are a one system solution for a complete solar PV system. They can automatically manage between 2 or more different sources of power (grid, diesel, solar). They have inbuilt charge controllers, MPPT controller, Anti Islanding solutions, DC and AC disconnects and other features like automatic on/off of the diesel generator, automatic data logging, and various kinds of protection for the different components of the system, making them ideally suited for solar plants that act as a diesel substitute.

There are many variables that can affect the efficiency of a solar energy inverter. With every manufacturer developing inverters with different MPPT (Maximum Power Point Tracker) ranges, enclosures, temperature variances, monitoring abilities, etc., it becomes critical to choose the right kind of inverter for your plant to maximise your returns.

3.1.4. Charge controllers

The charge controller is required to regulate supply of charging current from the solar system to the batteries. They improve battery performance by protecting the battery from overcharging. The charge controller can be separate unit or integrated with the inverter. There are two kinds of charge controllers

a) Pulse Width Modulated (PWM)
b) Maximum Power Point Tracking (MPPT)

3.1.4.1. Pulse Width Modulated (PWM)

This type of charge controller operates by sending out pulses of charge which helps in uniform distribution of the charges on the plates of battery. These are modulating the pulse widths and slopes of the voltage and current levels and also their rate of change. They operate in three phases:

i. Bulk phase: The voltage gradually rises to the bulk level (usually 14.4 to 14.6 volts) while the batteries draw maximum current. When bulk level voltage is reached the absorption stage begins
ii. Absorption phase: The voltage is maintained at bulk voltage level for specified times (usually an hour) while the current gradually tapers off as the batteries charge up
iii. Float phase: After the absorption time passes the voltage is lowered to float level (usually 13.4 to 13.7 volts) and the batteries draw a small maintenance current until the next cycle

3.1.4.2. Maximum Power Point Tracking (MPPT)

They constantly track and maintain the optimum voltage and current to charge the battery. They match the output of the solar panels to the battery voltage to ensure maximum charge (amps).

A 100 watt solar panel rated at 6 amps at 15.5 volts will be able to charge a 12.4 volt battery at 75 watts (6 amps times 12.4 volts). The MPPT module extracts the full 100 watts from the panel regardless of battery voltage by utilising a DC-to-DC converter to charge the battery by delivering 8 amps.

Table 2: Comparison of PWM and MPPT Charge Controllers

Parameter	PWM	MPPT
Capacity	a) Available only up to 60 Amps b) Can take only certain input voltages: 12V,24V,48V c) Limits solar panel output voltage	a) Available up to 80 Amps b) Can take a varying range of input voltages and hence, reduces losses in transmission and provides flexibility in solar module configuration
Cost	Inexpensive; <$250	Almost thrice that of PWM
Efficiency	60-80% (approx. 68%)	Increases charging efficiency to up to 30% Peak efficiency: 99%
Warranty and life	Low	Much higher than PWM

3.1.5. Batteries

Batteries are an optional component in solar power systems used to provide backup power when the sun isn't shining or to augment the solar systems when the output is low (such as when clouds pass by). Batteries come in several voltages, but the most common varieties are 6 Volt and 12 Volt. Solar PV systems typically use lead acid batteries which are of three types

a) Liquid vetted or flooded
b) Sealed (VRLA – Valve Regulated Lead Acid)
    a. Absorbed Glass Mat (AGM)
    b. Gel Cell

3.1.5.1. Liquid vetted or flooded

Flooded lead-acid (FLA) batteries are the most cost-effective variety. They require maintenance that involves monitoring voltage and occasionally replenishing the water in the battery. Additionally, FLA batteries vent hydrogen under heavy charging so they must be stored in a ventilated enclosure.

3.1.5.2. Sealed (VRLA – Valve Regulated Lead Acid)

Being sealed, they do not require watering, nor do they typically vent any gasses. As the electrolyte cannot be refilled, controlling the rate of charge is very important.

