Project Report of Major-II

DESIGN OF PORTABLE $1KW_p$ SOLAR PV POWER PACK FOR MULTIPLE USES IN RURAL AREAS

Submitted in the partial fulfilment of the requirement for the award of degree of

Master of Technology

In

Renewable Energy Technology

Submitted by:

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(2K13/RET/04)

Under the guidance of:

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DECLARATION

I hereby declare that the work, which is being presented in this dissertation, titled **"DESIGN OF PORTABLE 1KWp SOLAR PV POWER PACK FOR MULTIPLE USES IN RURAL AREAS"** towards the partial fulfillment of the requirements for the award of the degree of **Master of Technology** with specialization in **Renewable Energy Technology**, from Delhi Technological University Delhi, is an authentic record of my own work carried out under the supervision of **Dr. J.P. KESARI,** Associate Professor, Department of Mechanical Engineering, at Delhi Technological University, Delhi.

The matter embodied in this dissertation report has not been submitted by me for the award of any other degree.

LAVNISH GOYAL
2K13/RET/04
Place: Delhi
Date:

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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CERTIFICATE

It is certified that Lavnish Goyal Roll no. 2K13/RET/04, student of M.Tech Renewable Energy Technology, Delhi Technological University, has submitted the dissertation titled **"DESIGN OF PORTABLE 1KWp SOLAR PV POWER PACK FOR MULTIPLE USES IN RURAL AREAS"** under my guidance towards the partial fulfillment of the requirements for the award of the degree of Master of Technology.

His work is found to be satisfactory and his discipline impeccable during the course of the project. His enthusiasm, attitude towards the project is appreciated.

I wish him success in all his endeavors.

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LAVNISH GOYAL

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ABSTRACT

- The purpose of this project work is to develop an energy conversion device which can directly convert the abundant solar energy available in every part of India into electricity. Using the technical knowledge I have gained under the guidance of my teachers at Delhi Technological University, I would like to serve the people of India who do not have access to electricity (especially in rural areas) by giving them a source of clean energy which is easy to operate and reliable.

- The Portable Energy Generator will be a boon for rural India as it can easily generate the energy required per day by a rural house hold. It is noise and pollution free. It is portable and can be easily folded, hence no danger of being stolen.

- Few of the areas in which this device can be utilized are Domestic consumption for cooking, lightening. It can also be used in Industrial applications of Micro Small and Medium Enterprises and also for on farm energy consumption.
- In this Project work Chapter 1 deals with energy scenario in rural India. Chapter 3 sheds light on recent solar energy technologies and developments whereas the subsequent chapter gives in detail the policies and missions introduced by Indian government to flourish renewable energy in India. Chapter 5 shows the Design consideration of the PV pack and chapter 6 shows the solution which fits our needs. Complete results and conclusions are compiled in chapter 7.

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Symbols

Ah	Battery rating (how much ampere can battery deliver for how many hours)
η	efficiency, %
D	Days of Reserve
E	Energy required /day
N.V	Nominal System Voltage
%Discharge	Amount of Discharge Allowed in battery
η_{PV-T}	Efficiency at 60°C Cell Temperature (around 12.63% as calculated)
η_{Reg}	Efficiency of Inverter (MPPT (regulator) efficiency typically 90-95%)
η_{Batt}	Energy efficiency of the battery (Watt hour efficiency of battery is typically (70-80%)
W	WATTS (Unit of Power)
Wp	Energy produced by PV module under Standard Test Conditions
Wh	Units of Energy
Wh/m2	Energy produced per unit area
Wh/day	Energy Produced per day

.

LIST OF ABBREVIATIONS

DISE	District Information System for Education
LPG	Liquid Petroleum Gas
MOP	Ministry Of Power
MNRE	Ministry of New and Renewable Energy
MSME	Micro Small and Medium Enterprises
MPCE	Monthly per Capita Expenditure
NSSO	National Sample Survey Organisation
TERI	TATA Energy Research Institute

CHAPTER 1: INTRODUCTION

India has tremendous energy needs and is finding it difficult to meet those needs through traditional means of power generation. Electricity consumption in India has been increasing at one of the fastest rates in the world due to population growth and economic development. India's economic growth has been some what stalled because the amount of energy generated is inapt to keep the growth motor of India running at the desired speed and there are energy shortages almost everywhere in the country.

Now, the question arises, what can India do to meet the future energy demands and help eliminate wide –ranging power outages in the future? To this the answer is, "India has tremendous potential in respect to renewable energy sources and if properly utilized, India can realize it's place in the world as a great power which can not only take care of its own energy needs but also of other nations.

Installation of solar power plants require nearly 2.4 hectares (6 acres) land per MW capacity which is similar to coal fired power plants when life cycle coal mining, consumptive water storage & ash disposal areas are also accounted and hydro power plants when submergence area of water reservoir is also accounted. 1.33 million MW capacity solar plants can be installed in India on its 1% land (32,000 square km). There are vast tracts of land suitable for solar power in all parts of India exceeding 8% of its total area which are unproductive barren and devoid of vegetation. Part of waste lands (32,000 square km) when installed with solar power plants can produce 2000 billion Kwh of electricity (two times the total generation in the year 2013-14) with land productivity/yield of 1.5 million Rs per acre (6 Rs/kwh price) which is at par with many industrial areas and many times more than the best productive irrigated agriculture lands. Moreover these solar power units are not dependant on supply of any raw material and are self productive. There is unlimited scope for solar electricity to replace all fossil fuel energy requirements (natural gas, coal, lignite and crude oil) if all the marginally productive lands are occupied by solar power plants in future. The solar power potential of India can meet perennially to cater per capita energy consumption at par with USA/Japan for the peak population in its demographic transition. [1]

Renewable energy also has the advantage of allowing decentralized distribution of energy — particularly for meeting rural energy needs, and thereby empowering people at the grass roots level. Solar electricity could also shift about 90 percent of daily trip mileage from petroleum to electricity by encouraging increased use of plug-in hybrid cars. For drivers in India this means that the cost per km could be reduced by a quarter in today's prices.

Majority of India's population lives in villages. The population in these communities has grown substantially in past fifty years. This growth has put tremendous pressure on resources needed to support this sector. In addition, it has resulted in enormous pollution of air, water and land. There is also substantial growth of population in India's cities resulting in similar problems that are encountered by village and rural folks. Clearly, sustainable developments innovations and clean energy technologies are needed to accommodate the growing population in India for healthier environment. The presence of solar energy at any location in a village makes its uses attractive for such an environment. Most prominent of these are the drying of foods, vegetables and fruits for preservation and assured availability during off season periods of the year.

In December 2011, over 300 million Indian citizens had no access to frequent electricity. Over one third of India's rural population lacked electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. In 2010, blackouts and power shedding interrupted irrigation and manufacturing across the country.

However, to have an effective approach in addressing the issue one needs to differentiate between the energy security of rural and urban areas, because energy dynamics of both the areas are quite different. Energy security perhaps is more important for the rural people because they are very vulnerable, marginalized and lack access to most of the basic resources. Majority of rural households depend on traditional fuels like fuelwood to meet most of their energy requirements, supplemented by small amounts of kerosene and electricity for lighting (Cecelski et al., 1979).

1.1 Some facts of energy scenario in rural India

- About 668 million or around 70% of the Indians (in 6.4 lakh villages) live in rural areas and continue to use animal dung, agricultural waste and fuel wood as fuel for cooking,
- The thermal (energy) efficiency of these traditional sources is very low (15%),
- Particulate matter in the Indian households burning biomass is 2000 µg/cubic m which

is much higher than the permissible 150 μg/cubic m [9]

- Use of traditional fuel is estimated to cause around 400,000 premature annual deaths due to various respiratory problems.
- 75% of rural households depend on firewood for cooking (and 9% each on, dung-cake and LPG) as against 22% of urban households using firewood for cooking, another 10% on kerosene and about 57% on LPG.
- For domestic lighting 55% of rural households depend on electricity and another 44% on kerosene, while in urban areas dependency is 89% on electricity and 10% on Kerosene.

Nevertheless, around 412 million Indians have no access to electricity although records tell that around 82% of the villages (4.89 lakh) were electrified as on 31.12.2008 [10], only about 44% of the rural households have access to electricity compared to around 87% in urban India.

This is because of the adopted definition of electrification. To quote "A village will be deemed to be electrified if electricity is used in the inhabited locality within the revenue boundary of the village for any purpose what-so-ever" According to this definition, a single pole and a 40W bulb in the local police station or pacnchayat office would mean a village is electrified, irrespective of the actual number of households of the village using electricity.

However, the new definition of an electrified village issued by MOP, vide letter No. 42/1/2001-D(RE) dated 5th February 2004 and its corrigendum vide letter No. 42/1/2001-D(RE) dated 17th February 2004 seems to have broadened the definition of an electrified village. According to the new definition, a village will be considered electrified if,

I. Basic infrastructure such as Distribution Transformer and Distribution lines are provided in the inhabited locality as well as the Dalit Basti hamlet where it exists.
II. Electricity is provided to public places like Schools, Panchayat Office, Health Centers, Dispensaries, Community centers etc.
III. The number of households electrified should be at least 10% of the total number of households in the village

The power generation capacity of a state seems to be delinked to availability of power to rural households. As for example even though Jharkhand is a "power-surplus" state around 90% rural households have no electricity.

Plausibly, less priority to rural areas has legitimate technical and economic reasons like high cost of supply and maintenance, payment default, electricity theft, poor infrastructure etc. make the electrification of far flung villages through the preferred mode of grid financially unviable. A misinterpretation of the rural energy needs is also to be blamed for the current state of affairs in the rural energy sector. 'Rural' is usually equated with 'agriculture' and 'rural energy' with 'cooking and lighting'; which undoubtedly misses out the energy requirements of various other rural facets like rural schools (and its students) and rural enterprises etc.

- As per District Information System for Education (DISE), around 87% of the schools in the country are located in rural areas (http://www.dise.in/downloads/AnaReport2006-07/School Related Indicators.pdf).

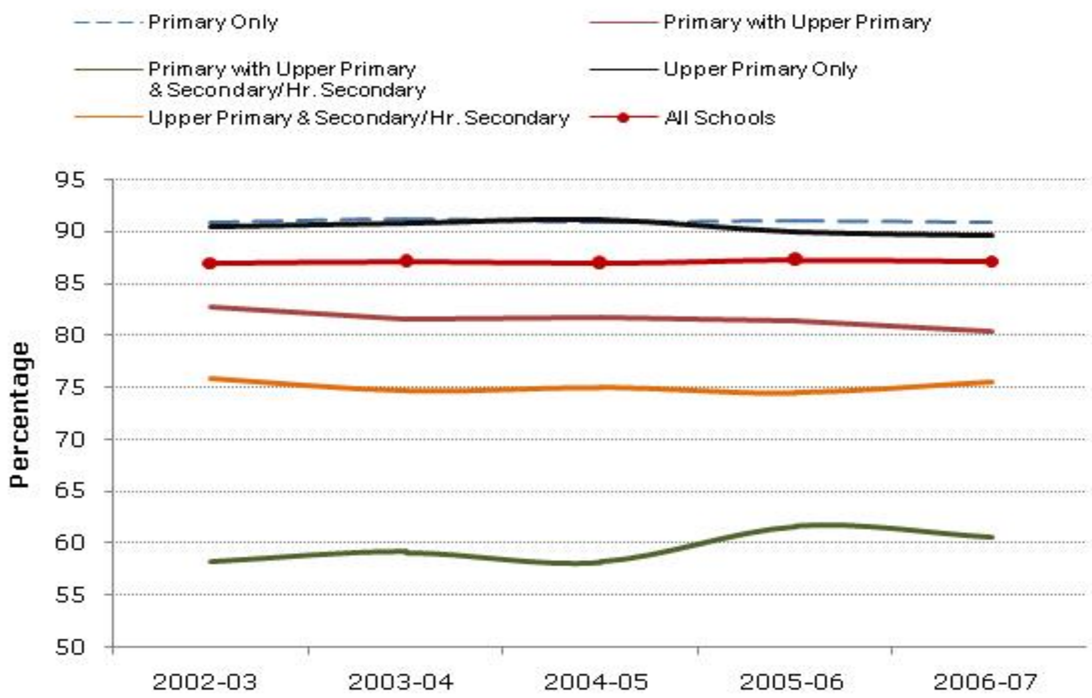


Fig 2: Percentage of schools in rural areas

Source: http://www.dise.in/downloads/AnaReport2006-07/School Related Indicators.pdf

As reflected in the Economic Census 2005, "there are 42.12 million enterprises in the country engaged in different economic activities other than crop production and plantation. Out of which, 25.81 million enterprises (61.3%) are in the rural areas and 16.31 million enterprises (38.7%) in the urban areas."

And more precisely, in the Micro Small and Medium Enterprises (MSME) segment, around 44.52% of the registered units and around 54.68% unregistered units are in the rural areas.

Besides, there are thousands of rural artisans like weavers who operate as Own Account Enterprises (OAEs) mainly in the rural areas with erratic power supply. The livelihood earning potential of these people could be enhanced by increasing their productivity through supply of clean energy on a regular basis.

Therefore, there needs to be a paradigm shift especially:

- in the perception of rural energy needs,
- defining the goals as well as strategies of India's energy security,
- shifting from centralized mega-thermal/hydro/nuclear plants etc, and,
- more importantly concentrating in renewable and sustainable sources of energy.

1.2 Pattern of Energy Consumption in Rural areas

In rural areas, power is consumed in three main ways:

Domestic consumption

- For cooking
- For lightening

Industrial consumption

- For Micro Small and Medium Enterprises
- For Big Industry

On-farm energy consumption

- Energy consumption for farming

Consumption of energy in Rural India for cooking:

Different types of energy sources are used for cooking in rural India:

- Firewood and chips
- Dung cake
- LPG

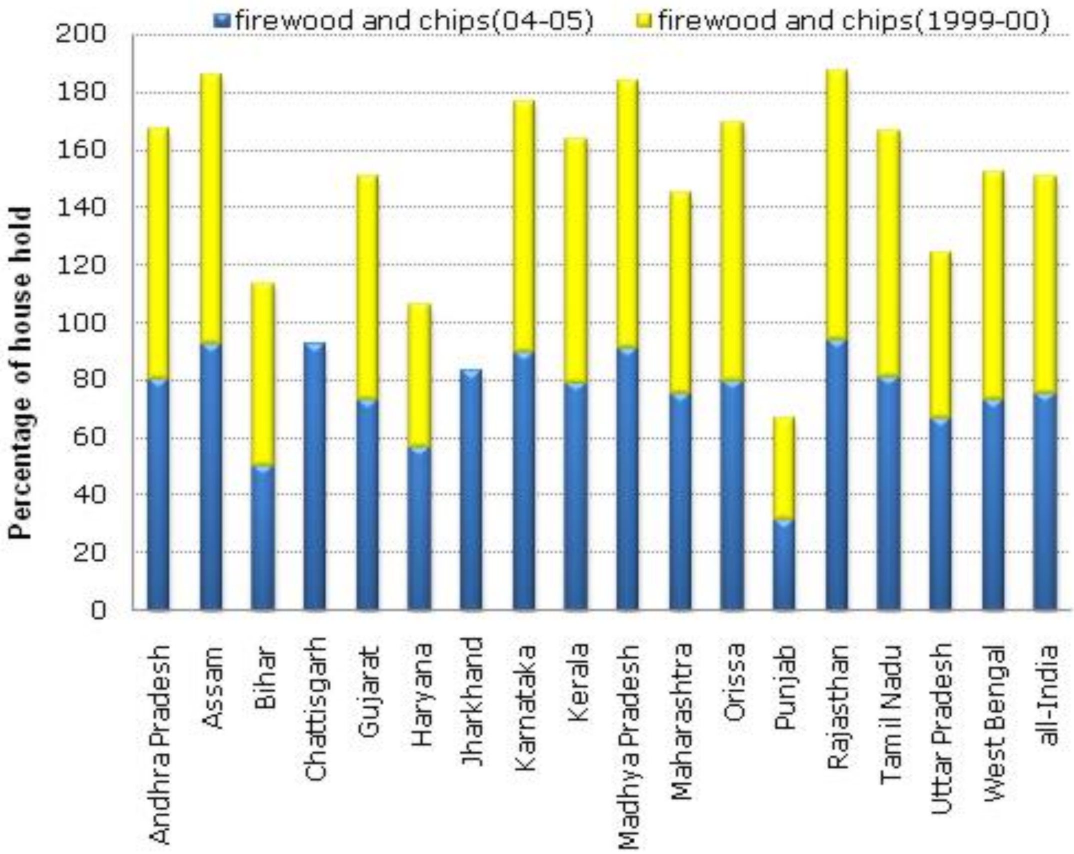


Fig 3: Consumption of firewood for domestic cooking across major states of India

Source: NSSO report no. 511, 61st Round, 2004-05

In rural India, firewood and chips continued to be the most important source of cooking energy. As on 2004-05, around 75% of the rural households are using firewood and chips for cooking. But the positive signal is the decrease in the number of households using firewood and chips for cooking by around 1% during the period 1999-2005.

