TECHNO-ECONOMIC FEASIBILITY ANALYSIS SOLAR ROADWAYS: A CASE STUDY OF DND FLYWAY DELHI.

Abrar Ahmad, Addit Anwar
Department of Electrical Engineering
Jamia Millia Islamia, New Delhi.

***Abstract*—**Solar energy is the most dependable form of energy but harnessing this energy requires a large area. India being the second most populous country in the world with increasing birth rate and population density in cities, renewable energy is the must be a priority. But, unfortunately one of the largest problems with solar technology is the large surface area required in order to collect enough solar rays to make their collection cost beneficial. This problem has led researchers to investigate a variety of methods in which solar panels are placed in a clever, space saving manner. Solar roadways are roads which contain both solar panels and transmission lines, encased in a glass outer surface. By combining two long existing technologies, solar panels and roadway systems, it is possible to achieve the necessary surface area required in order to help solar-based energy become a feasible solution to the energy crisis.

Keywords – Solar roadways, DND, renewable energy.

I. INTRODUCTION

Many island countries, for example, Fiji islands, Papua New Guinea, etc., are still suffering from the use of any kind of electricity system. Due to poor resources, they all depend on fossil fuel, mainly diesel, for electricity generation. In fact, 85% of their total electricity production is being generated mainly using diesel generators.

India was the third largest emitter of carbon dioxide in 2009 at 1.65 Gt per year, after China (6.9 Gt per year) and the United States (5.2 Gt per year). With 17 percent of world population, India contributed some 5 percent of human-sourced carbon dioxide emission Compared to China's 24 percent share. On per capita basis, India emitted about 1.4 tons of carbon dioxide per person, in comparison to the United States' 17 tons per person, and a world average of 5.3 tons per person. About 65 percent of India's carbon dioxide emissions in 2009 was from heating, domestic uses and power sector.

India's coal-fired, oil-fired and natural gas-fired thermal power plants are inefficient and offer significant potential for CO2 emission reduction through better technology. Compared to the average emissions from coal-fired, oil-fired and natural gas-fired thermal power plants in European Union (EU-27) countries, India's thermal power plants emit 50 to 120 percent more CO2 per kWh produced.[6] This is in significant part to inefficient thermal power plants installed in India prior to its economic liberalization in the 1990s.In France only 10% of electricity is generated from fossil fuels, the US is higher at 70% and China is at 80% and India is not far behind.

Solar PV power system, or PV system, is a power system designed to supply usable solar power by means of photo-voltaic. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity and solar inverter to change the electric current from DC to AC, as well as mounting, cabling and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware. Operating silently and without any moving parts or environmental emissions, PV systems have developed from being niche market applications into a mature technology used for mainstream electricity generation.

II. SOLARROADWAY (SR)

Solar Roadway (SR) is a modular system of specially engineered solar panels that can be walked and driven upon. These panels contain LED lights to create lines and signage without paint. The panels have microprocessors, which makes them intelligent. This allows the panels to communicate with each other, a central control station, and vehicles. The SR panels are made of specifically formulated tempered glass, which can support the weight of trucks. The glass has a traction surface which is equivalent to asphalt.

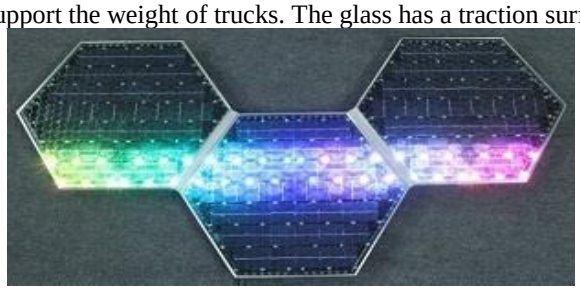

Fig. 1: Synchronized functioning of three SR panels

The Three Components of Solar Roadways are composed of three separate, but complimentary, parts the roads surface layer, the electronics layer, and the baseplate layer. These parts, working in unison, are able to produce clean energy, send it to the electronic grid, and power the solar roadways themselves in order to make driving a safer experience. The three components of a SR are:

1. Road Surface Layer
2. Electronics Layer
3. Baseplate Layer

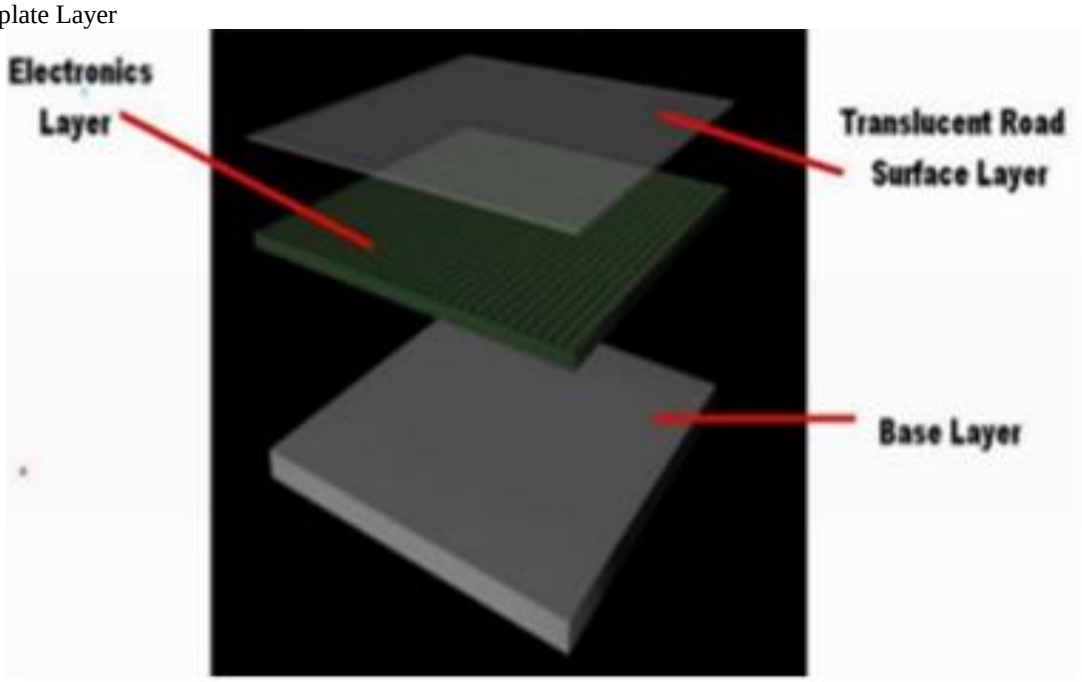

Fig. 2: Pictorial representation of different layers present in Solar Roadway.

The Road Surface Layer

The road surface layer is planned to be made up of translucent, high strength glass material. The glass will be textured in order to allow tire traction, while still remaining translucent enough to let a sufficient amount of the sun's rays reach the solar panels located in the roadways.

The Electronics Layer

The electronics layer contains the solar panels responsible for collecting the sun's energy, a microprocessor board, and several light-emitting diodes (LEDs). Once the solar panels have collected the sun's energy, a small amount is sent to the microprocessor board, which controls the lighting associated with the solar roadways. In place of painted lines on the ground, solar roadways use LEDs in order to represent barrier lines, warning signals, etc.

The Baseplate Layer

The baseplate layer ultimately distributes the power collected from the electronics layer to the energy grid. This layer distributes both power, as well as data signals (TV, phone, etc.) to the energy grid which is connected to the solar roadway. The baseplate layer, like the road surface layer, is weatherproof.

In order for solar roadways to be successful, the three parts need to be working in unison. The road surface layer needs to be clear enough to let the sunlight pass through to the electronics layer, the electronics layer needs to collect energy and keep the road functioning properly, and the baseplate layer needs to determine where the energy is supposed to go. Due to the fact that the road lines on solar roadways are actually LEDs, the baseplate layer needs to ensure the roadway has enough energy needed before sending the rest of the energy out towards the grid.