3.1.5.2.1. Absorbed Glass Mat (AGM)

Absorbed Glass Mat batteries use a fibreglass-like separator to hold the electrolyte in place. These are more expensive and more sensitive to overcharging than FLAs and offer the best vibration and impact resistance.

3.1.5.2.2. Gel Cell

Gel cell batteries use a thickening agent to immobilise the electrolyte. The cell will continue to function even if the container is cracked. These are the most expensive of the three types.

Table 3: Comparison of batteries

Parameters	Flooded	Sealed	
		AGM	Gel
Cost	Cost-effective, least cost per ampere hour	Nearly three times the cost of flooded batteries	2-3 times the cost of flooded batteries
Maintenance	Requires maintenance	No/negligible maintenance required	
Size and placement	Requires ventilation; mostly needs to be kept outdoors which hinders working at ambient temperature	Sealed batteries are advantageous in situations with space constraints that require you to store your batteries in unusual orientations or where venting is not possible	

3.2. Solar Plant Configurations

Designing the right kind of solar power plant for your application is critical as cost, reliability, and flexibility are determined by the design.

Solar power plants have three primary configurations

a) Stand-alone PV system
b) Grid-tied PV system
    a. Grid-Interactive Without Battery Backup
    b. Grid-Interactive With Battery Backup
c) Hybrid Solar PV system

3.2.1. Stand-alone PV system

Stand-alone PV systems operate independent of the electric utility grid, and are generally designed and sized to supply specific DC and/or AC electrical loads. This can be

3.2.1.1. Without Batteries

The DC output of the module or array is connected directly to a DC load. As there is no battery the load only operates during sunlight. An MPPT Charge Controller may be used to maximise the output from the array in some applications like positive-displacement water pumps.

3.2.1.2. With batteries

This system uses a hybrid inverter with charge controller to charge the batteries during daytime and power the load. The batteries supply the inverter when sunlight is not available. Priority is given to charging over fulfilling the load demand beyond a level of battery consumption.

3.2.2. Grid-tied Captive Power Plant

A grid-tied solar power system (also referred to as grid-intertied, or on-grid or utility-interactive) produces solar power that is fed to the load interactively with the utility grid, hence the term grid-tied, as the system is tied, literally, to the grid.

The critical component in a grid-tied plant is the inverter or power conditioning unit (PCU) which disconnects from the grid in the event of utility outage to prevent power generated by the solar panels from flowing back into the grid. This feature, known as anti-islanding function, is required in all grid-tied systems to protect utility personnel working on the grid during an outage.

3.2.2.1. With batteries

These systems are usually smaller in capacity, typically under 20 kW, due to the high cost of batteries. The battery is used to keep “critical load” circuits operating during a utility outage. When an outage occurs, the unit disconnects from the utility and powers the critical load circuits which are wired from a subpanel that is separate from the rest of the electrical circuits.

3.2.2.2. Without batteries

This system is much simpler and primarily consists of the solar array and a grid-tied inverter. It is simple to install and achieves the highest efficiency as the introduction of batteries lead to efficiency losses but excess power generated cannot be fed to batteries. If net-metering is not available in the region the surplus power cannot be monetised.

3.2.3. Hybrid Solar PV system

Systems with more than one source of power are called hybrid systems. Having multiple sources of power ensures availability of power even when the sun isn’t shining, or greater availability of power than from the solar panels. There are different kinds of hybrids, such as solar-wind hybrid, solar-biomass hybrid, etc., but this whitepaper will focus only on the solar-diesel hybrid.

Solar PV systems are often coupled with diesel generators due to the intermittent nature of solar power, limited solar plant capacity, or because the load might require heavy inrush current.

The diesel generator supplies the excess load during daylight hours and the entire load as well as charges the battery when the sun isn’t available. This system strikes an optimum balance between solar capacity utilisation, battery discharge levels, and diesel consumption.