The next important sources of energy in rural India are dung cake and LPG. Both these sources of energy are used by around 9% of the rural households in 2004-05. Nationally, use of LPG has increased by around 3 percentage points during 1999-2005; Punjab recorded 14% increase in the use of LPG during the same period and is the highest among all states.[11]

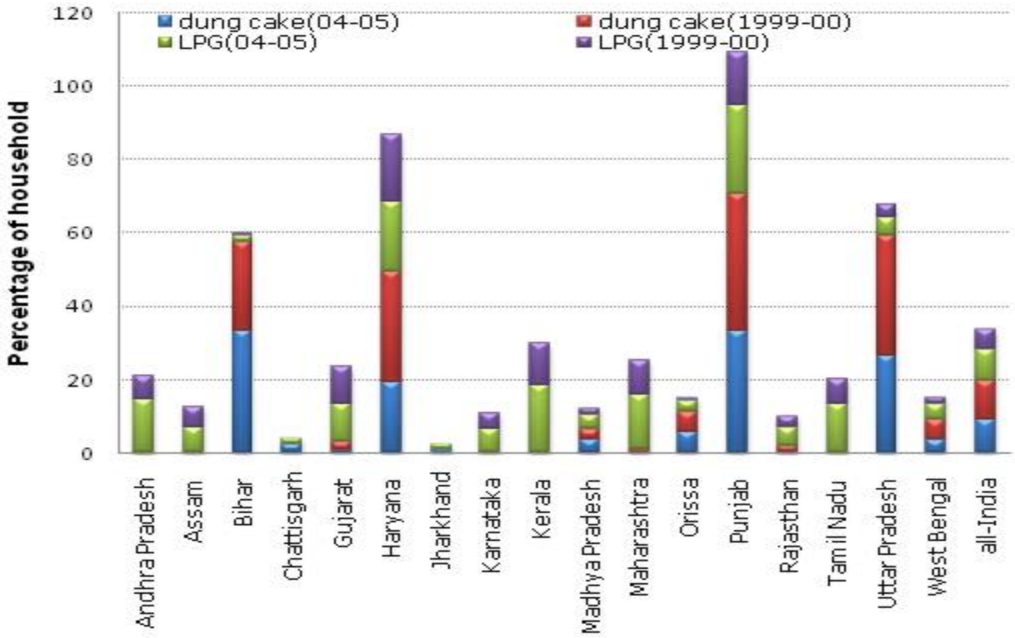


Fig 4: Consumption of dung cake and LPG for domestic cooking rural India **Source:** NSSO report no. 511, 61st Round, 2004-05

If we consider the source of energy used for cooking according to social group, it is apparent that use of firewood and chips is highest among the rural Scheduled Tribes, around 90% of the households in this category use firewood and chips for cooking.

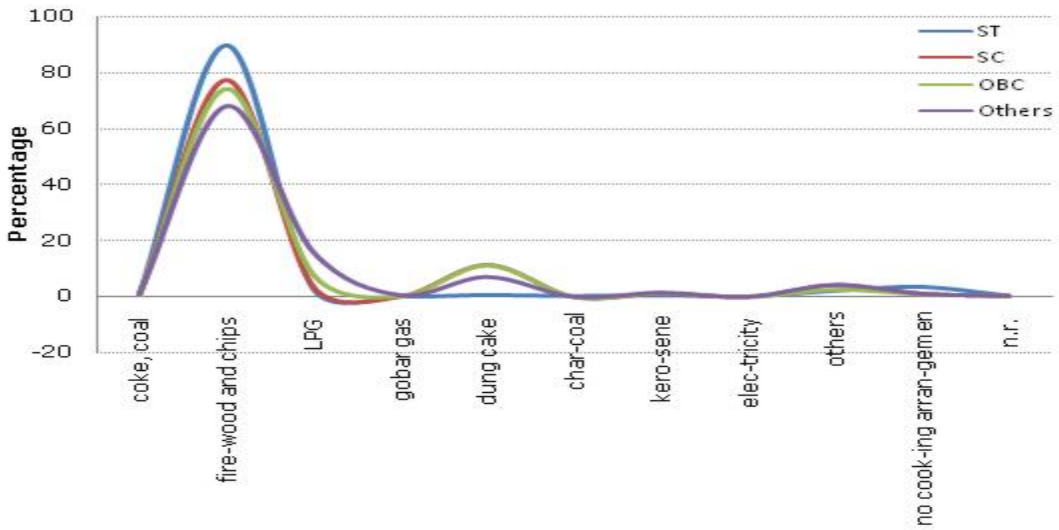


Fig 5: Break-up of households (per 1000) of each social group by primary source of energy used for cooking in Rural India

Source: NSSO report no. 511, 61st Round, 2004-05

Consumption of energy in Rural India for lighting:

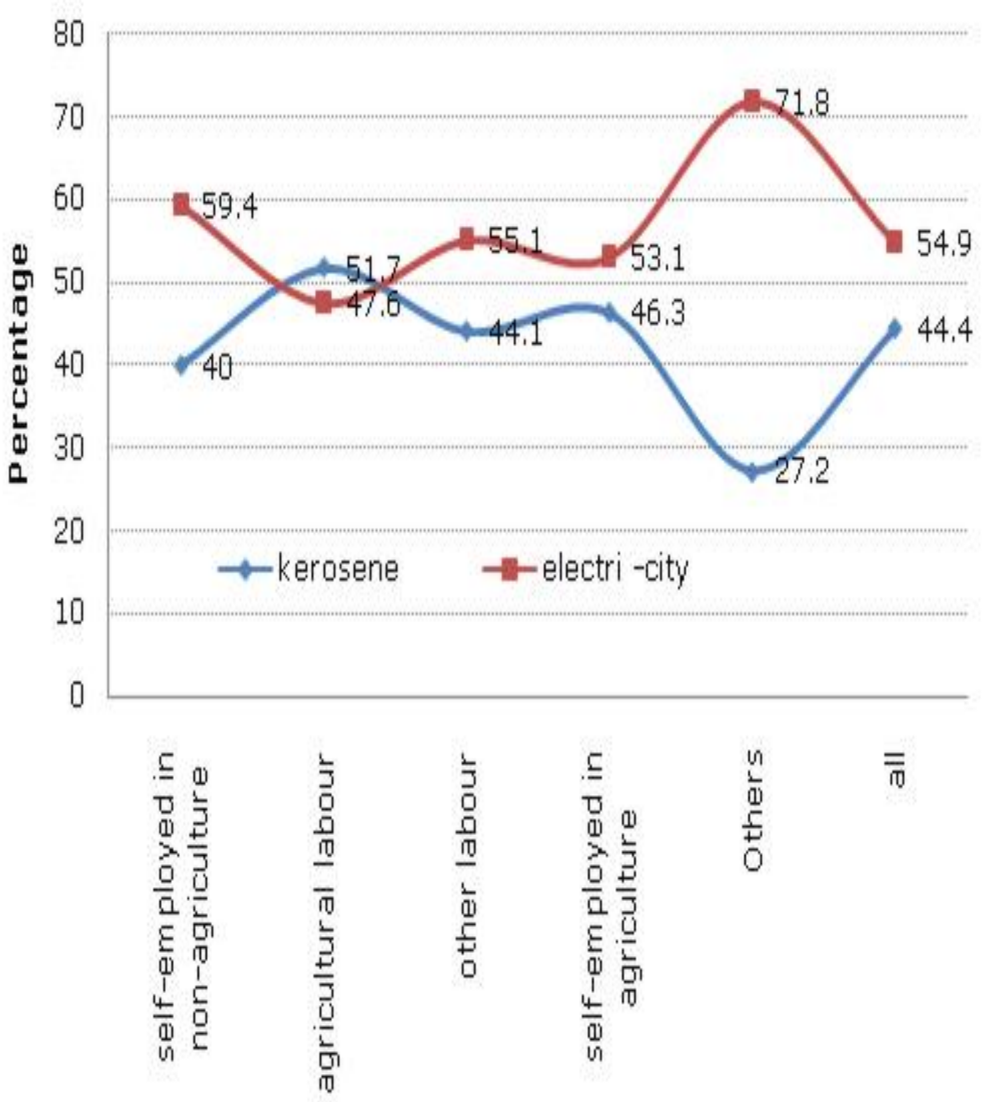


Fig 6: Distribution of households (per 1000) in different employment classes by primary source of energy used for lighting

Source: NSSO report no. 511, 61st Round, 2004-05

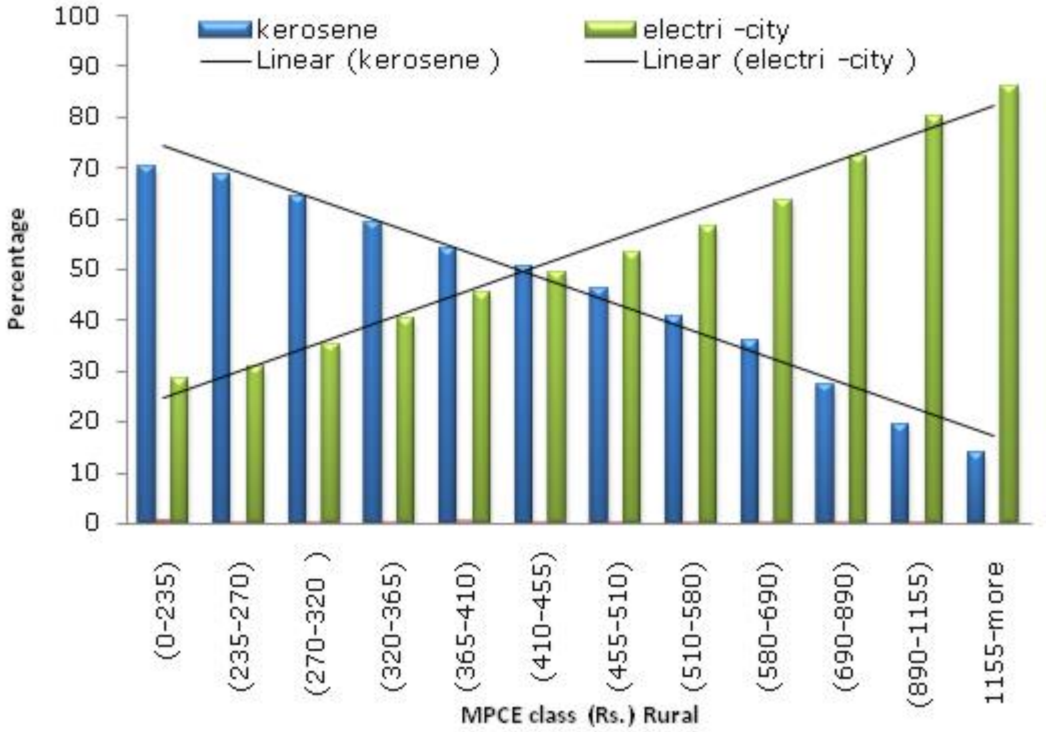


Fig 7: Distribution of households (per 1000) in each MPCE class by primary source of energy used for lighting (MPCE: Monthly per Capita Expenditure)

Source: NSSO report no. 511, 61st Round, 2004-05

These two graphs (above) represent the status of consumption of energy for lighting in rural India:

- Major source for lighting are kerosene and electricity.
- As a whole 55% of rural habitants are using electricity and 44% are using kerosene for lighting their house.
- And also higher MPCE class tends to use electricity for lighting.

Consumption of energy in Agriculture (~rural):

'Agriculture' is considered to be synonymous with 'rural', especially in countries like India where agricultural mechanization is not so much advanced. It is commonly believed that agriculture is one of the main power consumption areas in rural India. Agriculture consumes power both in the animate and non-animate forms.

The percentage of mechanical and electrical power used in agriculture increased from 40% to 84% during the years 1971-2003. It is also notable that in the first five year plan, power consumption in Indian agriculture was 316 GWh (3.97% percentage of total power consumption in India). In 2005 total power consumption in agriculture stood 88,555 GWh, which is approximately 22.93% of total energy consumption in India . Gujarat (46%), Andhra Pradesh (43%) and Haryana (45%) are the leading states regarding electricity power consumption in Agriculture [12] (TERI energy data directory & yearbook, 2005, P: 240).

The examples of technologies that are in use in rural India include mobile phones, home appliances, farm implements, vehicles for human, animal, and crop transport. The burning of wood and other materials for multiple uses continues. The cost and reliability for the supply of these energy sources has been a source of concern throughout India. The environmental impact from their use has also surfaced as a major concern.

For this reason, solar technologies for rural applications have to be rugged, reliable and easy to use and repair. The ease of maintenance is essential for successful technology intervention. Furthermore, costs associated with repair and maintenance should be minimal.

1.3 Consumption of energy in Rural MSMEs

As the micro and small enterprises are major part of Indian economy, we must investigate their status w.r.t. consumption of energy in rural areas. There are two types of MSME units in India:-

- Registered Units
- Un-Registered Units

Approximately 46% of un-registered and 35% of registered rural MSME have no access to power. Most of the remaining registered and un-registered units use electricity as a production input. The application of non-conventional energy (0.64-0.65%) in rural MSMEs is very meager.

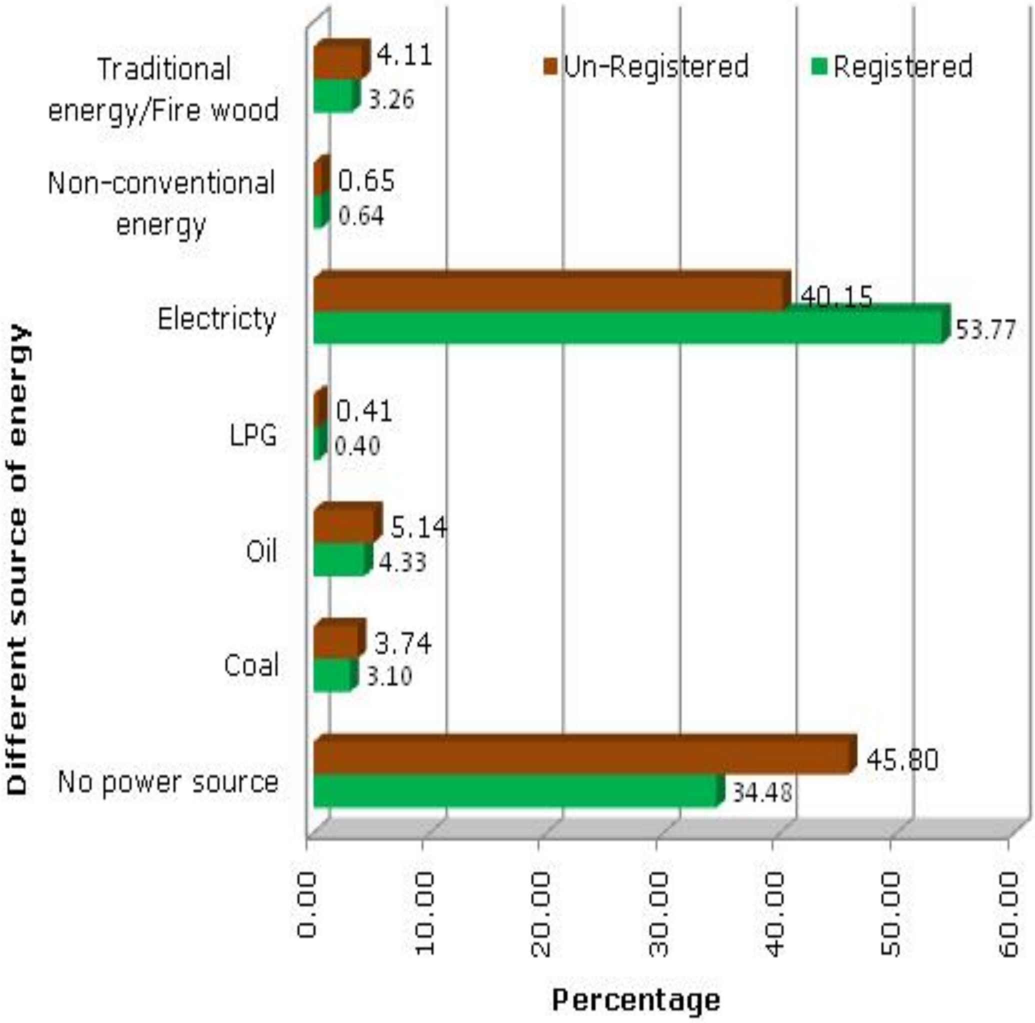


Fig 8: Sources of Energy for Indian Rural MSMEs

Source: MSME 3rd Census, 2001-02

1.4 Objectives of present work

1) To study energy needs of various sectors in rural India.

2) To calculate load of a sample household.

3) To find a feasible solar solution to supply the required energy.

4) To make a 3-D model of the Solar PV pack.

5) To observe the working of designed solar solution in different parts of India.

CHAPTER 2: LITERATURE REVIEW

V.Dixit et al [2]: Carried out a study on comparison of SPV and CPV in context with Indian climate. They carried out this study on 2 PV systems both with homemade dual axis tracking. They showed that in India where diffused part of Solar radiation is more it is more advantageous to go for SPV rather than CPV. In all they concluded that dual axis tracking of SPV gives far better results as compared to that of CPV, especially in tropical regions where DNI (Direct normal irradiance is low). CPV system with very high concentration ratio fail to perform at their rated power under such conditions. The difference gets compounded if the systems are left unclean as it actually happens in field conditions, especially in country like India.