III. India's Solar Potential

India's solar power generation capability with about 300 clear, sunny days in a year, India's theoretically calculated solar energy incidence on its land area alone, is about 5,000 trillion kilowatt-hours (kWh) per year .The solar energy available in a year exceeds the possible energy output of all fossil fuel energy reserves in India. The daily average solar power plant generation capacity over India is 0.25 kWh per m2 of used land area, which is equivalent to about 1,500–2,000 peak (rated) capacity operating hours in a year with the available commercially-proven technologies. Government-funded solar electricity in India was approximately 6.4 MW per year as of 2005. India is ranked number one in terms of solar electricity production per watt installed, with an insolation of 1,700 to 1,900 kilowatt hours per kilowatt peak (kWh/KWp). 25.1 MW was added in 2010 and 468.3 MW in 2011. As of 31 August 2015, the installed grid connected solar power capacity is 4,229.36 MW, and India expects to install an additional 10,000 MW by 2017, and a total of 100,000 MW by 2022. So, it is a high time to solve several problems with one shot. These SR panels will solve the energy need, the environmental pollution and wastage of land.

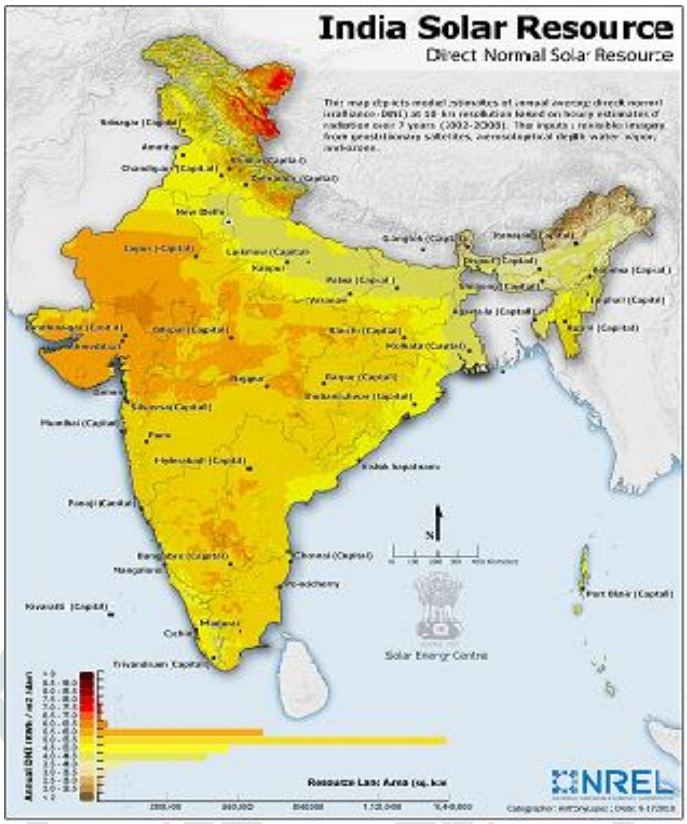

Figure 3: Model estimation of annual average direct normal irradiance (DNI) at 10km resolution based on hourly estimates of radiation over 7 years (2002-2008).

It is estimated that approximately half (different agencies provide different estimates, but the average is about 50 percent) of the greenhouse gases that are causing global warming come from the burning of fossil fuels (primarily coal) to generate electricity. The SR therefore has the ability to eliminate half of the greenhouse gases currently being produced.