Takeaways

- Most regions in India receive 4-7 $kWh/m^2/day$, making the country ideally suited for solar energy
- Solar energy systems need careful choice of technology in
  - Modules – Thin film or Crystalline technologies are chosen based on site conditions and cost/financing constraints
  - Mounting structures – East-West layout may provide more generation within the tropical zone
  - Inverters – Hybrid inverters are the preferred solution as they automatically manage two or more power sources, such as diesel and solar
  - Charge Controllers – MPPT controllers offer much better performance and features than PWM but can cost three times as much
  - Batteries – Flooded batteries are the least expensive but require maintenance and ventilation. Absorbed Glass Mat and Gel Cell are much more expensive and sensitive to overcharging but require no maintenance or ventilation
- Solar-diesel hybrid systems are very popular in India as the diesel generator overcomes some of the limitations of current PV technology

4. Solar as a substitute for diesel

Solar power represents an opportunity to achieve energy security using a clean source of energy at an economical cost, but there are several challenges to be overcome as well. A brief comparison with diesel power is provided below:

4.1. Comparing diesel power with solar

Table 4: Comparing Diesel Generator with Solar PV

Parameter	Diesel generator	Solar PV System
Financial		
Capital investment	Relatively low	Relatively high. The initial cost of the system is more expensive than the diesel generator, and the inverter will have to be replaced during the lifetime of the plant (frequency of replacement depends on maintenance). It should be noted that initial cost has seen a steep decrease over the last few years
Fuel cost	High, and continues to increase	Nil – A PV plant allows the consumer to fix energy cost for the next 25 years
Operating cost	High, due to • Ensuring supply of diesel • Transport and storage of diesel • Biannual servicing • Replacement of parts due to wear and tear	Low. Solar PV plants have few moving parts so they don't suffer from wear and tear. Recurring charges can include • Washing of panels (dust reduces the power output) • Checking and replacement of wiring and other electrical components • Inverter maintenance • Battery packs, if used, have greater maintenance requirements
Surplus power	The generator can be throttled down (to some extent) or turned off if the load is less than generating capacity	As solar PV plants almost entirely comprise fixed costs there is very limited saving potential from turning off the plant. Until net-metering is introduced in India the surplus power generated by a captive solar plant cannot be monetised
Operational		
Space required	The generator doesn't occupy much space, but requires a more secure	Solar panels require more space for installations. While they can be

	location for operations and maintenance. Diesel fuel requires space based on the amount of fuel to be stored. Special storage considerations may be necessary due to fire hazard, evaporation loss, and pilferage.	installed on unutilised rooftops, space constraints can restrict the capacity of the plant that can be installed. Additionally, the installation area should be shade-free throughout the year.
Noise & Vibration	Moderate to high (depending on damping materials used)	Nil
Emissions	High – exposure to diesel generator exhaust can lead to health hazards	Nil
Technical		
Reliable power	Fairly reliable. A genset can only be run a certain number of hours continuously and suffers from wear and tear, which impose limitations in addition to availability of fuel	Intermittent. Solar generation depends on sunlight therefore there is no power delivery during night time or on cloudy days. Variation in power output can be experienced during the day as well based on weather conditions. Battery packs can be used to partly offset these disadvantages, but will add to the cost of the system.
Loads supported	Diesel gensets can handle a wider variety of load, and have greater tolerance for starting current requirements.	Solar PV plants may not be able to handle starting current requirements, depending on the size of the system and the nature of load. This can be partly offset by • Battery packs • Dividing the load into critical and non-critical portions with critical loads primarily supported by the solar system

4.2. Designing a Captive Solar PV Plant

There are 7 crucial steps involved in designing a captive PV installation

- Scoping the project
- Calculating the amount of solar energy available
- Surveying the site
- Calculating the amount of energy needed
- Sizing the solar PV system
- Component selection and costing
- Detailed design

4.2.1. Scoping the project

Lay out your objectives from the plant, such as supporting your entire lighting load, or duration of backup required in the event of a power outage.