Elizabeth Cecelski et al [3]: to have an effective approach in addressing the issue one needs to differentiate between the energy security of rural and urban areas, because energy dynamics of both the areas are quite different. Energy security perhaps is more important for the rural people because they are very vulnerable, marginalized and lack access to most of the basic resources. Majority of rural households depend on traditional fuels like fuel wood to meet most of their energy requirements, supplemented by small amounts of kerosene and electricity for lighting.

Amit Jain [4]**:** Studied the bankability of Solar Energy resource in India. He studied and noted the DNI and GNI of Solar Radiation at different places in India and advocated the establishment of Solar data houses for easy analysis. He concluded that cost of Solar energy is getting reduced every year with increase in use and hence improving solar resource data and linked bankability will enable India to maximize use of Solar energy.

J.P Kesari et al [5]: states that India has emerged as a global power in the past decade with an animal GDP growth rate of 8.6%, . The government of India recognizes that in order to sustain this growth rate and strengthen its national competitiveness, solar energy innovation has a critical role to play in India. The Government of India's Solar Mission is a visionary and inspiring policy measure that has the potential to be a leading example for the world. Harnessing the potential of solar energy for the benefit of rural areas of India will enlighten the hearts and minds of the rural population. Research on all aspects of solar energy including science, technology, engineering, economics, and management will engage diverse body of faculty and students in a team environment. This can energize the entire University for a worthy cause. India's population lives in rural areas and the quality of life will positively be affected by innovative use of solar energy.

P.Natarajan and G.S. Nalini [6]: bring to our notice that according to world bank 300 million people around (24%) people are not connected to national grid . Globally 1.3 billion people are without electricity out of these 84% are in rural areas. India is the fifth largest renewable energy rich country in the world. People who have grid connection do not have access to electricity for a long time of the day because of non-availability of power supply. To make the country self sufficient in energy sector, various alternative energy should be promoted. The available renewable energies are either seasonal or place bound. Among the non-conventional energy, solar is the perpetual source which ensures sustainable energy stock for country like India. By realizing the benefit of solar which could combat energy poverty, both central as well as state government framed their own solar power policies. The government should scrutinize the implementation process to enhance the viability of solar power. And also, the government has to propose a subsidy and tariff model exclusively for vulnerable people living in poverty.

Sthita Prajna Mishra [7]: This Paper has a study and model design of Hybrid system comprising of solar and wind technology for a small locality rural area and proposed design for the stand alone hybrid system is designed with the help of HOMER software to calculate the exact load with the money and cost estimation by the project and This chapter comprises the simulation data of each component used in Project work as well as the cost effectiveness of project during working and during setup. This is known as Hybrid Optimization Model for Electric Renewable. In this both PV and Wind set has been taken care for the balanced load sharing and to feed the local home connectivity system. It concludes that it has been concluded that rural electrification presents different load patterns in relation to that of urban loads in terms of the daily variation expected and the yearly variation: rural patterns are smoother. Besides, in case of remote areas that present small incomes (common parameters for most rural areas), the extension of utility grids is not feasible and the total dependence on imported fossil fuels is economically unaffordable, fuel transport costs become prohibitive.

CHAPTER 3: SOLAR ENERGY POTENTIAL AND TECHNOLOGIES

Solar is the prime free source of inexhaustible energy available to all. And, India is one of the sun's most favored nations, blessed with about 5,000 Twh of solar insulation every year. Even if a tenth of this potential is utilized, it could mark the end of India's power problems — by using the country's deserts and farm land to construct solar plants. Renewable energy has the potential to re-energize India's economy by creating millions of new jobs, allowing the country to achieve energy independence, reduce its trade deficits and propel it forward as a "Green Nation". In short, renewable energy offers too many benefits for India to ignore, or delay its development.

India should take full advantage of this golden opportunity because renewable energy has particular relevance in remote and rural areas, where there are around 289 million people who don't have access to reliable sources of energy. Solar energy is the most cost-effective option for India to reduce energy poverty without having to extend national grid services to provide power for individual homes and buildings.

India's present generation capacity is about 272,687 MW. The country could potentially increase grid-connected solar power generation capacity to over 226,000 MW and wind energy to over 100,000 MW by 2030 if the right resources (and more importantly, energy policies) were developed. India can develop massive commercial wind farms to harness the strong onshore costal area and offshore wind to boost the country's supply of clean renewable energy. But, to tap this vast resource, India must develop and implement smart business models and favorable policies as quickly as possible.

3.1 INDIA's SOLAR RESOURCE MAPs

Solar radiation which we receive as heat and light can be converted to useful thermal energy or for production of electricity either through solar photovoltaic route or through solar thermal route. Availability of reliable solar radiation data is vital for the success of solar energy installations in different sites of the country. For solar collectors which are flat in nature, solar radiation data in the form of Global Horizontal Irradiance (GHI) is useful whereas for solar collectors which are concentrating in nature Direct Normal Irradiance (DNI) data is required. Solar thermal power plants are essentially Concentrating Solar Power (CSP) units. For designing solar thermal power plants, DNI data is therefore a pre-requisite.

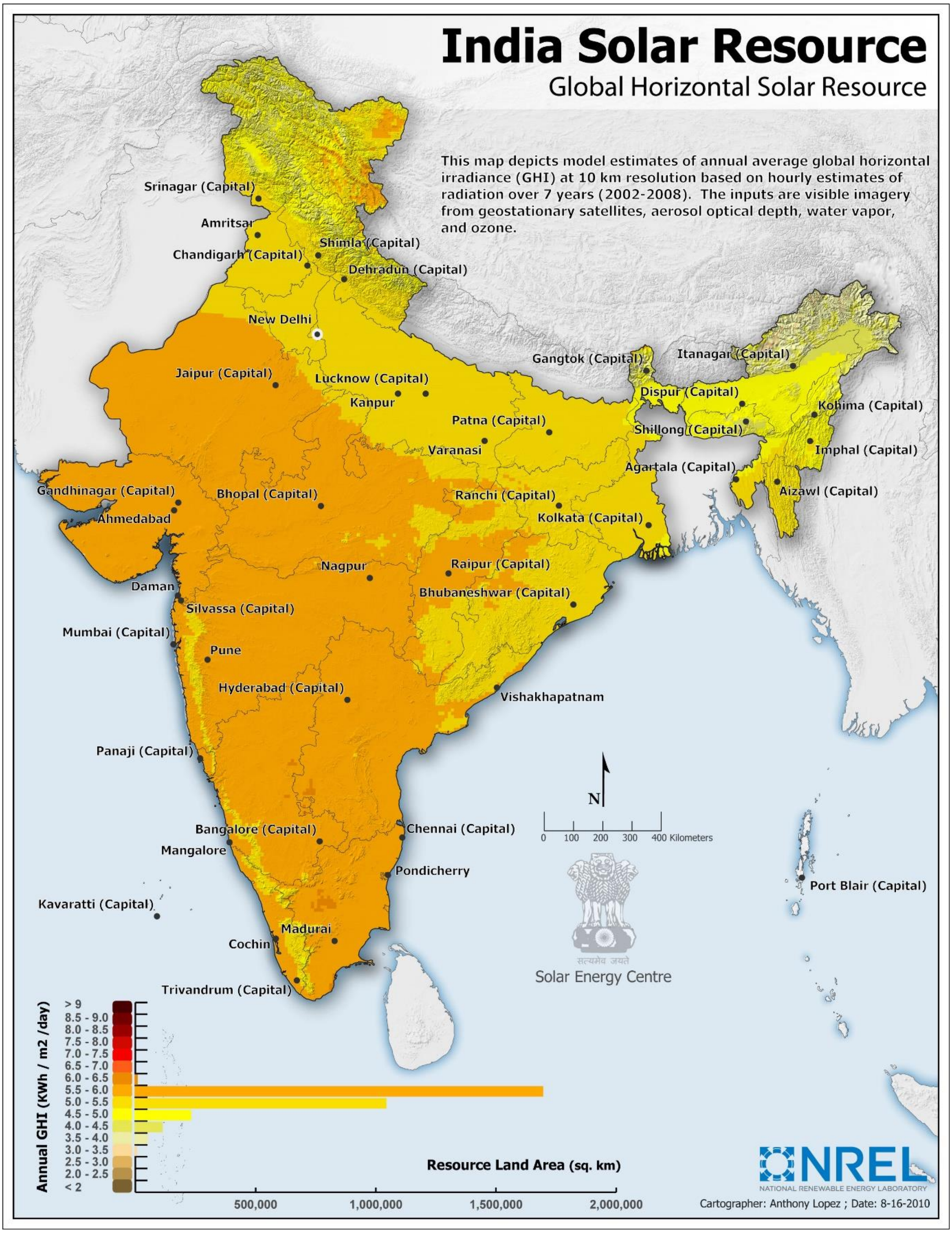


Fig 15: Global Normal irradiance

Source: http://mnre.gov.in/sec/solar-assmnt.htm

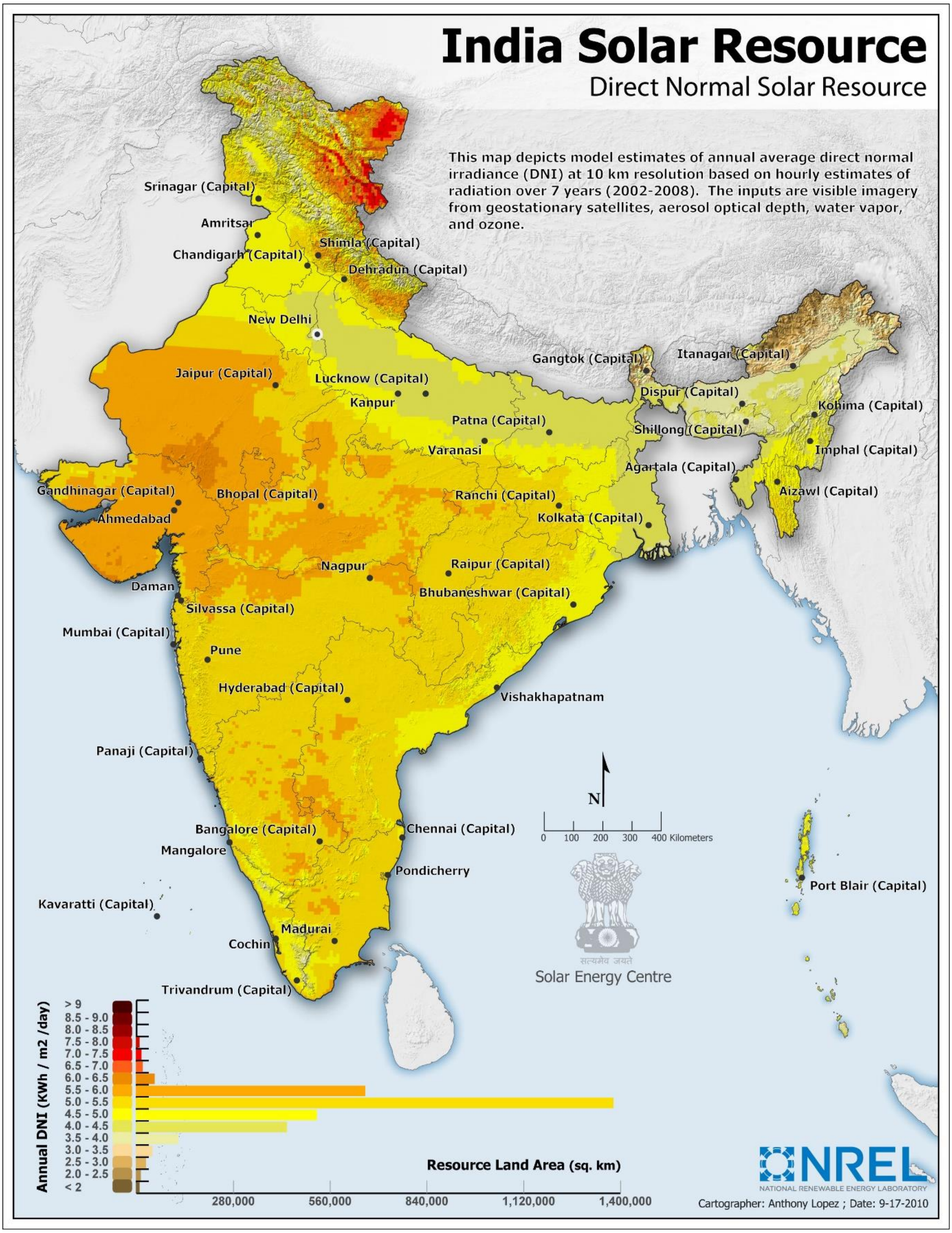


Fig 16: Solar Powered Waste Treatment

Source: http://mnre.gov.in/sec/solar-assmnt.htm

3.2 Solar Powered Battery Well:

The concept of Solar Powered Battery Well is similar to the village Community water well. In this case, the solar energy is harvested and stored and inhabitants can charge devices or energy storage systems from energy stored in batteries for a fee. The installation and maintenance of this system can be done through a village cooperative arrangement so that it can be made accessible to inhabitants at a lower cost per watt.

Fig 9: Solar Battery Well

3.3 Solar Powered Food Preservation Facility:

Farm products degrade in normal climatic conditions. Low temperatures and humidity allows these products to extend their usable life. Storages with compartmental design can be built in rural areas and their environment can be regulated with solar energy technology. These storages can be built through village cooperatives and then rented to farmers for their use. Food preservation will greatly help to satisfy India’s growing demands.

Solar lights are very commonly used in many cities to provide safety and needed light to enable an individual to accomplish jobs. Now they need to be used in rural areas.

3.4 Solar Powered Irrigation:

In a typical village in rural India, the villagers have community water wells drawing water from underground. They also have water wells for irrigating fields. Most of these are operated manually and those that operate on electric power are limited by the availability of such power. The power availability in rural India for use by farmers is extremely limited. Solar powered water wells will undoubtedly increase crop yield and better the quality of life of the inhabitants.

Fig 10: Solar Water Well

Source: www.solarpowerenergytoday.com

3.5 Solar Powered Rural Homes/Huts:

The technologies to be used in home include lights, phones, refrigerators, food cookers, heaters, television and other electronic devices, air/water coolers, water well and fans.

Fig 11: Solar Hut

Source: Renewable-solar-energy.info

3.6 **Solar Powered (Mobile) Tools/Implements:**

Tools are essential for farmers. From digging to harvesting the crops, several implements /tools are needed. Many of these are manually operated presently to save energy use. Solar powered farming will realize great leap forward in productivity and quality of life of farmers.

Fig 12: Solar Mobile Tower

Source: cleantechnica.com

3.7 Solar Powered Vehicles:

For fast transportation of materials, crops, animals, and humans, rural areas now depend on vehicles that run on gas/patrol. These vehicles could be designed to run on solar power.

Fig 13: Solar Plane (IMPULSE)

Source: inhabitat.com

3.8 Solar Powered Waste Management:

Farms and farm homes produce waste which largely pollutes land, water, and air thereby becoming a health hazard, in addition to being an eye sore. Solar powered compressors or waste conversion to useful products would benefit immensely the rural communities. [1]

Fig 14: Solar Powered Waste Treatment

Source: cleantechnica.com

CHAPTER 4: RENEWABLE ENERGY GROWTH, POLICIES & MISSIONS IN INDIA

4.1 Current Grid Installed Capacity:

Fuel	MW	%age
Total Thermal	**189,498**	**69.5**
Coal	165,236	60.6
Gas	23,062	8.5
Oil	1,200	0.4
Hydro (Renewable)	41,632	15.3
Nuclear	5,780	2.1
RES** (MNRE)	35,777	13.1
Total	**2,72,687**	

Renewable Energy Sources(RES) include SHP, BG, BP, U&I and Wind Energy

Programme/ Scheme wise Physical Progress in 2014-15 (During the month of March, 2015)			
Sector	FY- 2014-15		Cumulative Achievements
	Target	Achievement	(as on 31.03.2015)
I. GRID-INTERACTIVE POWER (CAPACITIES IN MW)			
Wind Power	2000.00	2312.00	23444.00
Small Hydro Power	250.00	251.61	4055.36
Biomass Power & Gasification	100.00	45.00	1410.20
Bagasse Cogeneration	300.00	360.00	3008.35
Waste to Power	20.00	8.50	115.08
Solar Power	1100.00	1112.07	3743.97
Total	3770.00	4089.18	35776.96

Fig 1: Renewable Energy Status in India as per Power Min

SOURCE: http://powermin.nic.in/power-sector-glance-all-india

4.2 MNRE current policies (2015):

India is one of the world leaders for installed renewable generation with a total capacity of almost 35.7 GW as of March 2015. The key drivers for renewable energy in India include:

- ✓ Good levels of resource availability.
- ✓ The forecast growth in energy demand.
- ✓ Energy security concerns in light of increasing imports of fossil energy.
- ✓ Economic and quality of life costs associated with the environmental impacts of fossil fuel combustion.

The Government of India has long recognized the potential business opportunities offered by growing demand for renewable energy in local and overseas markets. It established the world's first ministry focusing on renewable energy, the Ministry for New and Renewable Energy, (MNRE). The Indian Renewable Energy Development Agency (IREDA) is administered by MNRE and was established in 1987 to operate a revolving fund for development and deployment of new and renewable sources of energy. MNRE also administers national institutions such as the Solar Energy Centre (SEC).