IV. METHODS

The modeling of our present study is done through Google Earth Pro software programs. Before presenting the methodology, brief details of the software are presented in the following. Google Earth is a popular software to view satellite imagery, maps, terrain, 3D building, etc. and for research studies. It also provides tools to analyze and explore places with realistic views of an area and navigation through directions. The different features and high quality of satellite maps available through Google Path allow navigating through the Earth, finding addresses and location, marking location, etc. It is also helpful in obtaining the coordinates of different locations. Another better way of studying is to use the more advanced version of Google Earth -namely 'Google Earth Pro.' This is used in our study for more accurate results. With high-resolution imagery, it offers a comprehensive geospatial database for roads and historical imagery. One can visually see the surface of the Earth with all the field information. This is a very useful feature as one can get the field information without actually visiting the location. Since our present study is more of a regional nature, Google Earth Pro is found to be suitable in our study. Google Earth Pro, with the integrated measurement and drawing tools, is also used for radius and area measurement. Thus, this software helps for identification of thick vegetation, bridges, and unusable road locations with its dimensional parameters.

V. DETAILS OF THE SITES

The DND Flyway (Delhi Noida Direct Flyway) is an eight-lane 9.2 km (5.7 mi) access controlled tolled expressway which connects Delhi to Noida, an industrial suburb area. It was built and is maintained by The Noida Toll Bridge Company Ltd promoted the Infrastructure Leasing and Financial Services.

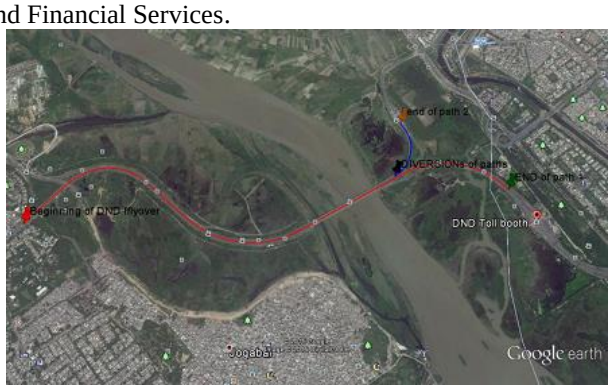

Figure 4: Overall path taken power power analysis.

For modeling purpose, we have chosen the 4 lane DND highway from Ashram to toll booth of the DND. The total span of the DND highway length is 9.2 km. Each lane on the highway has a width of 3.27m, and thus for four lanes, the total width is 13.07592m. For both sides (to and fro), the total width available for solar panels above the road is 26.16m. The width of the road has been also measured by the authors with measurement tapes from various places along the national highway. This also helps to measure the accuracy of Google Earth Pro software for modeling purposes. Additional information on the DND highways is also provided from virtual observation of the road using Google Earth Pro software, for example, the lengths of the road unavailable due to certain environmental reasons like bridges, crossing, unusable road, thick vegetation, etc. These parts have been identified with high resolution with high accuracy in measurements using Google Earth Pro software modeling without actually making the ground observation (but verified on various different places by travelling all along the DND highway).

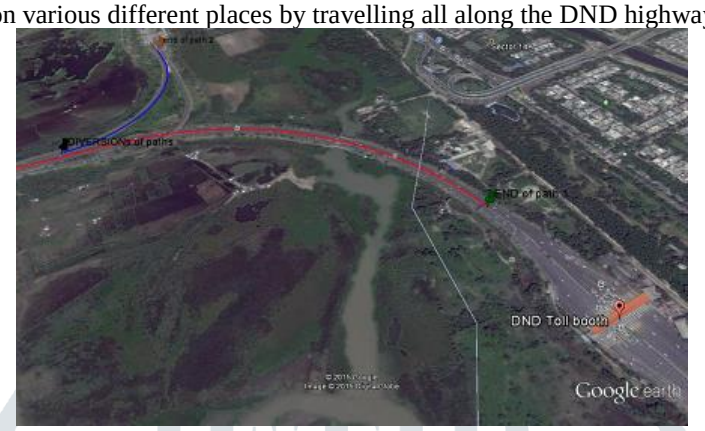

Figure 5: Path 1 after the diversion

Figure 6: Path 2 after the diversion

VI. EFFICIENCY

Assuming the energy produced in ideal condition of an 18.5% efficiency solar panel is *E*. Due to the horizontal placing of the panels there would be a loss of 31%, which would leave us with the net efficiency *E1=0.69E*. Now, we also have to take the loss occurring due to the textured glass which comes out to be 11-12% and after this the net efficiency of the SR would come out to be *E2=0.61272E*. Last but not the least, there would be other losses incurring due to the shadow casted by the car or green vegetation, therefore there would be an additional loss of at maximum 15%, that would give us the final Efficiency of *Ef=0.5208E*.