4.2.2. Calculating the amount of solar energy available

The insolation level, or the amount of sunlight on the installation area (expressed as $kWh/m^2/day$), is measured to determine the number of solar panels required. A rule of thumb measure is 1 W of PV panel will produce 4 Wh of electricity per day (at crystalline panel efficiencies). This is only an average and will vary with the location of the plant.

> It is important to estimate the insolation over a period of time – heavy mist in winter may significantly reduce the amount of power that can be generated.

4.2.3. Surveying the site

The survey conducted by the PV plant designer will check for

- Shade free area available (approximately 8 m^2 is required for 1 kW of solar PV)
- Azimuth – the orientation of the roof. South facing is ideal (in the Northern Hemisphere)
- Solar access – percentage of time the PV array receives the full, unshaded power of the sun

4.2.4. Calculating the amount of energy needed

The system load is determined by determining the wattage of the devices that will be powered by the solar system and the number of hours that load will need to be supported. The amount of energy required can be optimised by using energy conserving devices. The cost can be optimised by considering whether heavy/variable load should run on solar power

4.2.5. Sizing the solar PV system

The size of the solar PV system is calculated by considering

- The number of panels needed to meet the energy requirement based on the site insolation levels and panel rating. A 30% safety factor is usually added to the energy requirement
- Battery size, based on the number of hours of autonomy, depth of discharge, and battery efficiency
- Inverter size, based on the total wattage of all supported devices with a safety factor of 45%
- Mounting structures to bear the panels' weight even under high wind
- Sizing for miscellaneous components such as wires, connectors, switches, fuses, etc. that could fail if they are not correctly rated for the application

4.2.6. Component selection and costing

The solar PV plant is expected to last for 25 years. Therefore suppliers and products should be selected not just be considering price alone, but also considering the technical specifications, reliability, warranty periods, etc.

4.2.7. Detailed design

The detailed design is the more actionable form of the captive solar PV installation. Data collected from the previous 6 steps is accumulated, a layout of the installation is prepared on paper, and obvious engineering fallacies are removed.

4.3. Designing a Solar-Diesel Hybrid Plant

Due to some of the limitations of current solar technology, solar-diesel hybrids are very popular in India where the solar system operates in tandem with a diesel generator, supporting a wider variety of loads and achieving diesel savings. While this does present a best-of-both-worlds solution, it should be implemented by an experienced and knowledgeable installer due to several issues that can be encountered in integrating solar with diesel which can have a direct impact on savings possible and the returns from investment.

4.3.1. Optimising power supply using a solar-diesel hybrid

The critical part in designing a solar diesel hybrid plant is determining the load mix between solar and diesel power. While the theoretical maximum savings are achieved by using the largest possible solar installation to minimise the load supported by diesel, this may not be the optimal configuration in practical applications due to

4.3.1.1. Frequency and power quality

The frequency of the output AC power can vary beyond acceptable levels as the loading factor[5] of the diesel generator varies (as a result of introducing an intermittent solar power source into the mix), reducing the quality of power. Some modern day devices require high quality power to operate.

4.3.1.2. Reverse Current Flow

Some reverse current will flow into the diesel generator when the output of the solar power exceeds that of the load demand. There is a threshold beyond which this reverse flow causes the diesel generator to trip, removing the reference voltage for the solar plant and causing the system to break down.

4.3.1.3. Efficiency and Minimum Loading

Running a generator at loads below its minimum load factor[6] for prolonged periods affects its efficiency which in turn impacts fuel consumption, maintenance costs, and useful life. The generator may operate below its minimum load if a sizeable solar system is integrated into the supply and results in decreased lifecycle savings of the solar-diesel generator system.

Due to these reasons it is recommended that the solar system size be limited to 25% of the diesel generator set capacity i.e. if the diesel generator capacity is 1,000 kVA, it is recommended that the solar system be limited to 250 kW at most. Specific vendor solutions may permit higher solar system size integration with diesel generators.