India's existing capability and potential for innovation is supported by a well educated, professional and skilled workforce. There is a thriving renewable energy sector with strong growth in biomass generation, wind turbine and photovoltaic manufacturing that offers opportunities for synergy with the CSP sector.

Aggressively expand large-scale deployment of both centralized and distributed renewable energy including solar, wind, hydro, biomass, and geothermal to ease the strain on the present transmission and distribution system – and allow more off-grid populations to be reached. Facilitate growth in large scale deployment by installing 100 million solar roofs and large utility-scale solar generation, through both centralized and distributed energy within the next 20 years.

Enact a National Renewable Energy Standard/Policy of 20 percent by 2020 — to create demand, new industries and innovation, and a new wave of green jobs.

Develop favorable Government policies to ease the project permitting process, and to provide start-up capital to promote the exponential growth of renewable energy. Create and fund a national smart infrastructure bank for renewable energy.

Accelerate local demand for renewable energy by providing preferential Feed-in-Tariffs (FIT) and other incentives such as accelerated depreciation; tax holidays; renewable energy funds; initiatives for international partnerships/collaboration incentives for new technologies; human resources development; zero import duty on capital equipment and raw materials; excise duty exemption; and low interest rate loans.

Establish R&D facilities within academia, research institutions, industry, Government and civil society to guide technology development.

Accelerate the development and implementation of Solar and Wind farms; utility-scale solar and wind generation nationwide.

Initiate a move to electrify automotive transportation or develop electric vehicles and/or plug-in hybrids — such as the Nissan Leaf or Chevy Volt, etc. Develop and implement time-of-day pricing to encourage charging of electric vehicles at night. Adopt nationwide charging of electric cars from solar panels on roofs, and solar-powered electric vehicle charging stations around the country. Thousands of these solar-powered recharging stations could spread across India just like the present public call office (PCO), giving birth to the "Green Revolution." These recharging connections could be deployed at highly-concentrated areas including shopping malls, motels, restaurants, and public places where cars are typically parked for long periods.

Aggressively invest in a smart, two-way grid (and micro-grid). Invest in smart meters, as well as reliable networks that can accommodate the two-way flow of electrons. Such networks need to be resilient enough to avoid blackouts and accommodate the advanced power generation technologies of the future. (Develop large scale solar manufacturing in India (transforming India into a global solar manufacturing hub).

Work towards a Hydrogen Economy development plan. Hydrogen can be fed into fuel cells for generating heat and electricity — as well as for powering fuel cell vehicles. Produce hydrogen using renewable energy with solar and wind power. If done successfully, hydrogen and electricity will eventually become society's primary energy carriers of the twenty-first century. [1]

Policies and regulations for promoting renewable and energy efficiency have already been placed in India, issued by both Central and State Electricity Regulatory Commissions (CERC and SERCs), but the level of implementation of policies implemented by both central and state varies widely and support from utilities is often weak.
Civil society has the potential to act as a locomotive, both pressuring and supporting regulators in implementing RE/EE programmes.

Purpose

To empower civil society and consumer groups to participate in both state and federal level regulatory processes in India, and to demand ambitious EE / RE regulations, coupled with their effective implementation by utilities.

Main Activities

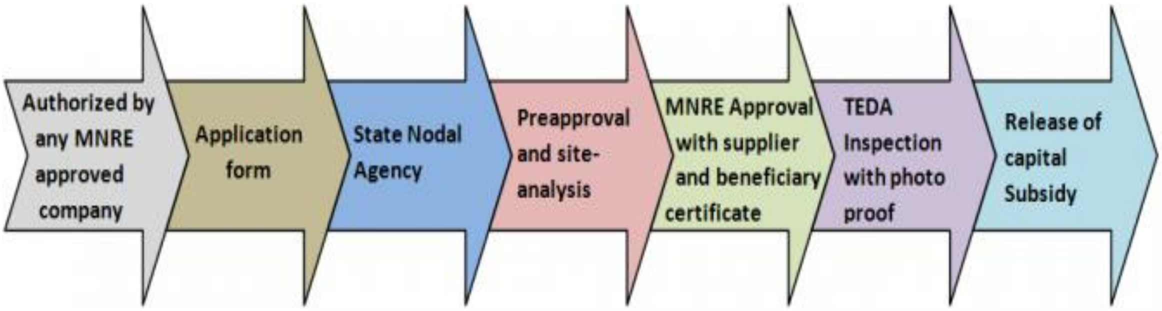
- Bonding with electricity regulators and stakeholders in different states (including states like Maharashtra, Andhra Pradesh and Orissa, or Tamil Nadu) to review state-level RE and EE programs
- Finding why RE/ EE programs have succeeded or failed, using inputs from the WR-Prayas Electricity Governance Initiative (EGI) toolkit as a guide for the analysis
- Suggest new approaches and guidelines to create demand from civil society for EE/ RE in regulation
- Engage representatives of the CERCs and the SERCs involved in the state level initiatives on how to implement the recommendations, and other interested SERCs to explore how to operationalize these recommendations
- Engage consumer groups and local and national media in India to build awareness of the opportunities to improve practice
- Facilitate an exchange between electricity regulators in India, Brazil, South Africa, and Thailand to share experiences in promoting RE/EE

  Expected Impact
- Improved SERC understanding of the options for promoting RE and EE
- Increased accountability of regulators to fulfill the RE and EE aspects of their mandates stipulated in India's 2003 National Electricity Act
- Support for electricity regulators in managing the tradeoffs involved in providing low cost, reliable energy
- Encouragement of progressive regulators to take bold steps to promote RE and EE, and to champion sustainable energy programs.
- **Central Government**

- **NAPCC**
- India is confronted with the task of satisfying its rapid economic growth while dealing with global threat of climate change. There are some detected vicissitudes in climate parameters in India too, like increase in surface temperature by 0.4 ˚C, variation in monsoon patterns, rise in sea levels by 1.06-1.75mm per year, extreme weather conditions breaking over 130 years records, Unpredictable water flow in perennial rivers originating from Himalayas. Alongside, the fast depleting conventional sources of power generation have aggravated the situations of energy crisis. India, in recent times, has started stressing power generation from renewable sources that is either grid interactive or off grid. India actively got involved in multilateral negotiations in the UN Framework Convention on Climate Change (UNFCCC), in a positive, constructive and forward-looking manner. In order to achieve a sustainable development path that simultaneously advances economic and environmental objectives, on 30 June 2008, the National Action Plan for Climate Change (NAPCC) was framed with eight core missions:
- National Solar Mission – renamed Jawaharlal Nehru National Solar Mission (JNNSM)
- National Mission for Enhanced Energy Efficiency
- National Mission on Sustainable Habitat
- National Water Mission
- National Mission for Sustaining the Himalayan Ecosystem
- National Mission for a Green India
- National Mission for Sustainable Agriculture
- National Mission on Strategic Knowledge for Climate Change

- **Jawaharlal Nehru National Solar Mission (JNNSM)**
- This National Solar Mission was outlined to promote the use of solar energy for power generation and other application; also encouraging the integration of other renewable energy technologies like biomass and wind with solar energy options. The Solar Energy can be tapped via two routes solar thermal and solar photovoltaic. Thus the framework is targeted to achieve Solar energy utilization via these routes:

- **Tax Incentives, Subsidies and Incentives under JNNSM**
- Various tax exemptions, capital subsidies and incentives are available for several components and sub-components of solar energy value chain. JNNSM promotes the assembly of solar modules after import of cells which is free from import taxes. Some steps to avails subsidy can be summarized as shown:



- Other benefits like Generation based incentives (GBI), 80% accelerated depreciation income tax benefits on renewable energy products including solar. Several products like Solar lanterns, street lights, blinkers and traffic signals are to be manufactured under specifications laid down by MNRE to avail capital subsidy benefits. Also the Generation based incentives and tax benefits are listed in links below:
- Specifications for Solar Lanterns
- Specifications for Solar street lighting
- Specifications for Home Lighting Systems
- Specifications for other systems
- Tax incentives
- Capital subsidy under different schemes
- Wind Solar Hybrid
- Generation Based Incentive on Grid Interactive Solar
- PV Power Generation Projects
- Generation Based Incentive on Grid Interactive Solar Thermal Power Generation Projects
- Guidelines for Offgrid Solar applications
- Offgrid refinance Scheme

Policies supporting Grid-interactive Renewable Power

National Rural Electrification Policy 2006

- Rural Electrification is high time need for India where still 45 million households are un-electrified. Several goals are set under this policy:

- Right to quality and reliable electricity at unswerving rates and minimum lifeline consumption of 1unit/household/day by year 2012.
- For remote villages where grid electrification is not feasible, off-grid based solutions based on stand alone systems to be taken up for supply of electricity.
- Every state to come up with rural electrification plan mapping details of electricity delivery mechanism that may be linked to district development plans and this has to be intimated to appropriate commission.

Rajiv Gandhi Gramin Vidyutikaran Yojana (RGGVY)

- This scheme is being implemented by Rural Electrification Corporation for permitting stand alone systems, rural electrification, bulk power purchase & management of local distribution (through franchisee model). Under this scheme, projects could be financed with 90% capital subsidy. For households below poverty line, 100% capital subsidy would be provided as per norms of Kutir Jyoti Programme. Main provisions under this policy are to set up-
- *Rural Electricity Distribution Backbone (REDB):* Provision of 33/11 KV (or 66/11 KV) sub-stations of adequate capacity and lines in blocks where these do not exist.
- *Creation of Village Electrification Infrastructure (VEI):* Electrification of un-electrified villages, un-electrified habitations and provision of distribution transformers of appropriate capacity in electrified villages/ habitation(s).
- Decentralized Distributed Generation (DDG) and Supply*:* Decentralized generation cum-distribution from conventional sources for villages where grid connectivity is either not feasible or not cost effective provided it is not covered under the programme of Ministry of Non-conventional Energy Sources for providing electricity from non-conventional energy sources under their remote village electrification programme.
- REDB, VEI and DDG would also cater to the requirement of agriculture and other activities including irrigation pumpsets, small and medium industries, khadi and village industries, cold chains, healthcare, education and IT. A total of 2,11,673 villages have been electrified among which 1,19,708 previously electrified villages have been intensively electrified.

Policies supporting Off-grid renewable power

Remote Village Electrification Programme

- This project covers all those villages that are not under RGGVY scheme. The decision for choosing particular technology for power generation in such remote areas is taken by state implementation agency after examination of technical feasibility and resource availability. The projects are eligible for central financial assistance and developers can propose projects under the format specified in the policy document. Out of 8722 villages sanctioned under this scheme, 6446 have been completed and 1705 villages under progress. And out of 2533 hamlets sanctioned, 1587 have been completed.

- **Special Area Demonstration Project Programme**
- The Special Area Demonstration Project Scheme of the MNRE has been introduced with an objective of demonstrating application of various Renewable Energy systems in a project mode at places of National and international importance The SADP Scheme is being implemented into two parts- Demonstration of Renewable Energy Systems at Prominent Places and the Energy Park scheme. Prominent places of national and international importance are categorized under world heritage sites, religious and educational institutions, tourist destinations, Zoos, museums, National Parks etc. Renewable energy Park scheme started in 1995, having objectives of creating awareness among rural and urban masses about the use and benefits of the renewable energy by demonstrating new and renewable energy systems and devices through working systems, cut models, LED models, blow ups etc. 30 State level renewable energy parks and 484 district level Renewable Energy Parks have been sanctioned so far.

Renewable Energy Supply for Rural Areas

- This scheme was framed with the objective of developing and demonstrating commercially viable models for de-centralized energy supply in rural areas from renewable sources. The implementation partners for the programme are: Ministry of New and Renewable Energy (MNRE), National Thermal Power Corporation Limited (NTPC Limited) and Kirloskar Oil Engines Limited. The partners are to frame out the business, governance and revenue models for target areas. The project is under demonstration mode for 30 target villages in Chhattisgarh**.**

Renewable Energy for Urban, Industrial and Commercial Applications

- The programmes implemented under this scheme are working for developing: Solar energy systems and devices (including solar thermal and solar photovoltaic systems); Energy recovery from urban, industrial and commercial wastes; and Bioenergy and cogeneration in industry.
- Under MNRE's the Energy Efficient Solar/Green Buildings Programme, GRIHA rating

system is being encouraged for a target of supporting approx.. 4 million sq.meter built up area during eleventh Plan. So far, 117 projects with about 4.98 million sq.meter built up area with 81 projects from Government Departments with 3.22 million sq. meter built up area have been registered for GRIHA certification. An independent registered society ‘Association for Development and Research in Sustainable Habitats’ (ADaRSH) for promotion and implementation of GRIHA rating system has been set up in the country.

- Under “Development of Solar Cities Programme” the Ministry had proposed to support 60 cities/towns for Development as “Solar/ Green Cities” during the 11th Plan period with the aim to promote the use of renewable energy in urban areas. At least one and a maximum of five cities in a State is being supported. Systems that can be installed are: Solar street lights, Solar traffic signals, Solar blinkers, Solar power packs/inverters, Solar illuminating hoardings/ Bill boards and other systems of community use as felt necessary by Implementing Agencies.
- Under the Akshay Urja programme, shops are being established in each district to make renewable energy products easily available to people and provide after sales and repair services. The programme is in operation through State Nodal Agencies . Financial support in terms of soft loans from designated banks and a maximum of 2.40 lakh as recurring grant/incentive for first two years of operation from the Ministry is available for establishing such shops. Service Charge is also provided to SNAs. A total of 294 shops in 31 States / UTs, (including 113 Aditya Solar Shops) have been established under the scheme.

4.3 Renewable Energy Commitments:

RE-Invest 2015 is the first Renewable Energy Global Investors Meet & Expo to be organised by the Ministry of New and Renewable Energy (MNRE). Its objective is to showcase the Government of India's commitment to the development and scaling up of renewable energy in India to meet the national energy requirement in a socially, economically and ecologically sustainable manner.

RE-Invest was the first major platform for investment promotion in this sector, and connected the global investment community with renewable energy stakeholders in India. RE-Invest was inaugurated by the Prime Minister of India, Mr Narendra Modi, and was attended by over 200 investors, 350 exhibitors and 1000 delegates, both domestic and international. RE-Invest was held from 15 - 17 February 2015 in New Delhi, India.

Senior representatives from the renewable energy industry, equipment manufacturers, global financial institutions, Public Sector Enterprises, regulatory authorities, central and state governments, research institutions and academia participated in the 3-day Conference & Expo**.** Commitments received were of 166 GW instead of 100 GW that was initially planned before organizing this event.

CHAPTER 5: DESIGN OF PORTABLE 1KW PV ENERGY GENERATOR

<u>Wattage of different electric loads (AC/DC) for PV Applications</u>

S.NO	AC LOAD	WATTAGE (W)
1.	FAN	20/45
2.	TV (Colour)	18
3.	Fluorescent tube/Cfl	11
4.	Radio	5-20
5	Water pump	200-2250wp
	DC LOAD	WATTAGE (W)
1	Fan	20
2	TV	18,20
3.	Fluorescent tube	20

Table 1: Power Consumption of Various loads

<u>Wattage requirement of sample rural household</u>

S.NO	LOAD	NUMBER	Wattage(W)
1.	CFL	3	11
2.	TV(Colour)	1	18
3.	Fan	2	20

Table 2: Power Consumption of sample household equipment

<u>Usage hours of sample rural household</u>

S.NO	LOAD	NUMBER	Wattage(W)	Hours/day
1.	CFL	3	11	5
2.	TV(Colour)	1	18	5

3.	Fan	2	20	8

Table 3: Energy Consumption of sample household equipment

5.1 TOTAL LOAD DETERMINATION

The total load is expressed in terms of watt hour/ day (Wh/day). This is determined by multiplying the number of devices with their respective wattage and the numbers of hours used per day.

For ex, for sample household a DC fan operational during summer (4 months) and not in winter is taken into account. The system design is for maximum electrical load requirement.

Total load calculated is as shown:

S.NO	LOAD	NUMBER	Wattage(W)	Hours/day	Load (Wh/day)
1.	CFL	3	11	5	165
2.	TV(Colour)	1	18	5	90
3.	Fan	2	20	8	320

Table 4: Load Calculation of sample household equipment

Total Wh = 575 Wh/day.

5.2 BATTERY DESIGN

Purpose of Batteries

- Energy Storage Capacity and Autonomy: to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand.
- Voltage and Current Stabilization: to supply power to electrical loads at stable voltages and currents. by suppressing or 'smoothing out' transients that may occur in PV systems.
- Supply Surge Currents: to supply surge or high peak operating currents to electrical.