VII. DATA

For the grid-connected system, the basic input parameters required for modeling are PV component database, grid inverter database, geographical site information, and monthly meteorological data for horizontal global irradiance and temperature.

In labs, solar cell efficiency has exceeded 44-percent, but they're not cost feasible yet. For our calculations, we use commercially available solar panels, which are cost competitive. The efficiency of 18.5% is commonly available, so for the calculations, Solar cells have an efficiency of 18.5%. There was 2658 hours of daylight hours in the year 2014 SR offers a 48 Watt solar panel rated at 18.5% efficiency. Its surface area is 13.4 square feet.

This is considered as one unit for the purpose of calculation, which will be extended for the entire length of the highway. Accordingly, 44,389 numbers of modules are used for DND highway (four lanes).

VIII. SR ORIENTATION

It is well known that the highest amount of energy generation can be produced through solar photovoltaic panels oriented exactly to the south in the northern hemisphere. Also, if the orientation of the solar panel is other than south, then the amount of energy generation is less.

Unfortunately, we can't angle roads or parking lots. Roads go up and down hills, have banks on curves (going both left and right). DND highway is plain and it has an inclination angle equal to zero degrees. The tilted solar panel produced more energy (an

average of almost 31 percent more than its horizontal counterpart), a phenomenon that was apparently previously unknown: The horizontal solar panel produced more energy than the tilted panel on certain overcast days. It is analogical to getting sunburned on a cloudy day, sunlight is still present, but it is scattered, so the horizontal solar panel is more likely to pick up the scattered photons than the solar panel aimed at the southern horizon. For fairness, let's subtract 31 percent from our totals since we can't angle roads and parking lots.

IX. MODELING THE DND HIGHWAY

In Table1 we describe the various parameters and dimensions considered to estimate the solar potential along the DND highway, i.e., the length of the highway identified suitable or unsuitable for the solar photovoltaic system installation as a roof of the road for energy generation. As described earlier, it has a length of 4.47 km with a two-way road (eight lanes) with a width of 26.16 m. Thus, the total area (Area = Length ×Width) available for solar panel installation is 0.0552593km2. The road is completely usable due to certain parameters, for example neither thick vegetation nor overhead bridges for road crossings with other roads. We have also not considered the portions of the road either under construction or not clearly visible with the Google Earth Pro software with high-quality resolution and clarity. Hence, the effective area available on DND highway is 0.0552593 km2.

X. ENERGY GENERATED

In the table you can see the average and total sun hours in different months in the year 2014. The total sun hour in the year 2014 is 2658. Now, taking the efficiency Ef from above we will get the energy generated to be equal to 255448.137841W/m^2 and the total energy that will be developed in 20 years(guaranteed life span offered by the company) is 5108.96275682 KW/ m^2. Now, we have the total area of the DND highway which is equal to 55259.3m^2 and therefore the total energy generated 14.11588528 GW every year and in the span of 20 years the SR will generate 282.3177057GW of pure renewable energy.