[5] Load factor refers to the demand load/capacity. Therefore, for a load of 400 kW and a DG capacity of 1000 kVa (800 kW) the load factor becomes 50%.

[6] Generator suppliers usually specify a minimum load factor below which the life of the lubricant, generator efficiency fall and the engine starts to slobber (emit black smoke).

4.3.2. Prominent solar-diesel hybrid installations

Some of the prominent solar-diesel hybrid installations in India include

- **Scope International –** SunEdision has put up a 100-kW solar plant on roof of building of Scope International in Chennai. Scope is Standard Chartered Bank's captive BPO and is headquartered in Chennai (more here)
- **Alpine Knits –** This Spinning Mill in Tirupur district of Tamil Nadu has the distinction of having a MegaWatt(MW) Scale, Roof Mounted, Grid-Connected Solar power plant with unique DG synchronization capabilities; the first of its kind in India, and only the second in the World (more here)

Takeaways

- The initial cost of a solar PV plant is higher than a diesel generator, but more than pays for itself through savings in fuel cost
- Solar PV plants have few moving parts and therefore require very little maintenance
- Without net-metering, surplus power from PV plants cannot be monetised
- PV plants do not generate power during non-daylight hours or on cloudy days
- A PV plant should be limited to 25% of diesel generator capacity in a hybrid plant to avoid solar-diesel integration issues

5. Favourable Policies

Both central and state policies have been announced in recent years to promote the adoption of solar power. We provide highlights of policy support below.

5.1. Jawaharlal Nehru National Solar Mission (JNNSM)

The Jawaharlal Nehru National Solar Mission (JNNSM) changed the solar landscape in India. Phase 1 of the mission providing a slew of incentives for grid connected, off-grid, decentralised solar applications, rooftop and small solar plants. Captive solar plants fall under the off-grid and decentralised applications and are eligible for Central Financial Assistance, summarised below.

Table 5: JNNSM - Salient Features

			GOI Support		
S. No.	Category	Maximum capacity	System with battery backup	System without battery backup	Interest Subsidy
1	Individuals for all applications	1 kWp	Rs.57/watt or 30% of project cost whichever is less	Rs.30/watt or 30% of project cost whichever is less	Soft loans @5% p.a.
2	Individuals for Irrigation, & community drinking water applications	5 kWp	Rs.57/watt or 30% of project cost whichever is less	Rs.30/watt or 30% of project cost whichever is less	Soft loans @5% p.a.
3	Non-commercial/ commercial/industrial applications	100 kWp	Rs.51/watt or 30% of project cost whichever is less	Rs.30/watt or 30% of project cost whichever is less	Soft loans @5% p.a.*
4	Non-commercial/ commercial/industrial Mini-grids	250 kWp	Rs.51/watt or 30% of project cost whichever is less	Rs.27/watt or 30% of project cost whichever is less	Soft loans @5% p.a.*

*for commercial/ industrial entities either of capital or interest subsidy will be available[7]

There are further incentives available under the scheme, such as for special category states and rural SPV implementation.

It should be noted, however, that there have been many issues faced in collecting subsidies under the scheme.

[7] http://mnre.gov.in/file-manager/UserFiles/amendmends-benchmarkcost-aa-jnnsm-2013-14.pdf

Phase 2 of the mission (which is yet to be cleared) has stressed rooftop PV, envisaging up to 1 GW of off-grid and grid connected projects.

The Solar Energy Corporation of India (SECI) has allocated 11.1 MW of rooftop PV projects in 6 cities – Delhi, Bhubhaneswar (1 MW each) in Orissa, Gurgaon in Haryana, Raipur in Chhattisgarh, Bangalore in Karnataka and Chennai in Tamil Nadu (2 MW each). SECI will incentivise the rooftop project owners by giving 30% capital subsidy.[8]

5.2. State-specific policies

Several states have come forward with state-specific solar policies that provide a fillip for captive solar PV. A snapshot of salient features of different state policies is provided here.