  Types of secondary batteries generally used in PV applications are:

  - Lead Acid Batteries - Flooded Electrolyte & VRLA*
  - Ni-Cd batteries
  - Lithium Ion
  - Vanadium Redox Battery and Zinc-Bromide Batteries

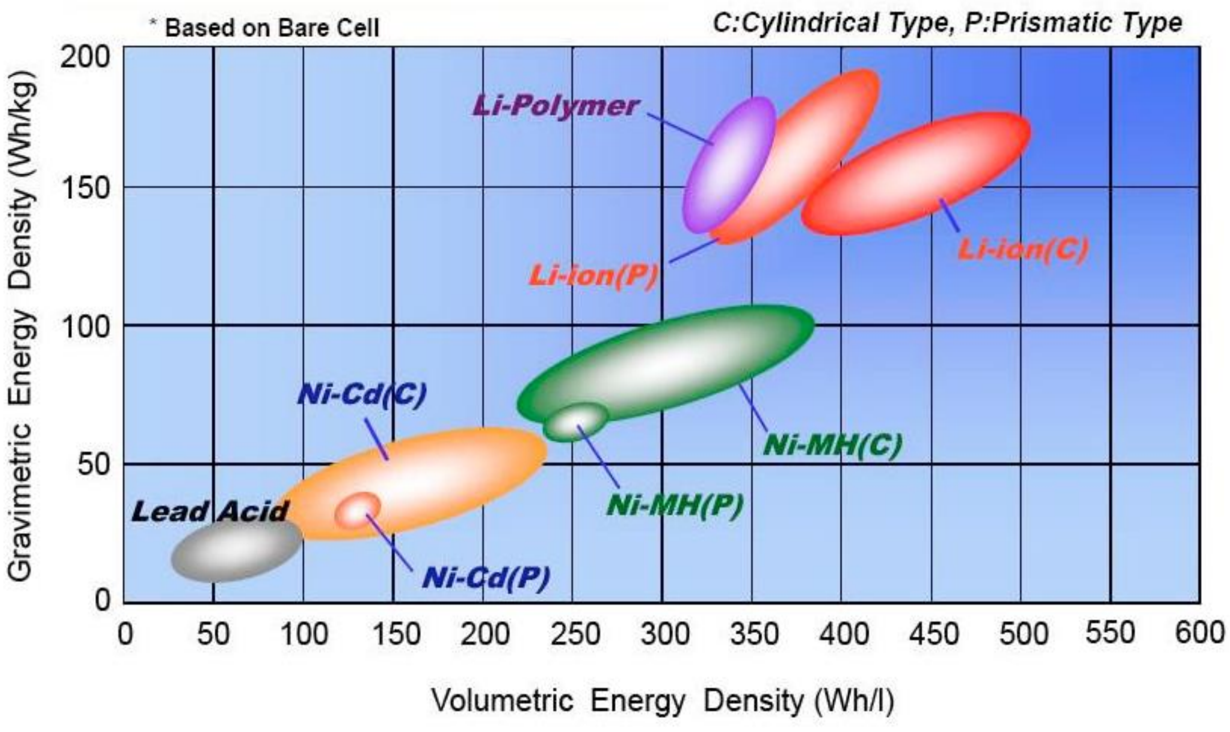


Fig 19: Gravimetric Vs Volumetric Energy Density
Source: GSES Fundamentals of Standalone PV

Factors affect capacity of the battery

- Temperature
- Discharge Rate
- Cut off voltage
- Self Discharge rate [13]

Factors that affect battery lifetime

- Vibrations
- Temperature
- Depth of Discharge
- Rate of charge/discharge
- Sulphation [14]

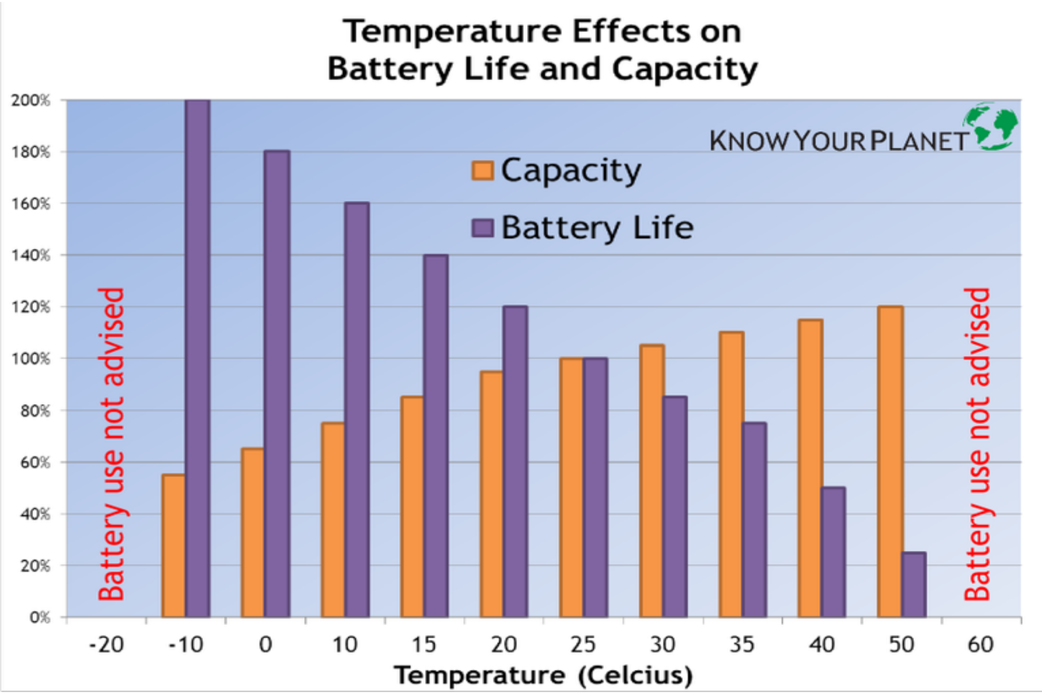


Fig 20: Battery Capacity Vs Temperature
Source: GSES Fundamentals of Standalone PV

Basic Battery Sizing Calculation

BATTERY SIZE = (D * E)*100/ (N.V * % Discharge)

Where

D = Days of Reserve

E= Energy Required /day

N.V= Nominal System Voltage

%Discharge= Amount of Discharge Allowed

Therefore for our system the battery Ah rating should be:-

For a load of 575 Wh/Day battery required for system with 2 days reserve backup will be as calculated below:-

Load = 575 wh/day

Reserve days = 2 days

Maximum allowable discharge = 50%

System Nominal Voltage = 12V

Battery capacity = (575 * 2)/(12 * .5) = 191 Ah

Hence the required size of battery is 191 Ah

5.3 NUMBER OF PV MODULES REQUIRED

The basic unit of a PV module is SOLAR CELL. Hence the number of PV modules required will depend on the parameters of Solar cells.

- **<u>VARIOUS PARAMETERS OF SOLAR CELL</u>**

  1) Short Circuit Current
  2) Open Circuit Voltage
  3) Maximum Power Point
  4) Current at Maximum Power Point
  5) Voltage at maximum Power point
  6) Fill Factor (FF)
  7) Efficiency

- **<u>Commercial Solar Cells Technology, Materials and Efficiency</u>** [15]

Solar PV Technology	Solar cell type	Materials Used	Efficiency (in percent)
Crystalline Silicon (c-Si) Solar cell	Mono Crystalline silicon, Poly or multicrystalline Si (mc-Si)	Mono Crystalline Silicon, Poly Crystalline Silicon	14-16, 14-16
Thin film Solar Cell	Amorphous Si (a-Si), Cadmium Telluride (CdTe), Copper Indium Gallium Selenide	Amorphous Silicon, Cadmium and tellurium, copper, Indium, gallium, Selenium	6-9, 8-11, 8-11
Multi Junction Solar cell	Gallium Indium phosphide, Gallium Arsenide, Germanium	Gallium, Arsenic, Indium, Phosphorous, Germanium	30-35

Table 5: Commercial Solar Cells Technology, Materials and Efficiency

Source: Solar Photovoltaic Technology and Systems, C.S. Solanki, 2014.

- **Typical Solar Cell Parameters of Commercial Solar Cells with Available Cell area** [16]

Solar Cell Type	Efficiency (%)	Cell area (cm^2)	Output Voltage (V)	Output Current (mA/cm^2)	Fill Factor (%)
Mono Crystalline Silicon	14-17	5-156	0.55-0.68	30-38	70-78
Poly Crystalline Silicon	14-16	5-156	0.55-0.65	30-35	70-76
Amorphous	6-9	5-200	0.70-1.1	8-15	60-70
Cadmium Telluride	8-11	5-200	0.80-1.0	15-25	60-70
Copper-indium-gallium-selenide	8-11	5-200	.50-.7	20-30	60-70
Gallium indium phosphide	30-35	1-4	1-2.5	15-35	70-85

Table 6: Solar Cell Parameters

Source: Solar PhotoVoltaic Technology and Systems, C.S. Solanki, 2014.

- **Factors Affecting Electricity Generated by a Solar Cell** [17]

  1) The conversion Efficiency
  2) The amount of light
  3) The solar cell area
  4) The angle at which day light falls
  5) The operating temperature

- **Effect of Conversion Efficiency** : Of the total light energy falling on a solar cell, only some fraction of the light energy gets converted into electrical energy by the solar cells. The ratio of electrical energy generated to the input light energy is referred as conversion efficiency of solar cells. Efficiency of a Solar cell is given in terms of maximum power that solar cell can generate for a given input solar radiation.
- **Change in the Amount of Input Light**: The electric current generated by a Solar cell is directly proportional to the amount of light falling on it.

- **Change in Solar Cell Area**: The current output is directly proportional to the cell area.
- **Change in Angle of Light Falling on Solar Cell**: Solar cell produces maximum power when sunlight falls perpendicular to the surface of solar cells. When light is not perpendicular to solar cells, it always give less output than maximum possible output power.
- **Change in Solar Cell Operating Temperature**: The Solar cells output voltage , power and efficiency ratings are given at standard condition (STC = 1000 W/m^2 and 25°C). With increase in temperature the Solar cell output voltage, efficiency and power reduces.

Parameter of crystalline Silicon Solar Cells	Decrease per ° C rise in cell temperature from standard test condition (STC) value of 25 °C
Voltage	-2.3 mV
Power	-0.45%
Efficiency	-o.45%

Table 7: Solar Cell efficiency

Source: Solar PhotoVoltaic Technology and Systems, C.S. Solanki, 2014

The number of PV modules can be calculated by either using the wattage of the module and the mean daily solar insolation in the region.

Hence efficiency at 60 ° C can be calculated by below mentioned formula:

η (actual at 25 ° C) – 0.45 (Temp_Outside – Temp_Standard)

η at 60 ° C = 15 – 0.45* (60-25) = 12.63%

Efficiency of the System:

ηSystem = ηPV-T * ηReg * ηBatt = 12.63 * 95 * 70 = **8.39 %**

η_{PV-T} = Efficiency at 60°C Cell Temperature (around 12.63% as calculated)

η_{Reg} = Efficiency of regulator (MPPT (Inverter) efficiency typically 90-95%)

η_{Batt} = Energy efficiency of the battery (Watt hour efficiency of battery is typically 70-80%)

Average solar insolation incident on Indian sub continent is 6KWh/m2 per day. The efficiency of Mono-crystalline solar cells (with system) is 8.39% hence amount of electrical energy generated = 503.4 Wh/m2. For a 9m2 (which I am planning to design area total energy generated will be 453060 Wh per day=4.53 KWh/day.

5.4 INVERTER REQUIREMENT

Inverter power = 1KWp

Voltage of inverter = 220V

Frequency = 50/60 Hz

Inverter Specifications:

1. Battery Voltage (V)
2. D.C. current (A)
3. Voltage Range (V)
4. Maximum short circuit current (A)
5. Output voltage (V)
6. Frequency (Hz)
7. Efficiency (%)
8. No load power consumption (W)
9. Surge power (W)

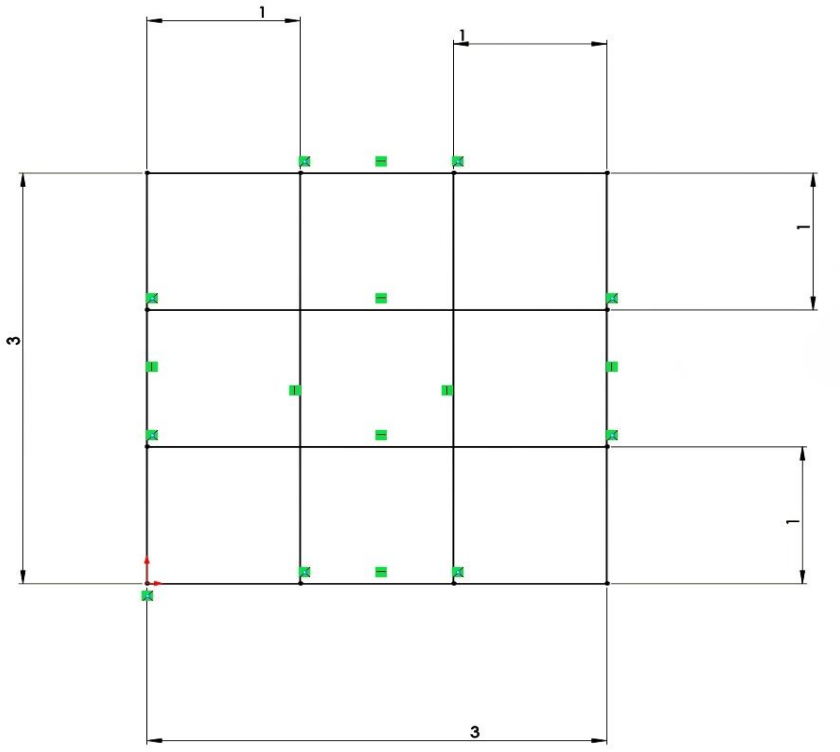
OUTPUT	
Continuous power rating	1000W@25 C
Ac output voltage (RMS)	220 V
AC output Frequency	50 Hz

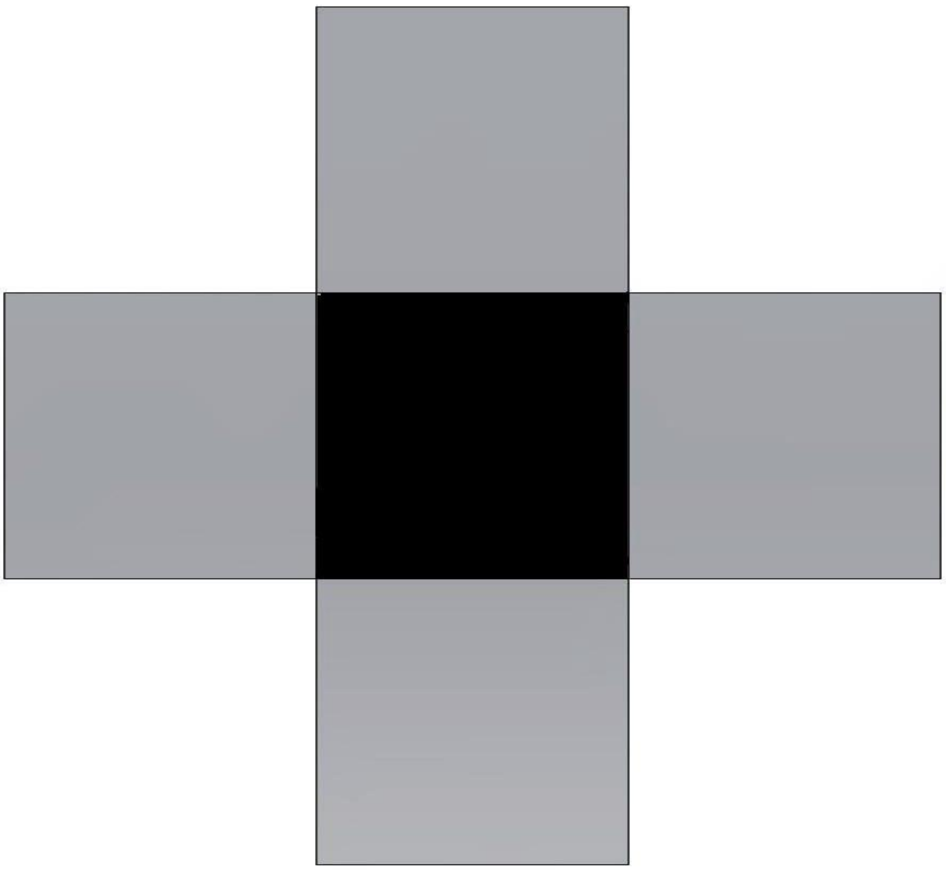
BATTERY INPUT	
Battery Voltage	10-15 V
DC current	34A
OFF mode current draw	<1mA