Table 1 - Sun hours in Delhi(2014)

S No.	*Month*	*total*	*average*
1	January	215	6.9354
2	February	216	7.7142
3	March	239	7.7096
4	April	261	8.7
5	May	263	8.4838
6	June	197	6.5666
7	July	166	5.3548
8	August	177	5.7096
9	September	219	7.3
10	October	269	8.6774
11	November	247	8.2333
12	December	216	6.9677
	TOTAL	**2658**	**7.2821**

XI. COST ANALYSIS

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Based on the modeling results along the DND highways, a few interesting observations can be made as such as the area of road and the potential of it to generate clean energy. Firstly, what we have achieved is the net efficiency of SR, which comes out to be Ef=0.5208E, where E is equal to the energy produced in an ideal condition by an 18.5% efficiency solar panel. The total surface area of DND highway marked in the figure 4, 5 and 6 is equal to 0.0552593 km2. This much area has the potential to generate 14.11588528 GW of renewable energy every year and 282.3177057GW of renewable energy over the span of twenty years and even more if they lasted longer. The size of a SR module is 1.24490 m^2 and therefore DND would require 44,389 modules to cover it up completely.

Amount of money agglomerated from the energy produced can be find out by multiplying the energy produced to the tariff rate of the city. In the year 2015 the tariff rate was 7.5Rs per unit of energy consumed. Now, even after assuming that the tariff rates did not increase the money agglomerated will be equal to 211.7382793 crores. Apart from this, the capital cost can also be recovered from the TOLL CHARGE, and above all this energy created will be completely clean.

XII. Conclusion

In this paper, we have suggested an alternative approach to utilize solar energy to meet the global challenges like climate change, pollution, and energy insecurity and also to address the biggest challenge for the photovoltaic technology, i.e., land cost. This efficiency of the vehicle and life of the road are equally important. Through this paper, we are also answering some of these issues. It is well known that the availability of land is becoming more expensive and also becoming a rare commodity. In view of this, we proposed a new concept to use the existing land in a more effective way and did the energy analysis for the DND highway. We suggest that they should be used to generate electricity. For this purpose, with one-time investment, one can replace the asphalt roads with SR modules which would perform 10 times the function of asphalt roads. As observed from the figure 3 we can perceive the latent potential energy of India as a whole with such possibly rich future in terms of solar power generation, but the only thing stopping us was the availability of land but with the SR this problem can be solved.

Using Google Earth Pro software, the national highways are carefully scanned and the part of the road that cannot be used for structural construction due to environmental and other factors has been deleted in the estimation. From the result of our study, we recommend to initiate solar panel installations on all the National Highways. This will open up large potential of power generation in a very short period of time which is very much needed in India to have aggressive industrial growth which is presently in strong need for power.

In summary, the national highway space can contribute to the huge amount of energy generation without extra cost for the land. By this, we can also say that this idea can be a part of the key concept of solar grand plan. Apart from this, there are various fringe benefits. For example, if implemented, it will provide us with an intelligent network, negligible pot holes because they then would be replaced in a considerate amount of less time. Apart from that it would provide us with plethora of advantages like LED lights for lines and signage, protection of fauna, modular for faster maintenance, no paint requirement and aesthetic benefits. For all the above ideas, to see the light of day, there is an urgent need for an attractive policy by the government of India to increase the solar potential if one dreams to realize it.

References

[1] Jami, Majid., Kirmani, Sheeraz.,Rizwan, Mohammad., " TechnoEconomic Feasibility Analysis of Solar Photovoltaic Power Generation: A Review". In Smart Grid Renewable energy, 2012, pp. 266-274

[2] Astuti, Duwi. Suryoatmajo, Heri., Ashari, Mochamad,"Design Simulator Solar Panels Using the Lab View". Surabaya : Teknik Elektro ITS , 2012

[3] Chakrabarti, S. and S. Chakrabarti. (2000). Rural electrification programme with solar energy in remote region - a case study in an island. Energy Policy, Vol. 30, pp.33 42. Denton, J. C. (1977).

[4] Solar power systems, Energy Conversion, Vol. 16, pp. 181-198. Dracker, R. and P. De Laquil. (1996).

[5] Progress commercializing solar-electric power systems. Annual Review of Energy and the Environment, Vol. 21, pp.371 402.

[6] Fthenakis, V., J. E. Mason and K. Zweibel. (2009). The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US. Energy Policy, Vol. 37 (2), pp.387 399.