Table 6: State Solar Policies

	Gujarat	Kerala	Tamil Nadu	Karnataka	Rajasthan
Capacity addition targeted	25 MW	10 MW	350 MW	250 MW	50 MW
Rooftop Segment	80% Government 20% Residential	Residential Only	Domestic and commercial	All Buildings with rooftop space	All Buildings with rooftop space
Project Owners	Rent a Roof type	Owner Own	Owners Own/ Rent a Roof type	Rent a Roof type	Owners Own/ Rent a Roof type
Incentives available	1. 5 MW rooftop programme on the PPP model in the capital which is now extended to about 5 more cities and towns 2. Monthly incentive of Rs.3/kWh for the roof owner	1. 30% Subsidy from MNRE + Rs.39000/system from the Government of Kerala	1. GBI (Generation Based Incentives) which are Rs. 2/kWh for first two years and Rs. 1 per kWh for next two years, and there after Rs. 0.5 per kWh for subsequent two years 2. Net metering allowed at	Tariff of Rs 3.40 per KWh along with Net Metering facility plus any other incentives available to rooftop systems	Tariff-based competitive bidding

[8] http://mnre.gov.in/file-manager/UserFiles/draft-jnnsmpd-2.pdf

			multiple voltage levels		
Offtake/Power Purchaser	State Distribution Agency	Captive home use	Captive and State Distribution Agency	State Distribution Agency	State Distribution Agency
Base Requirement	Various sizes of SPV systems ranging from 500 KW, 100 KW, 50 KW, 20 KW, 10 KW, 5 KW, 1 KW or more	Minimum system Size 1kW		Developers should guarantee a minimum of 450 units a year for half kW systems and 900 units for 1 kW.	Small solar power plants connected at 11 kV of a minimum of 1 MW

In addition, Maharashtra, Haryana and Chhattisgarh are also in the process of releasing solar rooftop policies.

5.3. Accelerated depreciation

Accelerated depreciation of 80% is available for captive solar PV plants.

5.1. Renewable Energy Certificates (RECs)

The captive solar PV plant is eligible to earn RECs on any power that it generates that is not used to satisfy a solar purchase obligation. 1 MWh of generation earns 1 REC, which can then be traded through the power exchanges with entities that need to satisfy a renewable purchase obligation. This forms an additional source of revenue for the PV plant operator.

5.1.1. A note on RECs

The REC mechanism depends on the Renewal Purchase Obligations (RPOs) of obligated entities, such as utilities, to create a demand side “pull” to complement the supply side “push”. The REC mechanism comes with the risk of uncertainty of demand and pricing, due to

- **Non-enforcement of RPOs –** Obligated entities are currently not penalised for failing to meet their RPOs. This results in reduced demand for RECs and only about 50% (or even less) are sold (there is a floor price of Rs. 9,300 per solar REC which prevents the price from reducing until supply meets demand)

- **Future of REC price –** There is uncertainty on the pricing of RECs beyond 2017. EAI estimates that Solar REC prices will be similar to current prices of non Solar RECs – a band of Rs. 1,500 to Rs. 3,900 per REC – between 2017 and 2022.

Takeaways

- The Jawaharlal Nehru National Solar Mission (JNNSM) provides attractive incentives such as capital subsidy of 30%
    - Issues have been faced in collecting subsidy
- Several states have announced state specific solar policies, and more states are formulating their own solar policies
- Accelerated depreciation of 80% is also available
- Captive PV plants are eligible for RECs but lack of enforcement of RPOs and uncertainty in price beyond 2017 should be considered

6. Economics of Captive Solar PV

The primary motivation to use solar PV as a substitute for diesel is the lower cost of generation. Therefore the economics of the plant are of vital importance. We will examine the capital costs of a captive plant and evaluate its financial performance against diesel power.