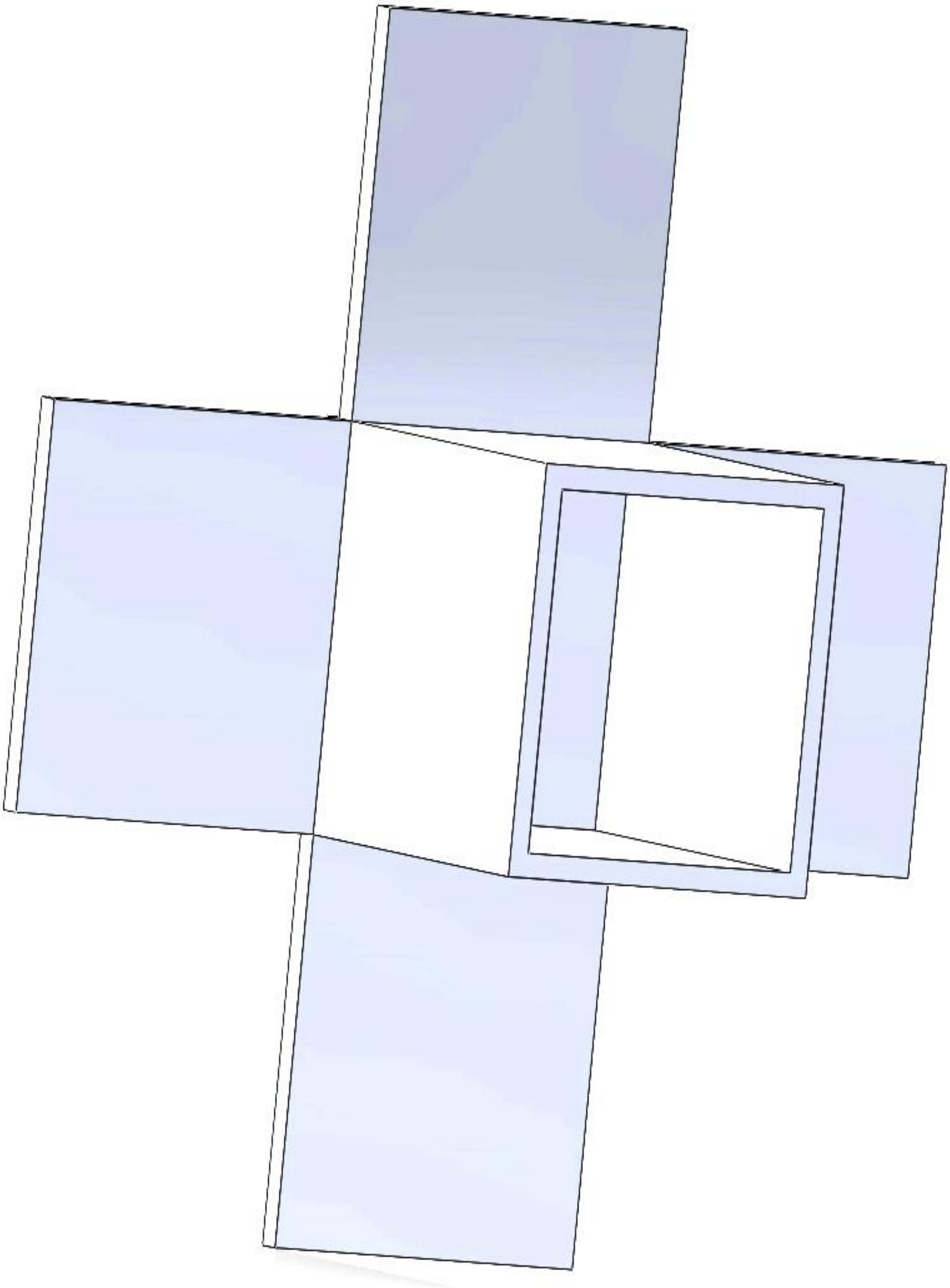
SOLAR PANEL INPUT	
Voltage Range	25-42 V
Maximum Short Ckt current	16 A

CHARGER OUTPUT	
Maximum charging Voltage	15 V
Maximum charging Current	24 A

INITIAL PLANNED DESIGN



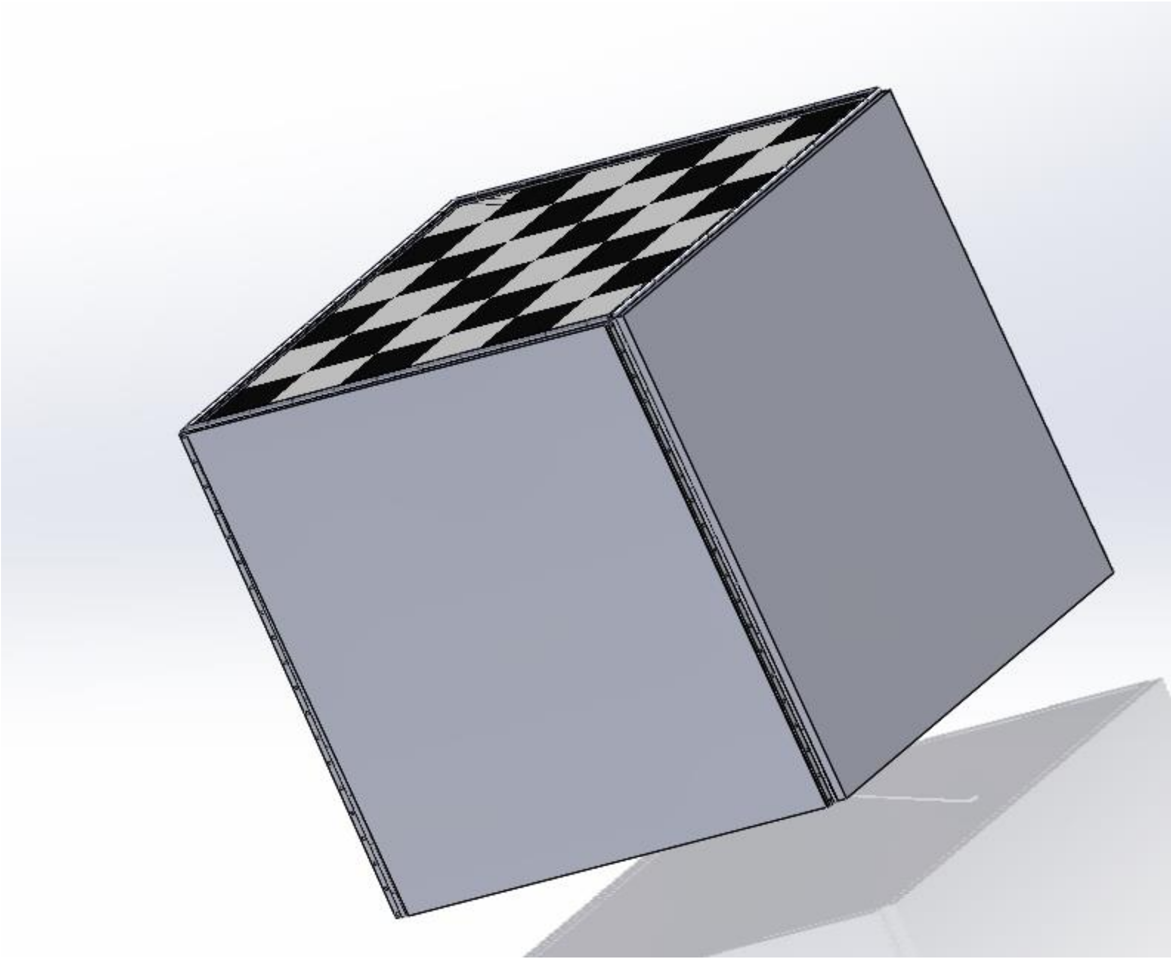




FINAL 3-D DESIGN

DIFFERENT UNFOLDING STEPS

1



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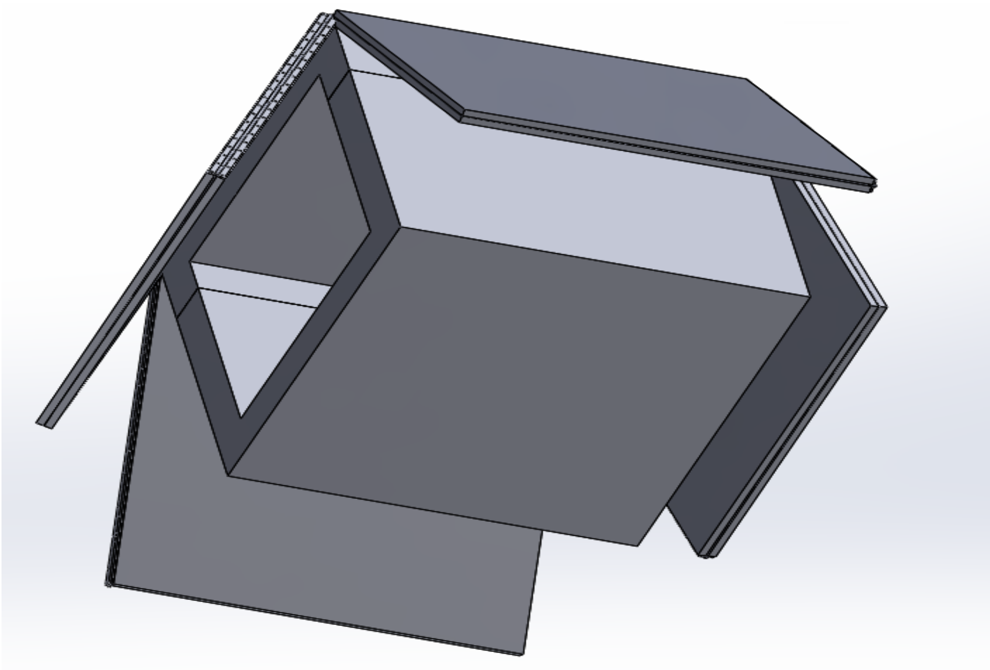

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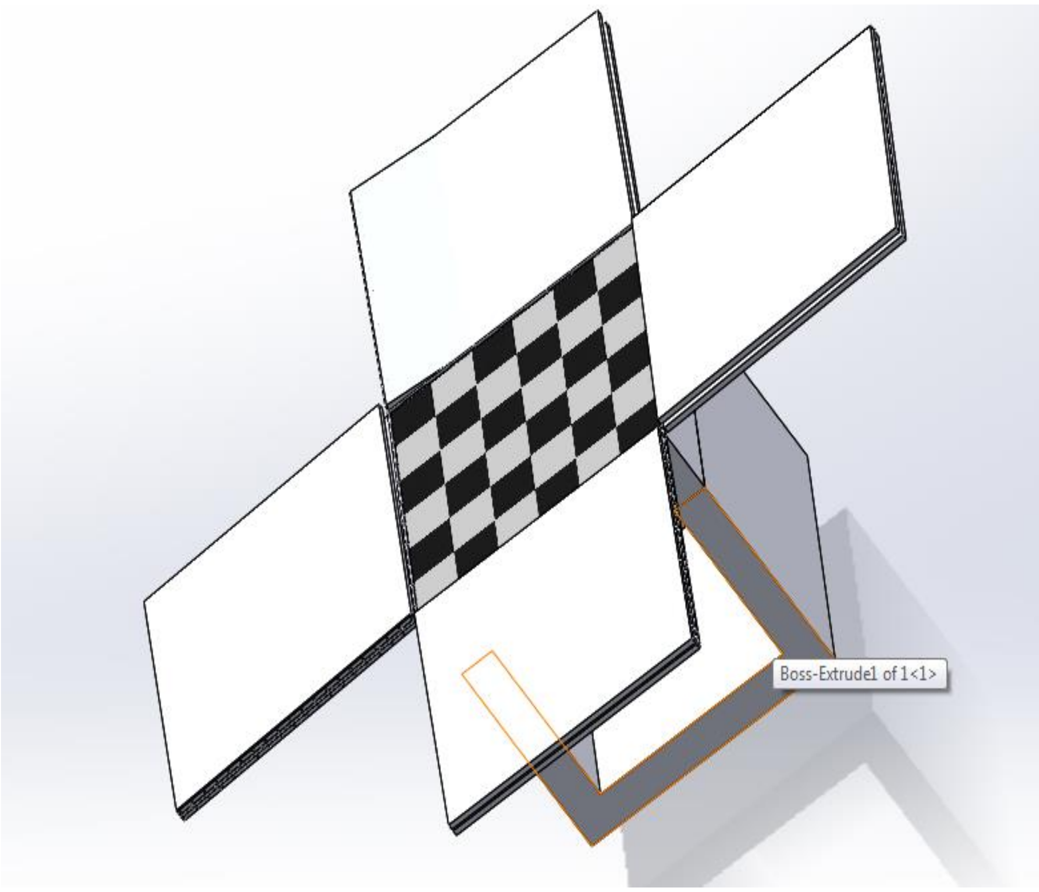

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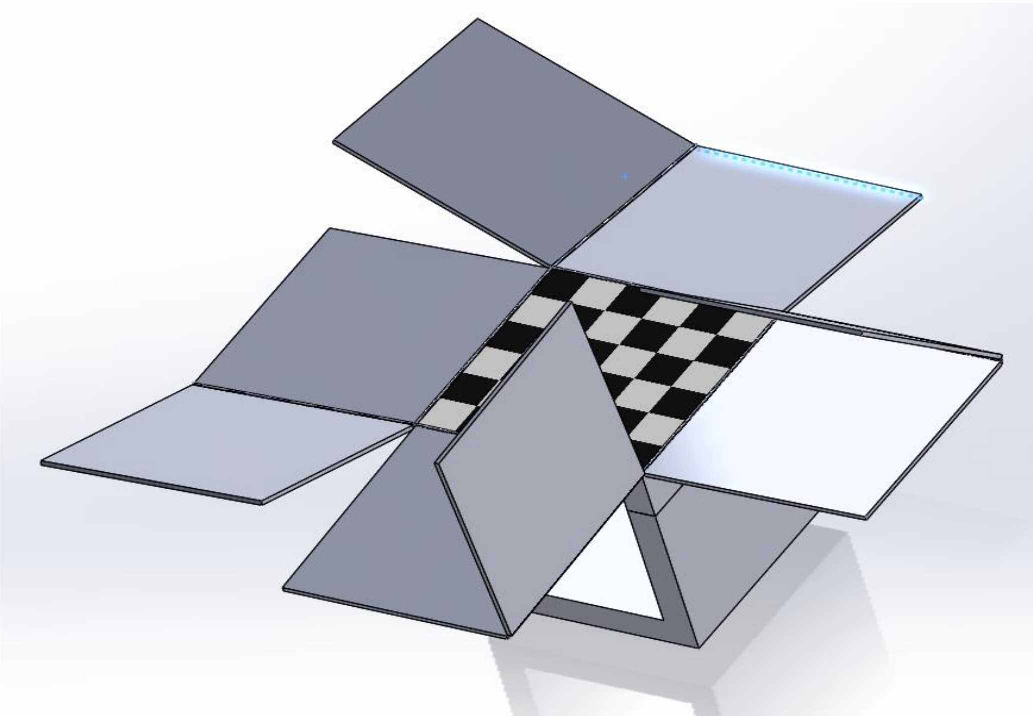

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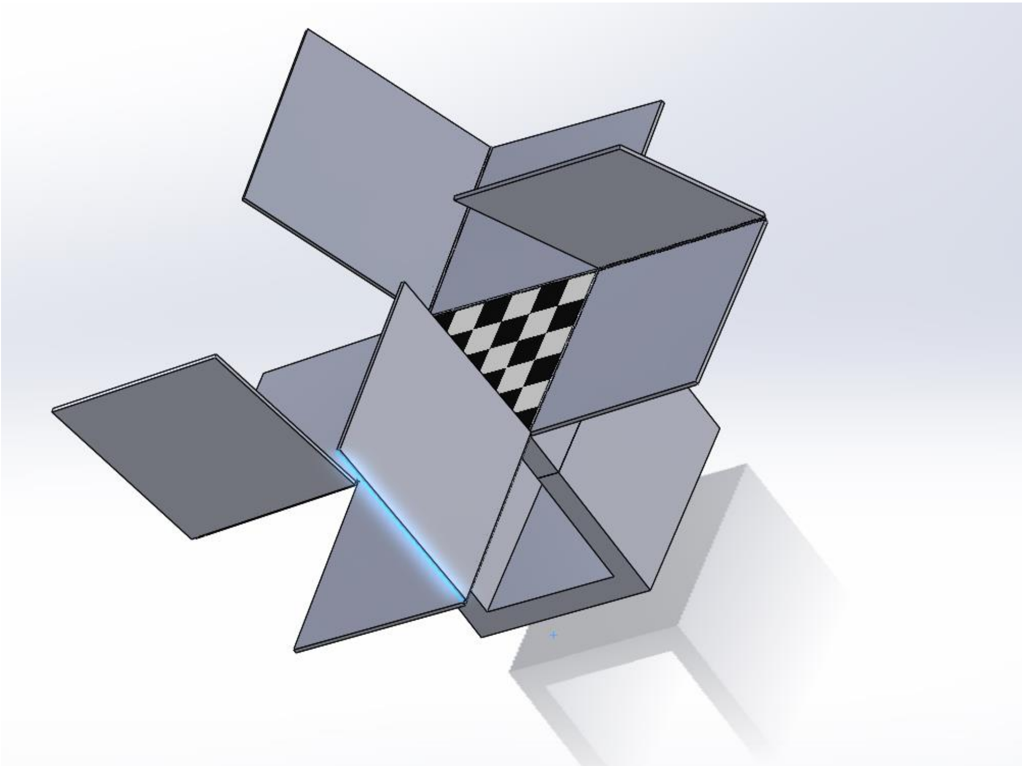