6.1. Capital cost of Solar PV

A 100kW solar PV plant without batteries has been used as the basis of comparison with diesel as that is the maximum up to which the MNRE subsidy is available.

Due to the high cost of battery storage, systems beyond 50 kW typically do not use battery backups, and where used, very minimal battery backup is employed.

6.1.1. Cost break up of a 100 kW solar captive system – without batteries (grid-tied)

Table 7: Capital cost of a Solar PV system

Item	Rs. Lakhs
PV modules	31.5 - 33.8
Inverters	7.7 - 8.3
Balance of System (transformers, cables and wires, etc.)	23.8 - 25.5
Installation (civil & general work)	6.3 - 6.8
Total	**70.0 - 75.0**

6.2. Assumptions used in calculations

As there are many factors that vary from site to site and project to project, the returns from substituting diesel with solar were calculated based on a few assumptions

6.2.1. General assumptions

- The diesel genset being used is sized so as to meet the demands of a 100 kW load
- Revenue earned is the cost of diesel saved over 300 days of operation of the solar PV plant
- The entire output of the solar PV plant may not replace diesel. The replacement will depend on the timing of power cuts, loads used, and output from the solar plant. Therefore some of the PV output will replace grip power which is cheaper than solar power. To account for this a weighted average is used

6.2.2. Scenario-specific assumptions

We will calculate returns based on a conservative/pessimistic scenario where only 10% of diesel consumption is replaced by solar power.

PV Plant assumptions	
Total Capacity (kW)	100
Capital Cost (Rs. Lakhs)	75
Capital Subsidy (Rs. Lakhs)	22.5
Effective Capital (Rs Lakhs)	52.5
Equity (%)	100
Discounting factor (15%)	15
O & E Expenses for 1st year (% of project cost)	0.75
O & E Cost Inflation (%)	5
Accelerated Depreciation (%)	80
Degrading (%)	1
Derating (%)	90

De-rating: Even if a system is supposed to produce 1,00,000 W, it rarely produces that. There are many steps in processing the power (efficiency losses in the inverter, cables, and other operations), that eat up about 10% of the power produced by the module.

Degradation: Systems degrade over time – and this includes the PV modules themselves. Most assume that degradation is between 0.5% and 1% per year. Most modules are warranted to perform up to 90% of their rated power for 10 years, and 80% of their rated power for 25 years – numbers that aren't far off from 1% annual loss.

Diesel generator assumptions	
Genset total capacity (kW)	100 (125 kVA)
Cost of diesel (Rs./Litre)	60
Annual diesel price escalation (%)	3
Fuel consumption (Litres/kWh)	0.294

6.3. Returns from the Captive Solar PV Plant

For the scenario detailed above, the returns are calculated as

Project Economics for the given inputs	
Project IRR	16.7 %
Payback Period (Without discounting)	6.41 Years

Even under pessimistic[9] assumptions, the plant provides Project IRR of 16.7% which is quite favourable. The length of the payback period may deter some investors but it should be kept in mind that these are the returns under a harsh set of assumptions.

[9] For a more in-depth discussion of the economics of captive solar PV with analysis under other scenarios, please refer to EAI's Replacing Diesel with Solar report.

Several other costs associated with diesel, such as transportation and storage costs, have not been considered which would make the returns more favourable even under a conservative scenario.

6.4. The BOO(T) Model

The Build Own Operate (Transfer) model is an option that can be considered by enterprises that are hesitant to invest the large amounts that are required initially to install a captive PV plant.

> The BOO model allows energy consumers to buy the energy generated by the solar plant, just as they buy power from the utility, rather than buy the plant itself. A variation of the model allows the plant to be Transferred (T) to the consumer at the end of a certain period.

The system provider bears the capital expenditure for the solar plant provided the customer satisfied certain criteria (such as credit rating or provides a bank guarantee) and enters into a power purchase agreement (anywhere between 5-15 years) with the provider.

Takeaways

- The cost of a 100 kW solar PV system is Rs. 70-75 lakhs
- Even with conservative assumptions, Project IRR of 16.7% with a payback period of 6.41 years can be achieved
- Due to the high cost of batteries, systems beyond 50 kW either do not use batteries or employ minimal battery backup
- A BOO(T) model can be considered where the energy produced by the plant, rather than the plant itself, can be purchased

7. Conclusion

Solar PV plants can provide a viable solution for firms grappling with the power shortage and crippling cost of diesel. While complete replacement of diesel generators might not be possible under current solar technology, significant savings can be achieved through partial abatement of diesel using solar-diesel hybrid systems. Achieving favourable returns from the project, however, involves careful evaluation of several factors

- The potential to generate solar energy at your location – e.g., mist in winter can limit solar power production
- Constraints that limit the size of solar PV plant that can be installed – 1 kWp of crystalline solar panels typically require 8 m^2 of shade-free area and generates 4 kWh of power per day (on average)
- The nature and duration of loads to be supported – heavy inrush current from equipment using electric motors may require diesel generator support
- The configuration of the solar plant
- Timings of load shedding that affect the amount of solar power available to abate diesel
- Issues with integrating solar plants with diesel generators – We recommend limiting the solar plant capacity to 25% of generator capacity (subject to some vendor specific solutions)
- Whether buying the solar energy alone would be better than buying the solar plant
- Identifying capable and effective vendors

Even under a conservative scenario, IRRs of **16.7%** with payback period of **6.4** years are possible from captive PV plants. Financial returns can be improved through a thorough understanding of the factors that affect solar PV performance and careful system design and integration.

7.1. Want to know more?

For a more detailed discussion on substituting diesel with solar, please refer to EAI's Replacing Diesel with Solar report. This exhaustive study includes in-depth discussions on returns from solar PV plants under multiple scenarios, design of solar PV plants, technology options, applications of solar PV, and the breadth and depth of opportunities in this sector.

8. Replacing Diesel with Solar Report

Looking to save on diesel by moving to captive solar power? EAI's **Replacing Diesel with Solar** report is a one-stop resource for all the information you will need to assess, implement, and profit from substituting diesel with solar. Within this report you will find

- Captive solar PV technology and components
- Constraints in replacing diesel with solar
- Government incentives and regulations
- Inputs on capital and operational costs and financial scenario analysis
- Case studies for those businesses that already use solar for captive power
- Financing options
- Vendors, component suppliers, and system integrators
- List of solar PV captive power plant systems all over India

Please click here for detailed contents, critical questions answered, and a free preview of the report.

9. About EAI

EAI is a boutique research and consulting firm in renewable energy technologies. Our expertise ranges from Solar PV and Wind Energy to Algae fuels and Jatropha biodiesel. Our work has been sought after by some of the largest corporate and multilateral organizations in the world such as The Bill and Melinda Gates Foundation, Reliance Industries, World Bank, PepsiCo, iPLON, Vedanta Group, Accenture, Boston Consulting Group, and more.

Our services for clients seeking to abate diesel consumption through renewable energy include

- Analysis of the technical and economic feasibility of integrating various renewable energy/power sources in your operations
- Identification and due diligence of vendors
- Structuring PPAs for solar, wind, and biomass power
- Complete guidance on regulations, approvals, processes, and procedures involved in procuring and integrating RE power

EAI provides a range of services for various stakeholders in the Renewable Energy and Cleantech space, covering

- Developer/IPP Assistance
- Assisting Industrial consumers go green
- Diversification into/within renewable energy
- Market entry for international firms
- Research and Publications
- Renewable energy catalysis

Please visit http://www.consult.eai.in/ for more information on our consulting services.

To hear more on how we can help your organisation abate diesel consumption through renewable energy, write to us at consult@eai.in.