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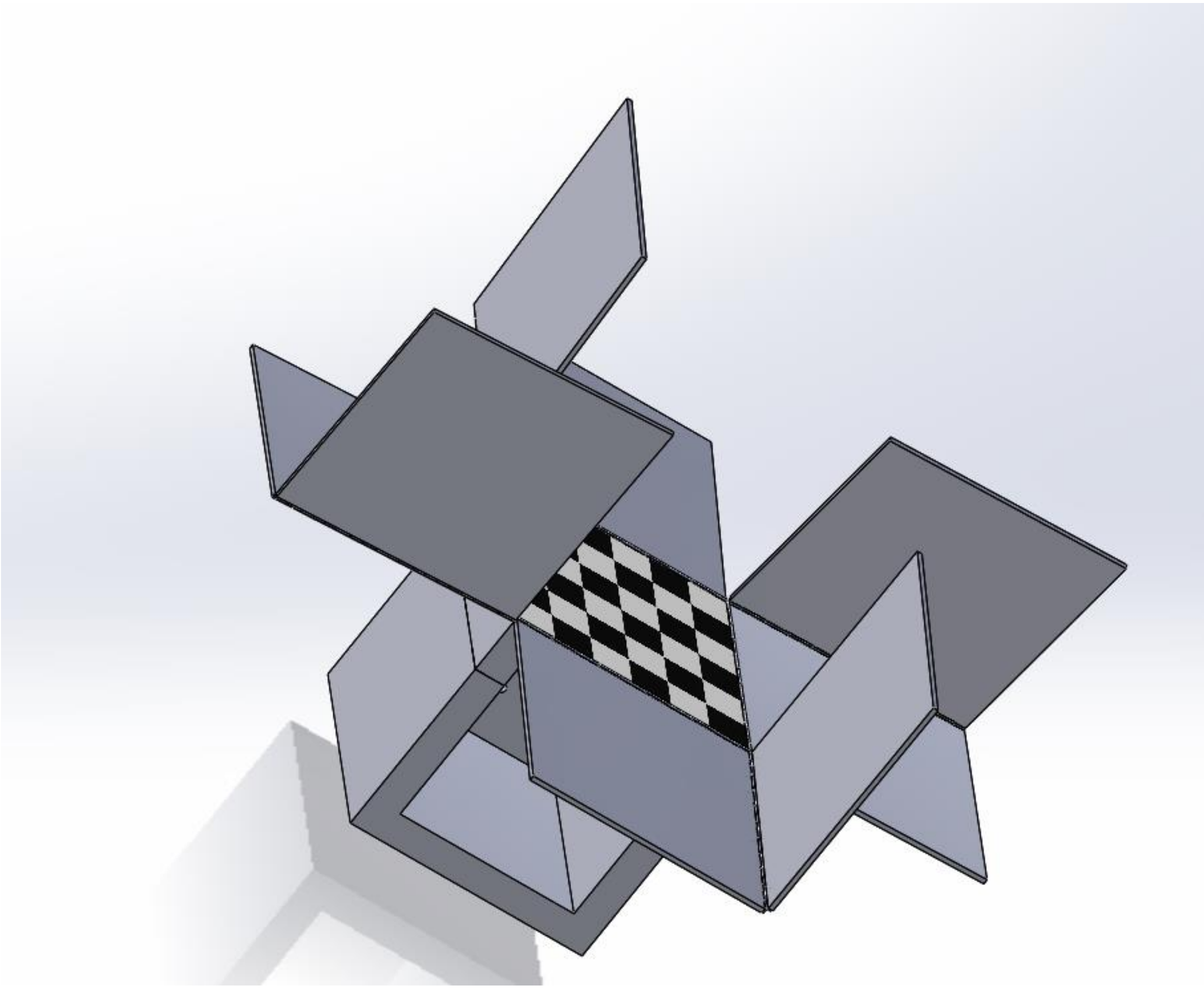

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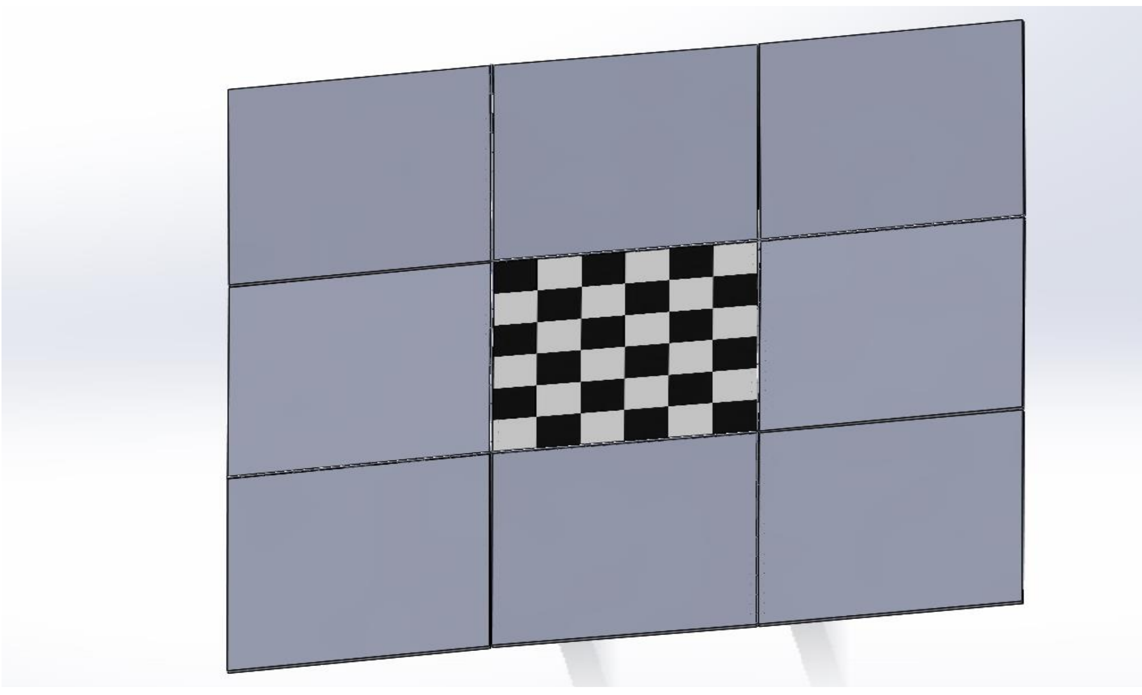

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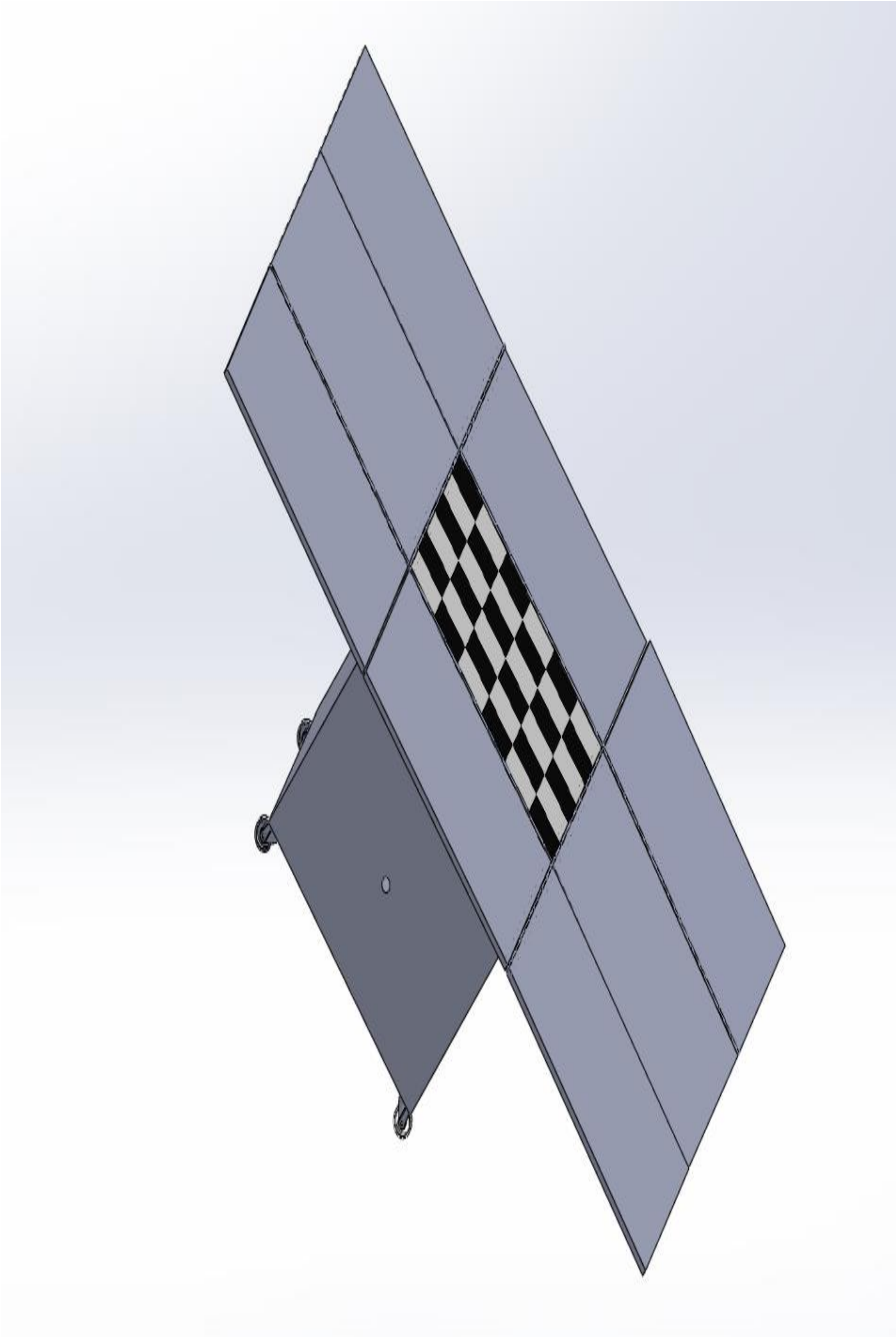

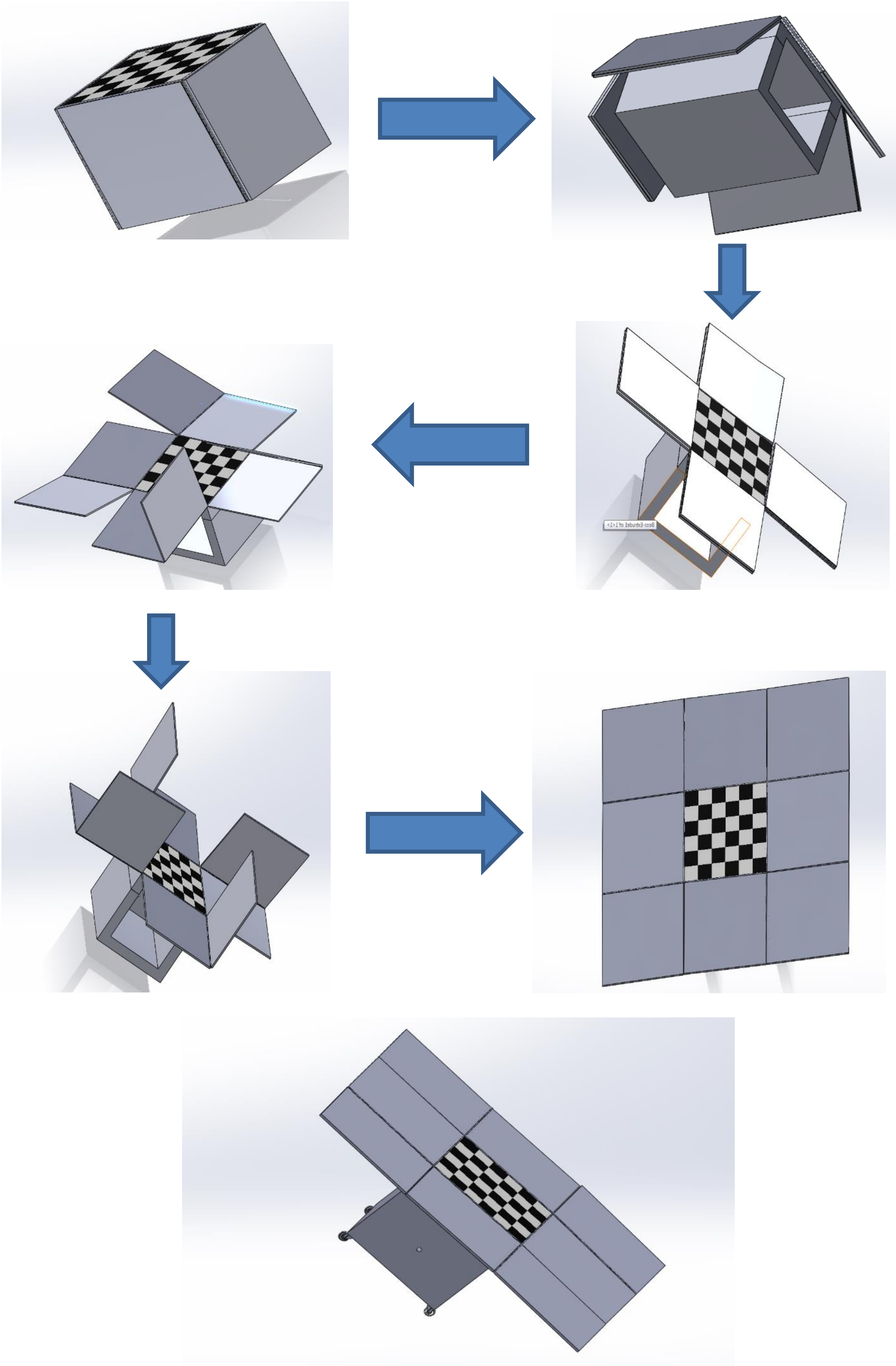

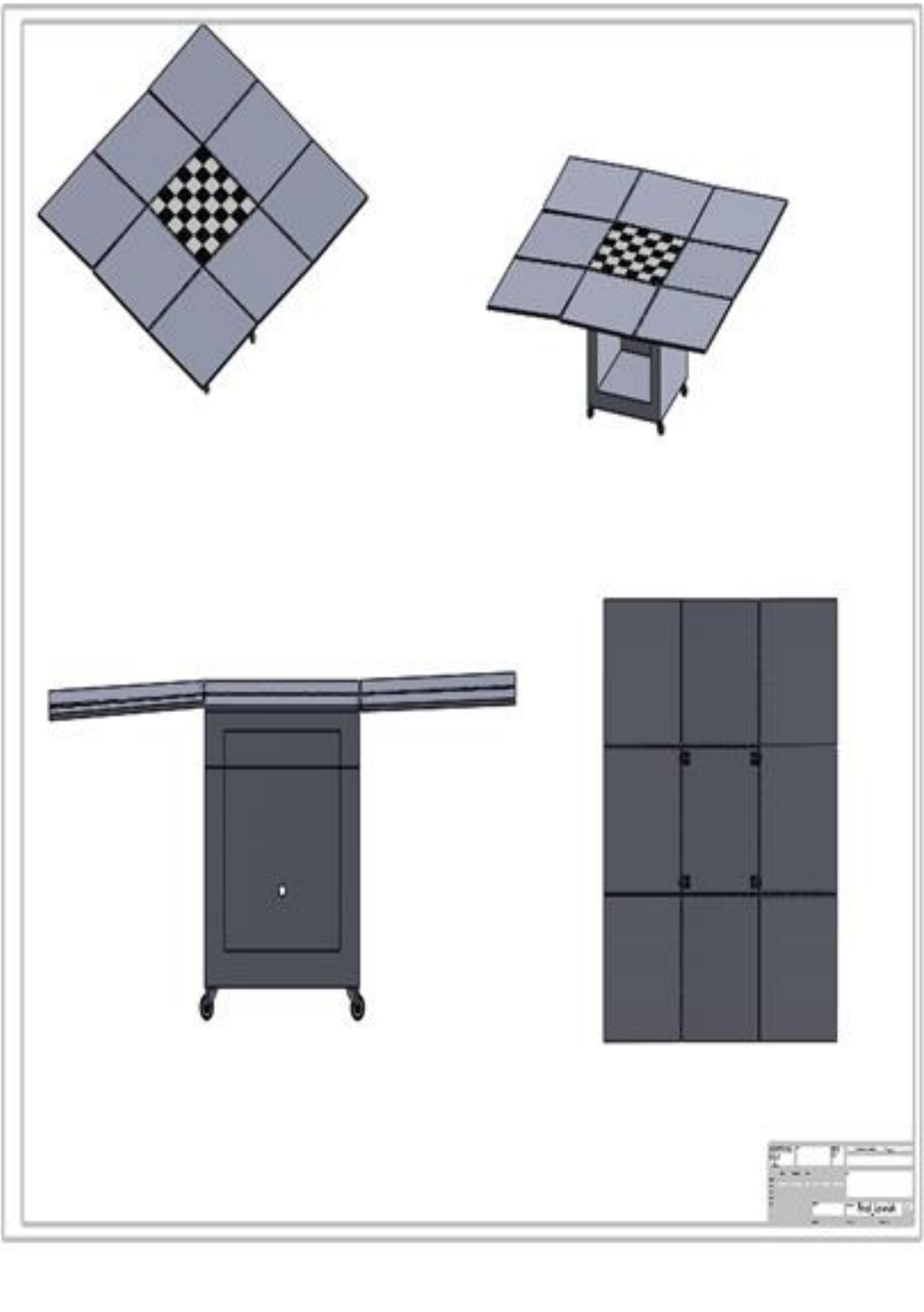

CHAPTER 6: THE SOLAR SOLUTION FOR RURAL INDIA

What seems to be an appropriate solution to all the rural needs is development of Energy Generator which has the following qualities:-

1) **Reliable**
2) **De-centralized**
3) **Caters to individual household needs**
4) **Noise and pollution free**
5) **Not bulky**
6) **Easy to understand, operate and maintain**

All these qualities are incorporated in **PORTABLE SOLAR PV POWER PACK**

MAJOR COMPONENTS

1. PV MODULE
2. BATTERY
3. INVERTER

6.1. PV Module: The basic unit of a PV module is SOLAR CELL. Hence the number of PV modules required will depend on the parameters of Solar cells.

- **Commercial Solar Cells Technology, Materials and Efficiency** [15]

Solar PV Technology	Solar cell type	Materials Used	Efficiency (in percent)
Crystalline Silicon (c-Si) Solar cell	Mono Crystalline silicon, Poly or multicrystalline Si (mc-Si)	Mono Crystalline Silicon, Poly Crystalline Silicon	14-16, 14-16

Thin film Solar Cell	Amorphous Si (a-Si), Cadmium Telluride (CdTe), Copper Indium Gallium Selenide	Amorphous Silicon, Cadmium and tellurium, copper, Indium, gallium, Selenium	6-9, 8-11, 8-11
Multi Junction Solar cell	Gallium Indium phosphide, Gallium Arsenide, Germanium	Gallium, Arsenic, Indium, Phosphorous, Germanium	30-35

Table 5: Commercial Solar Cells Technology, Materials and Efficiency

Source: Solar Photovoltaic Technology and Systems, C.S. Solanki, 2014.

- **<u>Typical Solar Cell Parameters of Commercial Solar Cells with Available Cell area</u>** [16]

Solar Cell Type	Efficiency (%)	Cell area (cm^2)	Output Voltage (V)	Output Current (mA/cm^2)	Fill Factor (%)
Mono Crystalline Silicon	14-17	5-156	0.55-0.68	30-38	70-78
Poly Crystalline Silicon	14-16	5-156	0.55-0.65	30-35	70-76
Amorphous	6-9	5-200	0.70-1.1	8-15	60-70
Cadmium Telluride	8-11	5-200	0.80-1.0	15-25	60-70
Copper-indium-	8-11	5-200	.50-.7	20-30	60-70

gallium-selenide					
Gallium indium phosphide	30-35	1-4	1-2.5	15-35	70-85

Table 6: Solar Cell Parameters

Source: Solar PhotoVoltaic Technology and Systems, C.S. Solanki, 2014.

- **<u>VARIOUS PARAMETERS OF SOLAR CELL</u>**

1) Short Circuit Current
2) Open Circuit Voltage
3) Maximum Power Point
4) Current at Maximum Power Point
5) Voltage at maximum Power point
6) Fill Factor (FF)
7) Efficiency

6.2. Battery: Batteries, as electrical storage medium, are very important part of standalone PV systems. They are important because without energy storage, a solar PV system will not be able to deliver the energy to the load when there is no sunlight. In the case of standalone systems we need electrical energy for running our appliances in non-sunshine hours, while in the grid connected scenario we do not require energy storage. Grid, if operational, provides the energy whenever it is required. In standalone PV systems batteries are delicate because the misuse or non-optimal use of batteries can reduce their life significantly.

A battery is a 2 terminal device. One terminal is +ve and the other terminal is –ve. In the charged condition there will be a voltage difference between 2 terminals. This voltage difference drives the current in appliances when connected. For giving supply to a device from battery the terminals of battery are connected to corresponding terminals of device.

The standard parameters of a battery specified by the manufacturers are following:

- Battery terminal Voltage (in Volts)
- Charge stored in battery (in Ah)
- Depth of Discharge (in percentage)
- Number of charging-discharging cycles (in number)
- Life cycle (in years)
- Self-Discharge (in%)

:

Fig 17: Battery

Source:www.exide.com

6.2. Inverter: A PV installation needs several components other than PV panels. These components are jointly referred to as Balance of System (BoS) and include batteries, battery charge controllers, DC to DC converters (inverters) for AC loads and grid connected systems, supporting structures for mounting the PV panels, protection relays and so on.

One of the component called inverter is an important part of BoS in PV systems. The PV module generates direct current power for DC applications but most of the loads available are AC loads therefore before feeding the power from the PV module or the battery to the load we need to convert DC power into AC power. The job between conversion of DC power into Ac power is done be device called inverter. In the absence of inverter, we will not be able to operate AC loads using Solar Power.

TYPES OF INVERTERS

1. **Standalone Inverters or Off-Grid Inverters:-** These inverters are not connected to grid. They are normally used in standalone PV Power Systems. In standalone system, there is no backup of power for energy storage, therefore, this type of inverters has battery back-up to supply the power to the load in case of non-sunshine hours.

2. **Grid-tie inverters or grid interactive inverters:** These inverters are connected to grid and do not have battery backup. They have special circuitry to match inverter output voltage and frequency with that of grid. Grid is used as battery back-up when power generated by PV array is insufficient. These inverters also have in-built MPPT to extract maximum power from PV array.

When the Sun is shining and PV array is generating more power than our usage, then the extra power after meeting our load is supplied to the grid. If PV array power is less than our load requirement the some power is drawn from the grid to make up the shortage power.

3. **Battery back-up grid tie inverters:** These inverters are grid tied but also have battery back up like standalone inverters.

Inverter Specifications:

1. Battery Voltage (V)
2. D.C. current (A)
3. Voltage Range (V)
4. Maximum short circuit current (A)
5. Output voltage (V)
6. Frequency (Hz)
7. Efficiency (%)
8. No load power consumption (W)
9. Surge power (W)

Fig 18Inverter (Source: www.leonics.com)

CHAPTER 7: RESULTS, CONCLUSIONS & RECOMMENDATIONS

- Battery size required = 191 Ah
- Inverter size required = 1KWp
- PV module area = 9m2 area
- Total Energy that can be generated theoretically = 4.53 KWh/day
- No of sample households that can meet their energy demand =7

Cost Analysis

COMPONENT	COST (Rs)
BATTERY	30,000-40,000
INVERTER	10,000
PV MODULES	42,000 (Rs 42/w)
MISCELLANEOUS	10,000
TOTAL	90,000-1,02,000

Table 8: Cost Analysis

RESULTS

1,423 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
January	4.20	101	1,774
February	5.31	112	1,976
March	6.32	142	2,506
April	6.66	142	2,506
May	5.89	130	2,294
June	5.29	115	2,020
July	4.51	104	1,835
August	4.79	111	1,962
September	5.38	119	2,103
October	5.80	132	2,330
November	4.91	111	1,958
December	4.33	103	1,817
Annual	**5.28**	**1,422**	**$ 25,081**

Location and Station Identification

Requested Location	delhi	
Weather Data Source	(IN) Gridded 10km Satellite Data	5.7 km
Latitude	28.65° N	
Longitude	77.25° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	28.5°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 $/kWh
Initial Cost	80.00 $/Wdc
Cost of Electricity Generated by System	4.25 $/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

RESULTS

1,440 kWh per Year *

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value (₹)
January	3.94	95	1,670
February	4.81	102	1,796
March	6.12	138	2,442
April	6.79	145	2,556
May	6.56	142	2,501
June	5.91	126	2,214
July	5.40	122	2,153
August	5.68	129	2,271
September	5.58	120	2,120
October	5.57	126	2,227
November	4.45	100	1,767
December	3.99	95	1,673
Annual	**5.40**	**1,440**	**₹ 25,390**

Location and Station Identification

Requested Location	punjab	
Weather Data Source	(IN) Gridded 10km Satellite Data	0.9 km
Latitude	31.15° N	
Longitude	75.35° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	20°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	127.38 ₹/Wdc
Cost of Electricity Generated by System	6.68 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

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RESULTS

1,473 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (₹)
January	3.99	96	1,689
February	5.48	115	2,029
March	6.33	142	2,505
April	6.85	146	2,574
May	6.22	135	2,389
June	5.66	122	2,146
July	5.11	117	2,061
August	5.89	135	2,382
September	5.78	127	2,242
October	5.60	128	2,263
November	5.02	112	1,982
December	4.05	96	1,699
Annual	**5.50**	**1,471**	**₹ 25,961**

Location and Station Identification

Requested Location	haryana	
Weather Data Source	(IN) Gridded 10km Satellite Data	3.6 km
Latitude	29.05° N	
Longitude	76.05° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	20°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	150.00 ₹/Wdc
Cost of Electricity Generated by System	7.69 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

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RESULTS

1,595 kWh per Year *

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value (₹)
January	5.21	123	2,163
February	6.00	124	2,192
March	6.81	153	2,693
April	6.98	149	2,620
May	6.80	150	2,642
June	6.02	131	2,308
July	5.40	124	2,180
August	5.34	124	2,184
September	6.11	136	2,389
October	6.47	146	2,582
November	5.38	119	2,095
December	5.03	117	2,065
Annual	**5.96**	**1,596**	**₹ 28,113**

Location and Station Identification

Requested Location	rajasthan	
Weather Data Source	(IN) Gridded 10km Satellite Data	4.3 km
Latitude	27.05° N	
Longitude	74.25° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	20°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	150.00 ₹/Wdc
Cost of Electricity Generated by System	7.10 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

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RESULTS

1,402 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (₹)
January	3.94	94	1,660
February	5.24	110	1,944
March	6.33	142	2,507
April	6.73	143	2,521
May	6.01	131	2,312
June	5.19	113	1,998
July	4.79	112	1,971
August	5.02	116	2,050
September	4.87	110	1,932
October	5.54	127	2,240
November	4.61	105	1,849
December	4.07	99	1,741
Annual	**5.20**	**1,402**	**₹ 24,725**

Location and Station Identification

Requested Location	uttar pradesh	
Weather Data Source	(IN) Gridded 10km Satellite Data	0.5 km
Latitude	26.85° N	
Longitude	80.95° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	20°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	150.00 ₹/Wdc
Cost of Electricity Generated by System	8.07 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

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RESULTS

1,367 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (₹)
January	4.82	113	1,997
February	5.51	116	2,052
March	5.87	134	2,356
April	5.09	112	1,972
May	4.89	110	1,947
June	4.39	97	1,712
July	4.55	105	1,854
August	4.91	112	1,967
September	4.95	109	1,930
October	5.11	116	2,048
November	5.55	123	2,168
December	5.14	119	2,098
Annual	**5.07**	**1,366**	**₹ 24,101**

Location and Station Identification

Requested Location	assam	
Weather Data Source	(IN) Gridded 10km Satellite Data	5.6 km
Latitude	26.25° N	
Longitude	92.95° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	26.25°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	100.00 ₹/Wdc
Cost of Electricity Generated by System	5.53 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

NREL

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WARRANTIES OF MERCHANTABILITY AND FITNESS

RESULTS

1,516 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value ($)
January	5.88	135	2,382
February	6.37	130	2,294
March	6.70	148	2,604
April	6.77	142	2,498
May	6.20	135	2,388
June	4.85	108	1,906
July	4.17	98	1,733
August	3.96	94	1,650
September	5.04	114	2,004
October	6.08	139	2,450
November	6.24	138	2,429
December	5.91	135	2,385
Annual	**5.68**	**1,516**	**$ 26,723**

Location and Station Identification

Requested Location	chattisgarh	
Weather Data Source	(IN) Gridded 10km Satellite Data	3.6 km
Latitude	21.25° N	
Longitude	81.85° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	21.25°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 $/kWh
Initial Cost	100.00 $/Wdc
Cost of Electricity Generated by System	4.99 $/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

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RESULTS

1,525 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (₹)
January	4.75	116	2,049
February	5.44	119	2,100
March	6.25	148	2,604
April	6.26	141	2,492
May	5.93	137	2,422
June	5.13	116	2,049
July	4.46	107	1,893
August	4.24	102	1,791
September	5.20	119	2,095
October	6.59	155	2,740
November	6.06	139	2,459
December	5.11	124	2,184
Annual	**5.45**	**1,523**	**₹ 26,878**

Location and Station Identification

Requested Location	Himachal pradesh	
Weather Data Source	(IN) Gridded 10km Satellite Data	5.5 km
Latitude	31.15° N	
Longitude	77.15° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	31.15°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	100.00 ₹/Wdc
Cost of Electricity Generated by System	4.96 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

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RESULTS

1,492 kWh per Year *

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value (₹)
January	5.79	136	2,306
February	6.15	128	2,178
March	6.70	150	2,549
April	6.61	141	2,392
May	5.94	133	2,254
June	4.98	111	1,889
July	4.18	99	1,680
August	4.23	100	1,698
September	4.92	111	1,893
October	5.67	131	2,221
November	5.45	123	2,097
December	5.51	130	2,214
Annual	**5.51**	**1,493**	**₹ 25,371**

Location and Station Identification

Requested Location	jharkhand	
Weather Data Source	(IN) Gridded 10km Satellite Data	5.4 km
Latitude	23.65° N	
Longitude	85.25° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	23.65°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.00 ₹/kWh
Initial Cost	100.00 ₹/Wdc
Cost of Electricity Generated by System	5.06 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

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RESULTS

1,573 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (₹)
January	5.98	139	2,453
February	6.50	132	2,331
March	6.77	150	2,636
April	6.39	139	2,454
May	6.10	141	2,478
June	5.50	124	2,194
July	5.47	128	2,262
August	5.83	135	2,374
September	5.91	133	2,336
October	5.45	126	2,216
November	4.78	109	1,919
December	5.05	118	2,082
Annual	**5.81**	**1,574**	**₹ 27,735**

Location and Station Identification

Requested Location	Tamil Nadu	
Weather Data Source	(IN) Gridded 10km Satellite Data	2.7 km
Latitude	11.15° N	
Longitude	78.65° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	11.15°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	100.00 ₹/Wdc
Cost of Electricity Generated by System	4.80 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

http://pvwatts.nrel.gov/India/pvwatts.php

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RESULTS

1,518 kWh per Year *

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (₹)
January	5.45	132	2,332
February	5.35	116	2,047
March	6.18	146	2,574
April	6.32	144	2,534
May	5.50	129	2,276
June	5.10	117	2,055
July	4.19	102	1,794
August	3.94	96	1,690
September	5.09	117	2,058
October	6.28	148	2,609
November	5.94	137	2,409
December	5.60	136	2,390
Annual	**5.41**	**1,520**	**₹ 26,768**

Location and Station Identification

Requested Location	Uttrakhand	
Weather Data Source	(IN) Gridded 10km Satellite Data	3.5 km
Latitude	30.05° N	
Longitude	79.05° E	

PV System Specifications *(Residential)*

DC System Size	1 kW
Module Type	Premium
Array Type	Fixed (roof mount)
Array Tilt	30.05°
Array Azimuth	180°
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	17.63 ₹/kWh
Initial Cost	100.00 ₹/Wdc
Cost of Electricity Generated by System	4.98 ₹/kWh

These values can be compared to get an idea of the cost-effectiveness of this system. However, system costs, system financing options (including 3rd party ownership) and complex utility rates can significantly change the relative value of the PV system.

http://pvwatts.nrel.gov/India/pvwatts.php

COMPARISON OF DIFFERENT STATES

State	Latitude	Average Insolation (kw/m2/day)	Units /Year (KWh/Year)	Money saved/Year (Rs)
DELHI	28.65 N	5.28	1422	25,091
PUNJAB	31.15 N	5.40	1440	25,390
HARYANA	29.05 N	5.50	1471	25,961
RAJASTHAN	27.05 N	5.96	1596	28,113
UTTAR PRADESH	26.85	5.20	1402	24,725
ASSAM	26.25	5.07	1366	24,101
CHATTISGARH	21.25	5.68	1516	26,723
HIMACHAL PRADESH	31.15	5.45	1523	26,878
JHARKHAND	23.65	5.51	1493	25,371
TAMIL NADU	11.15	5.81	1574	27,735
UTTRAKHAND	5.41	5.41	1518	26,768

Table 9: Comparison of different States

CONCLUSIONS

After detailed analysis it can be safely said that portable Solar Power Pack can be used effectively for the following purposes

- **Domestic consumption**
  - **For cooking**
  - **For lighting**
- **Industrial consumption**
  - **For Micro Small and Medium Enterprises**
- **On-farm energy consumption**
  - **Energy consumption for farming**

ADVANTAGES

- **No of sample households that can meet their energy demand with 1KW SPV =7.**
- **It is easy to use and can be operated by rural people both Men and Women.**
- **It contains static parts hence is maintenance free.**
- **Can be connected in parallel to supply energy for small community functions in villages.**
- **Can be used in hilly areas where otherwise grid connection is not possible due to hilly terrain.**
- **Can be used in areas with frequent power cuts.**
- **The cost of production can further be reduced if manufactured on large scale.**
- **Payback period is approximately 5 years.**
- **Can work efficiently up to 25 years.**

RECOMMENDATIONS:

The design after thorough analysis can now be put into manufacturing locally thereby reducing its production cost and making it more feasible and serviceable for meeting daily load requirements of rural household. Presently about 400 million people in India are living in the dark hence we must go faster for using solar lighting solutions. I think India must adopt Chinese way of manufacturing small to large scale solar lighting and other uses.

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